Hosted by the USGS Land Remote Sensing Program, Geography Discipline

Report of the First National Lidar Initiative Meeting, February 14-16, 2007, Reston, Va.

By Jason Stoker[1], Jay Parrish, David Gisclair, David Harding, Ralph Haugerud, Martin Flood, Hans-Erik Andersen, Karen Schuckman, David Maune, Paul Rooney, Kirk Waters, Ayman Habib, Eddie Wiggins, Bryon Ellingson, Benjamin Jones, Steve Nechero, Amar Nayegandhi, Tim Saultz, and George Lee

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Introduction

The first National Lidar Initiative meeting was held on February 14-16, 2007 at the USGS National Center in Reston, Virginia. This meeting was a successor to a meeting held September 12, 2006 of several agencies, including the National Aeronautics and Space Administration (NASA), the Association of American State Geologists (AASG), and the U.S. Geological Survey (USGS). During the 2006 discussion, the USGS presented a plan to organize a meeting to discuss the feasibility and strategy of a National Lidar Initiative. Originally scheduled as a workshop to be held in June, 2007, the meeting was moved up to February to accommodate the desire of AASG to have talking points available at their Annual Meeting in March, 2007. The original workshop was recast as a meeting of representatives from Federal, State, and local government, and from private industry, to formulate a national initiative with the goal of collecting high resolution, high accuracy light detection and ranging (lidar) data for all 50 states.

The goals of the National Lidar Initiative meeting were to:

1) Identify government staff with all scales of applications who are willing to help devise a potential national strategy and communicate the initiative throughout the lidar community.

2) Identify points of contact for future meetings, information exchanges, and design teams.

3) Compose a document explaining the need of a consistent national lidar dataset.

4) Identify champions of this idea who would be willing to work toward funding this effort.

This report is intended to summarize the views expressed by the invited speakers and the participant's discussions on a National Lidar Initiative. It is not intended to be a comprehensive document on the technical aspects of lidar, what lidar can be used for, or the state of the art in lidar technology, although many of these aspects do come through in the views of the presenters.

The USGS invited speakers based on their expertise and diverse points of view. Speakers came from State and Federal government, academia, and private industry in the United States and Canada. Although every invited speaker confirmed their acceptance, the North Carolina and National Digital Elevation Program (NDEP) groups were not able to attend because of weather.

20 Questions

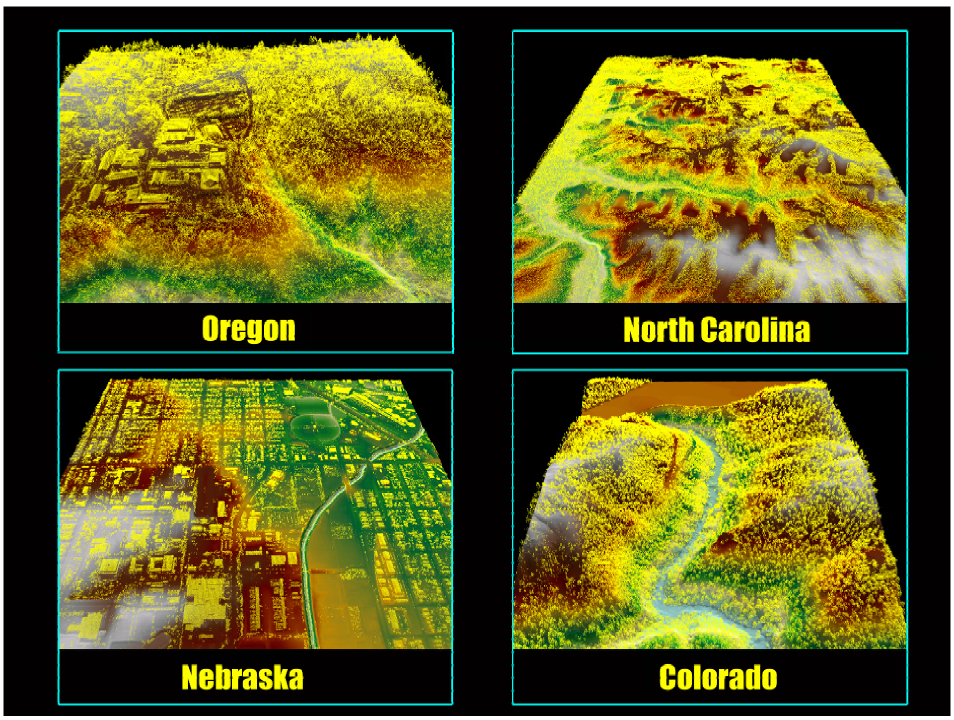
Following the speakers' acceptances, USGS provided 20 questions to guide their talks and the following discussions. Based on early responses and suggestions, the 20 questions were revised somewhat to better illustrate the theme of the meeting. The 20 questions provided were as follows:

1) What are the most desired resolutions?
2) Should we have multiple resolutions?
3) What vertical accuracy is needed or wanted for your interests?
4) What horizontal accuracy is needed or wanted for your interests?
5) How can Quality Control / Quality Analysis be done in a nationally consistent manner?
6) Would national calibration / validation sites be beneficial?
7) Should States / Feds / locals be in charge and control of their own regions of interest?
8) What roles should agencies play in the actual data collection?
9) What timetables should be acceptable for acquiring funding, and acquiring data?
10) How do we prioritize areas of collection?
11) What derivatives should be created from the source lidar remote sensing data?
12) What derivatives do we produce ourselves, and what do we contract for?
13) What variables are needed (return number, class, scan angle, GPS info, intensity, etc.)?
14) How do we incorporate bare earth derivatives into the National Elevation Dataset?
15) Where and how are the final and intermediate data stored, disseminated, and archived?
16) How do we acquire multi-agency and multi-scale funding?
17) How are costs shared and distributed?
18) Would buy-ins for upgrades be an option?
19) Is the LAS format acceptable as a standard file format?
20) Should this be a one-time event, or a 5-10 year cycle? In other words, should this be a mapping effort, or a monitoring effort?

Overview

The idea of a lidar dataset encompassing the entire country is not a new one. In September, 2004, Scottie Barnes, editor-in-chief of Geospatial Solutions Magazine wrote an editorial entitled "Elevate Your Data," based on a panel session she moderated at the 2004 ESRI International User Conference in San Diego, California. This editorial showed that even before it was technically or financially feasible, there was interest and a growing consensus that a seamless, consistent elevation product created by lidar remote sensing data would be a good idea.

As the technology has matured, and the analysis and utilization of the entire lidar signal has improved and increased, utilizations of the entire dataset and not simply bare earth derivatives have developed dramatically. Lidar data are being utilized extensively in the forestry and ecology realms, and new uses are being demonstrated in feature extraction of man-made structures in urban settings for building delineations and emergency response and homeland security purposes.



Figures 1 and 2 show examples of how much information is in an unfiltered point cloud. Bare earth in Figure 1 is color-coded from blue to white, and the points discarded are in yellow. Depending on variables such as the point density, the number of returns the sensor records, and the type of vegetation and land cover being flown, a large amount of the data can and usually is thrown out to create a bare earth DEM. The value of discarded data was a common meeting theme.

Figure 1. Points commonly discarded, in yellow, for 4 regions in the United States.

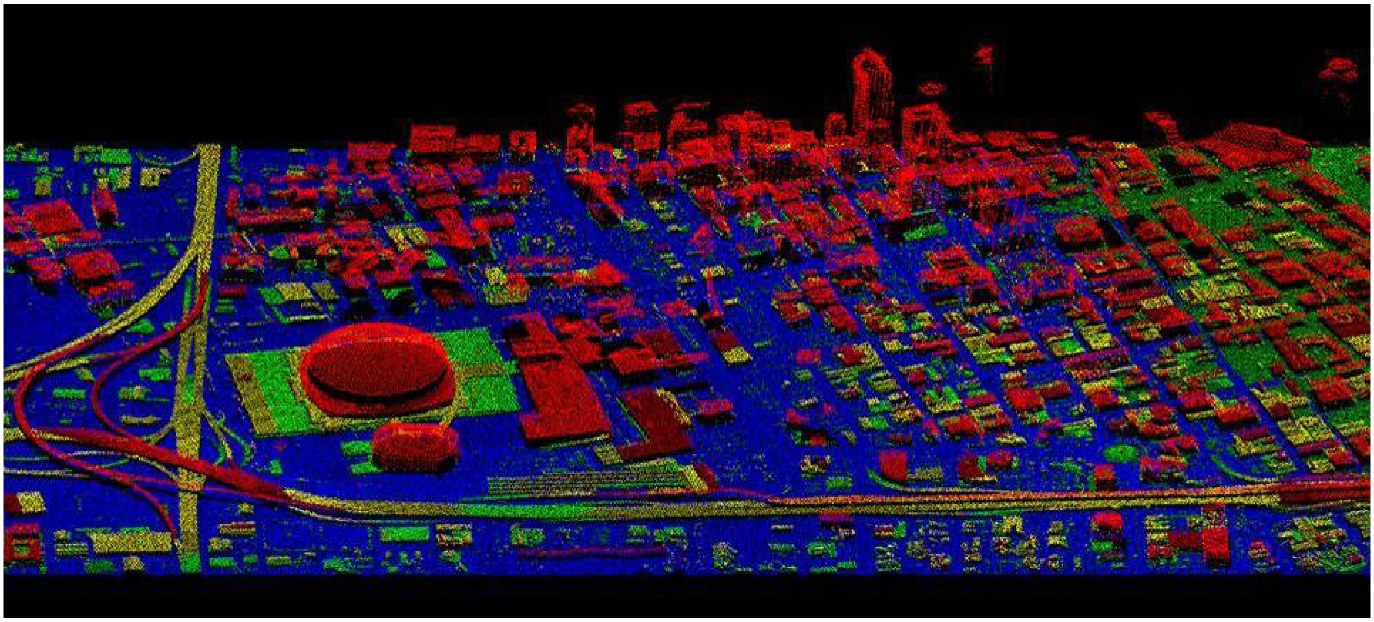


Figure 2. Unfiltered multi-return lidar data in New Orleans, La.

Agenda

The Agenda was originally designed to highlight some of the large-area and statewide lidar collection efforts that have been underway for the past several years. This was to be followed by a day of Federal-level discussions as well as some technical presentations on sensor possibilities, program management, calibration, and quality assurance / quality control. Also provided was a town hall forum for the private sector to voice their concerns. Friday was set aside for a half-day of breakouts and specific discussions on several topics. Because of the weather, the agenda was changed at the last minute to accommodate travelers and the delayed opening of the USGS National Center in Reston on Wednesday. The agenda was as follows:

Wednesday

Wednesday, February 14th, 2007
(Location: Auditorium)

12:15 p.m.	Welcome	Barbara Ryan
12:30 p.m.	Goals of the meeting / Overview	Jason Stoker
1:00 p.m.	Louisiana Lidar Discussion	David Gisclair
1:30 p.m.	Pennsylvania Lidar / AASG Discussion	Jay Parrish
2:00 p.m.	Puget Sound Lidar Consortium Discussion	Ralph Haugerud and Craig Weaver
2:30 p.m.	Imagery for the Nation Discussion	George Lee
3:00 p.m.	GPSC Contracting Discussion	Tim Saultz
3:30 p.m.	***BREAK- Sponsored by Photo Science***	
3:00 p.m.	Calibration / QA/QC Discussion (Moved)	Ayman Habib
3:45 p.m.	States Open Discussion	ALL
5:00 p.m.	Poster Session	ALL

Thursday

Thursday, February 15th, 2007
(Location: Auditorium)

8:00 a.m.	USGS Perspective	Jason Stoker
8:30 a.m.	FEMA Perspective	Paul Rooney
9:00 a.m.	USFS Perspective	Hans-Erik Andersen
9:30 a.m.	NRCS Perspective	Steve Nechero
10:00 a.m.	***BREAK- Sponsored by GeoCue***	
10:15 a.m.	EAARL Coastal Mapping Perspective	Amar Nayegandhi
10:45 a.m.	NOAA Perspective	Kirk Waters
11:15 a.m.	NDEP Perspective	Bryon Ellingson
11:45 a.m.	***LUNCH***	
1:00 p.m.	Army Corps of Engineers Perspective	Eddie Wiggins
1:30 p.m.	Alaska Perspective	Ben Jones
2:00 p.m.	NRC Floodplain Mapping Report: "Base Map Inputs for Floodplain Mapping"	Karen Schuckman / Dave Maune
2:30 p.m.	***BREAK – Sponsored by Merrick***	
2:45 p.m.	NASA Perspective	David Harding
3:15 p.m.	Lidargrammetry Discussion	Martin Flood
3:45 p.m.	Calibration / QA/QC Discussion	Ayman Habib
4:15 p.m.	Vendor Town Hall Discussion	All

Friday

Friday, February 16th, 2007
(Location: Auditorium)

8:00 a.m.	North Carolina statewide Lidar Discussion (Cancelled)	Tonda Sheldon/ Gary Thompson / Sarah Wray
8:15 a.m.	Ohio statewide Lidar Discussion	Bob Brinkman
8:45 a.m.	Iowa statewide Lidar Discussion	Pete Kollash
9:15 a.m	**Concurrent Breakout Discussions:** Derivatives Discussion Data Dissemination Discussion Roles and Responsibilities Technical specifications Legal / political Discussion	ALL/Breakouts
10:15 a.m.	Breakout Briefings	ALL/Breakouts
11:30 a.m.	Formalize teams for report writing	ALL/Breakouts
12:00 a.m.	Adjourn	ALL/Breakouts

Summary of Presentations

Each invited speaker was given 30 minutes to provide their expertise and present their opinions on what might make a National Lidar Initiative successful, based on their requirements and past experiences. The presentations can be found at: *http://lidar.cr.usgs.gov/presentations.php*. This section summarizes the presentations given by each of the speakers, and their relevance to a National Lidar Initiative.

State and Regional presentations

Statewide and regional presentations were given by David Gisclair representing Louisiana, Jay Parrish representing Pennsylvania and AASG, Ralph Haugerud representing the Puget Sound Lidar Consortium (PSLC), Bob Brinkman representing Ohio, and Pete Kollasch representing Iowa.

Louisiana Perspective

Louisiana's statewide lidar project started in 2000, largely in response to the high flood loss rates reported by the Federal Emergency Management Agency (FEMA)'s National Flood Insurance Program and the private insurance industry in the state. The project is funded by FEMA with matching funds. Data are publicly distributed by Louisiana State University (**Figure 3**)

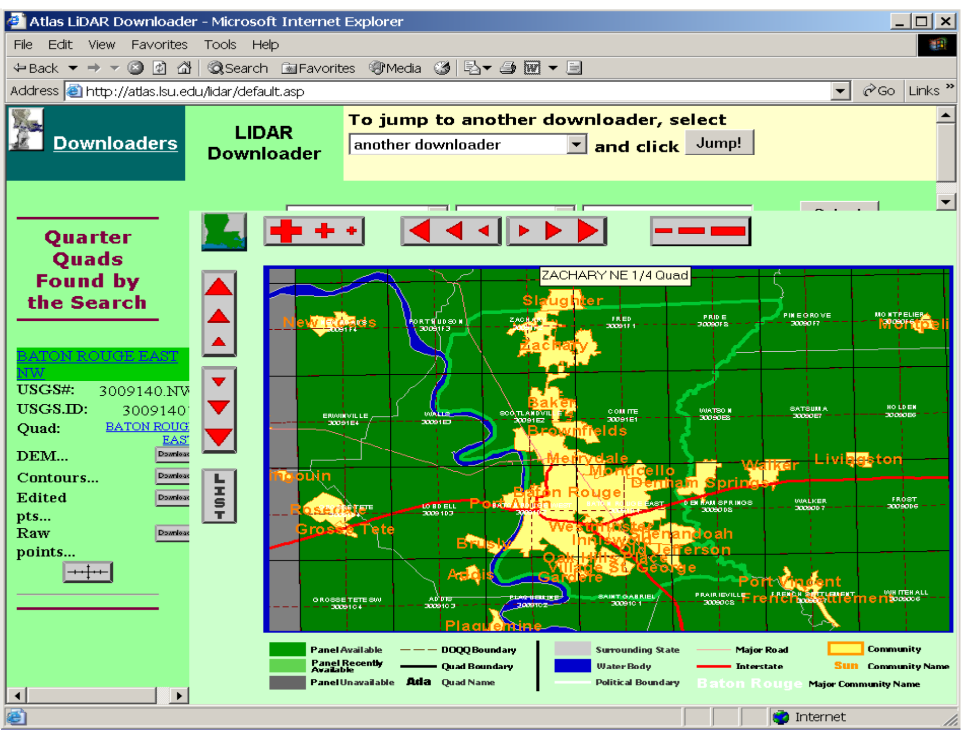


Figure 3 - Louisiana Distribution of Lidar Based Elevation Data

The state sponsor has been the Louisiana Oil Spill Coordinator's Office (LOSCO), which has managed the project and arranged for state matching funds through the budget process. The Louisiana Governor's Office of Homeland Security and Emergency Preparedness (GOHSEP) has recently assumed budgetary responsibility for the project with LOSCO responsible for project acquisition and distribution. The project is proceeding in seven phases over eight years, with the first and second phases completed in 2003 **(Figure 4).**

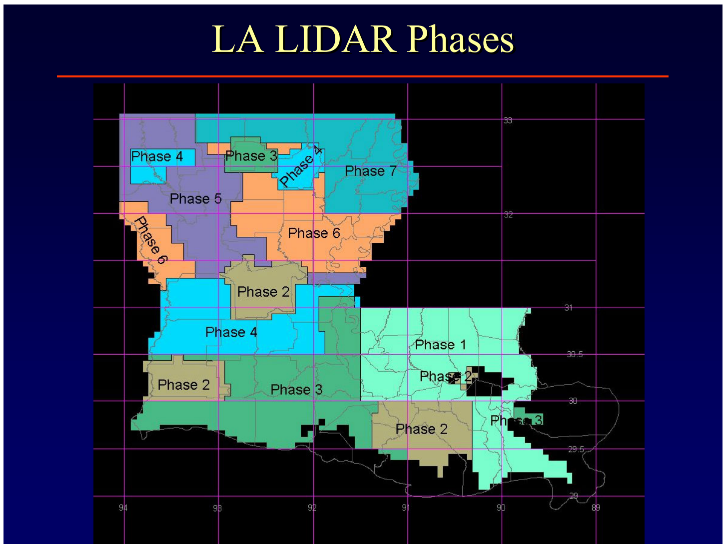


Figure 4 - Louisiana Lidar Phases

Phase one of the project was based on acquiring lidar-based elevation data in the four major terrain types encountered in Louisiana – wetlands, forested, agriculture, and developed (**Figure 5**). The goal was to test this unproven technology in the various major terrain types in Louisiana and Phase 1 included those types.

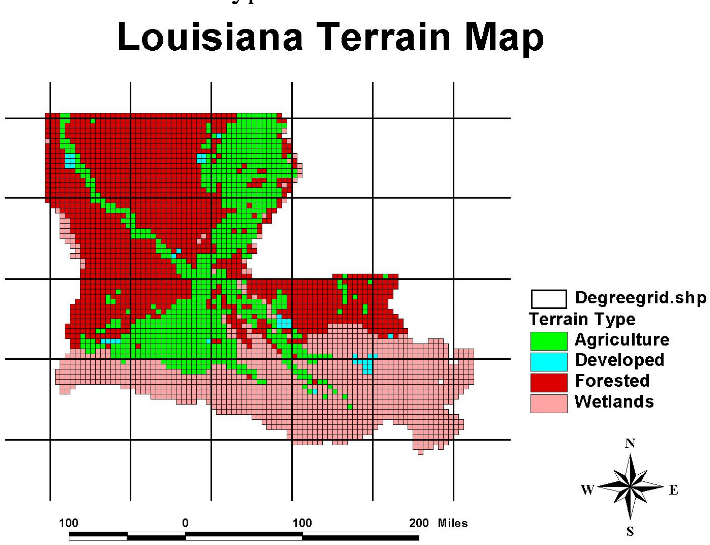


Figure 5 – Louisiana's Four Major Terrain Types

After Phase 1, subsequent phases focused on coastal areas where improved elevation data were desperately needed, with phases being adjusted to assist local government participation in creating new Digital Flood Rate Insurance Maps (DFIRMs) as indicated in Figure 2.

As of 14 February 2007, Louisiana has acquired 2,211 quarter-quadrangles of new elevation data using lidar technology (**Figure 6**).

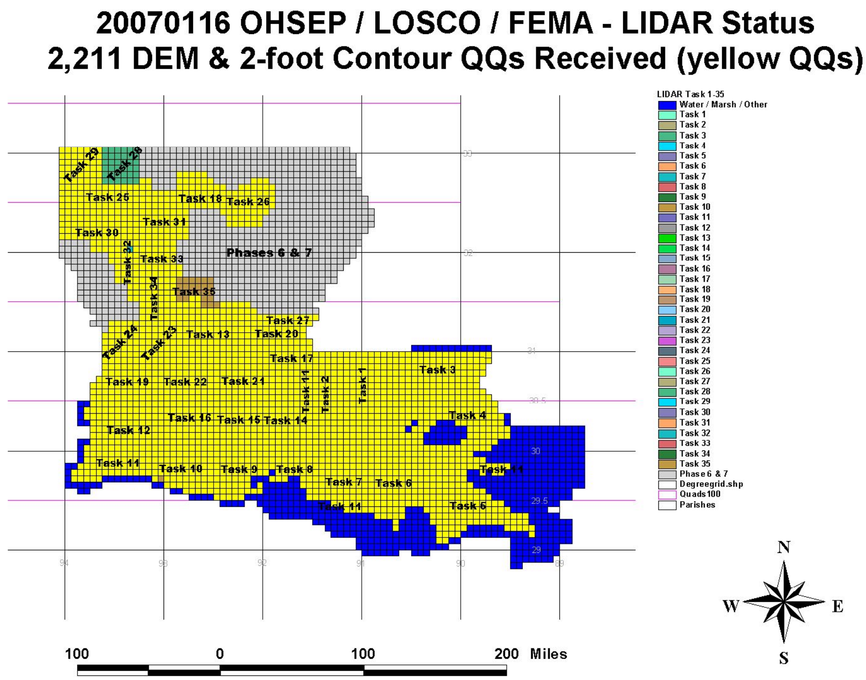


Figure 6 – Louisiana Lidar Acquisition Status

After thoughtful reflection on the lessons learned thus far, the Louisiana presentation addresses both technical and management issues encountered in producing over 2,000 quarter-quadrangles (approximately 35,000 square miles) of new high resolution elevation data using lidar technology.

Technical Issues

From a technical perspective, five major issues should be addressed in a national business plan:

1. Acquisition (flight) Specifications
2. Post-Processing (Reduction & Filtering) Specifications
3. Product Deliverables
4. Documentation (Multi-dimensional Spatial Metadata)
5. Quality Assurance / Quality Control (QA/QC for all aspects)

Acquisition (flight) Specifications

This is the first major category of technical issues that must be addressed in performing a national lidar survey.

a) **Point Spacing**

Most state procurements could employ a 2- to 3-meter point spacing acquisition with FEMA survey specifications.
High vertical relief, very low vertical relief, densely vegetated areas and urban areas with tall buildings (densely populated areas) – 1- to 2-meter point spacing (until about 150 feet above Mean Sea Level from the shoreline).
Semi-Arid and other areas of fairly flat topology – 3- to 5-meter point spacing may suffice.
Note, a denser point spacing occurs at Nadir (ex: 3-meter collection can be as dense as 2-foot posting at Nadir).

b) **Flight Line Length**

Flight lines should not be any longer than 35km due to drift in flight heading.

c) **GPS Base Stations**

Accuracy requirements determine the number of base stations used during acquisition.
Requirements:
Two base stations are always required.
The aircraft can never fly no more than 35km away from the base stations.
Base Station Configuration – two base stations equally spaced over the acquisition area are required.

d) **System Calibration (Bore sight)**

Requires repetitive overflight of known terrain for each mission (flight).

e) **Overlap Area**

30% ground point overlap (15% of overlap on each side of the flight line) for lidar sensor packages with roll stabilizer.

f) **Number of Returns**

At least three returns as a minimum are required. We recommend acquiring intensity data values for each return.

g) **PDOP (Position Dilution of Position)**

Four or more satellites are required at any given time during acquisition.

Post-processing (Reduction & Filtering) Specifications

This is the second major category of technical issues that must be addressed in performing a national lidar survey.

h) **Terrain Type**

Terrain type affects the type and amount of post-processing required in achieving desired bare-earth results. Therefore, terrain type is by far the best indicator for estimating post-processing resources.

i) Ephemeris Information

Use the best available at time of processing (rapid ephemeris is available in 2 days & precise ephemeris is available in 14 days)

j) Base Stations

Need to ensure that precise coordinates are being used during processing. Coordinates need to be verified by tying the base stations to the local Continuous Operating Reference Stations (CORS) Network and Quality Assurance / Quality Control (QA/QC) Control Network.

k) Bore-sight Calibration

For every mission, a bore-sight calibration must be performed to properly remove distortion due to roll, pitch and heading.

l) Overlap Area

Generally speaking, the margin of error increases as you move further away from nadir. Therefore we recommend the removal of the overlap area, which generally improves the point space density and eliminates less precise data at the edge of field of view.

m) Filtering

We recommend the FEMA filtering specification as a starting point: +/- 18.5 cm vertical accuracy for 95% of flat terrain and +/- 36.5 cm vertical accuracy for 95% of rolling to hilly terrain.

Product Deliverables

This is the third major category of technical issues that must be addressed in performing a national lidar survey.

n) Point Cloud

The point cloud acquired in the acquisition phase is a required product deliverable and intensity images are a recommended product deliverable.

o) Bare Earth

Using the point cloud, the bare earth terrain model is a required deliverable by removing vegetation and man-made features like homes, buildings, bridges, etc.

p) Breaklines

The breaklines used to create the triangular irregular network (TIN) is a required deliverable.

q) TIN

The triangular irregular network generated for the formulation of a digital elevation model (DEM) is a required deliverable. A standard TIN format should be adopted.

r) DEM

The digital elevation model (DEM) generated from the TIN and breaklines is a required deliverable.

s) Contours

The contours generated from the DEM are a required deliverable. The contour interval will be based on the accuracy of the DEM.

t) Format

The spatial extent or footprint of each deliverable should be in a Digital Orthophoto Quarter-Quarter Quadrangle (DOQQQ) 1 7/8-minutes (1:6,000 scale) grid format to facilitate use by engineering and architectural disciplines. Perhaps some overlap should be included in each DOQQQ DEM panel. The overlap could be in the 10-15 meter range.

u) Other Products

The basic unit of a DOQQQ does not preclude the formulation of other types of products having a larger spatial extent. For example, the assembling of 512 DOQQQ into a 1:100,000 scale USGS paper map series footprint may be desired for the entire nation.

Documentation

This is the fourth major category of technical issues that must be addressed in performing a national lidar survey. We propose a new paradigm.

v) Multi-dimensional Spatial Metadata – A New Paradigm

Metadata assembled in a spatial context will be extremely useful to describe the terrain model. This subject is described in greater detail under the section Spatial Extent under the Management Issues section.

Quality Assurance / Quality Control (QA/QC)

This is the fifth major category of technical issues that must be addressed in performing a national lidar survey. QA/QC must be applied in the acquisition, post-processing, deliverables, and documentation aspects described above.

w) Tie line

Required: A tie line (perpendicular flight line) must be flown through each project area flight line to improve QA/QC during acquisition (see Section Acquisition (flight) Specifications).

x) Ground Control

As per the FEMA specification, ground cover Categories 1-5 (low grass, high grass, brush lands, forested, urban) are fairly common. FEMA experience with Categories 6 and 7 (saw grass and mangrove) have vegetation so dense that lidar pulses do not penetrate to the ground, but instead map the top reflective surface. These categories (6 & 7) must be treated as "obscured terrain" with conventional photogrammetry whereby bare-earth elevations within such vegetation category polygons can only be estimated by interpolating elevations from ground points surrounding such polygons. A minimum of 20 test points for each major vegetation category identified must be evaluated. Therefore, a minimum of 60 test points shall be selected for three (minimum) major land cover categories, 80 test points for four major categories, and so on.

y) **Breaklines**

At a minimum, breaklines are required for hydrological features and obscured areas.

Management Issues

Three important project management issues should be addressed in formulating a national terrain model using lidar technology. These consist of acquisition issues, storage and retrieval issues, and distribution issues.

Acquisition Issues

z) **Terrain Type**

Terrain type has a direct effect on the amount of time required to process lidar data to bare-earth, which in turn affects acquisition resources. To greatly improve a national estimate, a terrain type map is vital. By spatially intersecting the terrain type map with a predefined spatial extent unit of area (see Spatial Extent section), a weighted post-processing estimate can be applied nationwide, thereby improving the estimated cost for each county (parish), State, or the nation.

aa) **Spatial Extent**

A well-defined spatial extent, or footprint, assists in planning and cost estimates. Owing to file size limitations and engineering application limitations, a quarter-quarter-quadrangle tile size is recommended (**Figure 7 and 7a**).

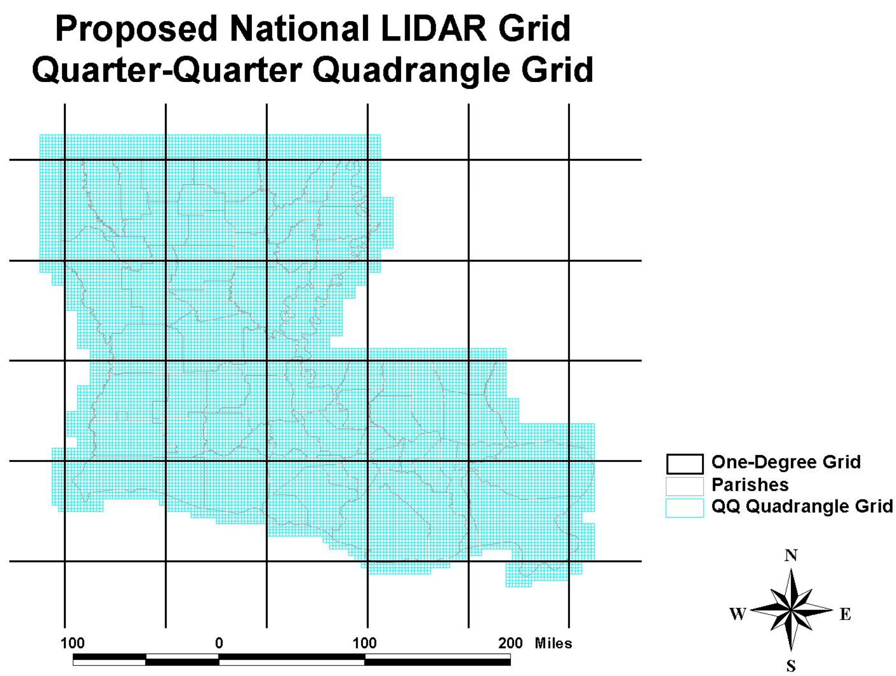


Figure 7 – Proposed National Lidar Quarter-Quarter-Quad Grid

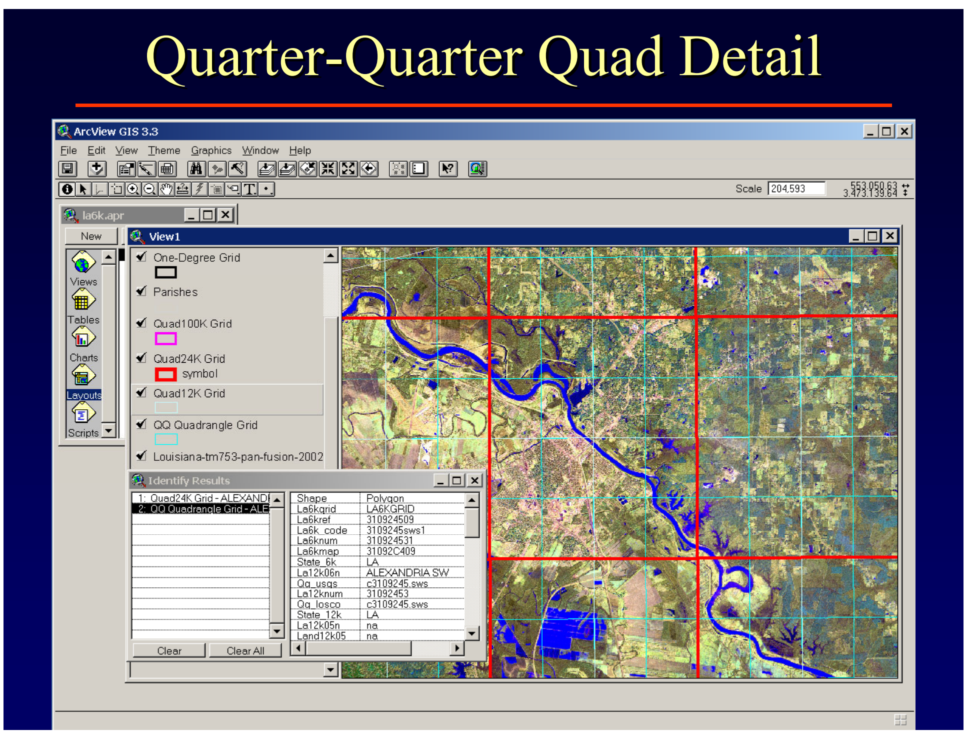


Figure 7a – Quarter-Quarter-Quadrangle Tile Size Detail

To effectively manage a national program, a tiled system is highly recommended to keep track of procurement progress. Unlike the Louisiana lidar project, a tiling scheme based on a quarter-quarter-quadrangle scheme would be more appropriate. The scheme allows the program to utilize a method similar to the successful National Digital Orthophoto (NDOP) program. This tile size reduction would reduce a 2- to 3-meter point spacing quarter-quadrangle file from approximately eight million points down to approximately two million points – a file size far better suited for most engineering and architectural applications.

Note: this does not preclude the use of other types of multi-dimensional spatial metadata including polygons representing acquisition phases (**Figure 8**), polygons representing work flow (**Figure 9**), and polygons representing individual flight line acquisitions for example.

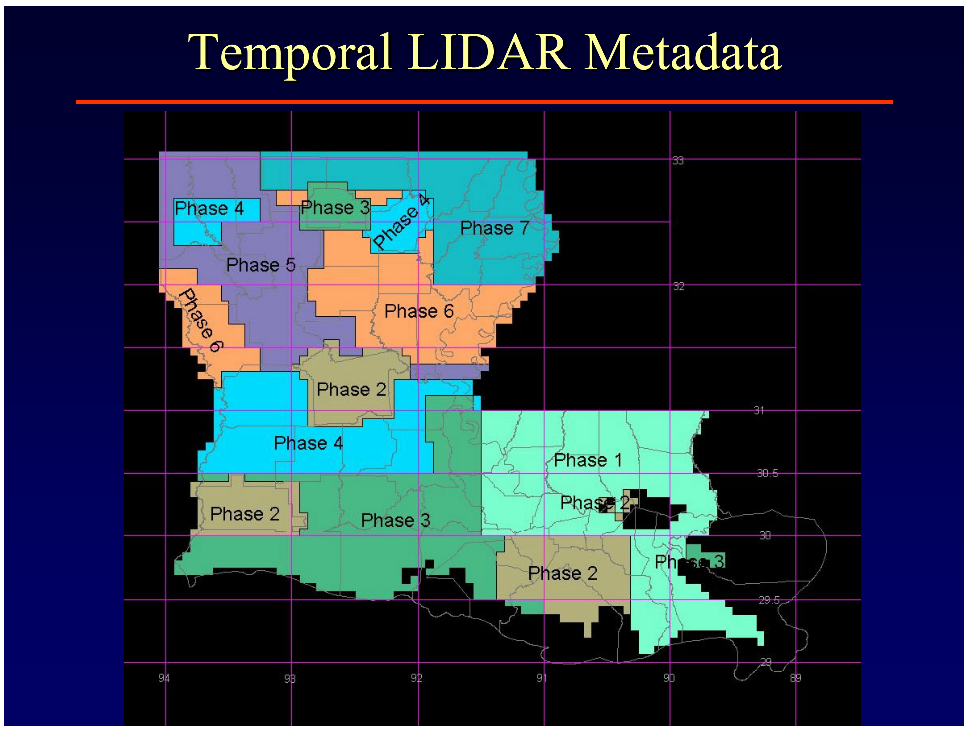


Figure 8 – Temporal Metadata

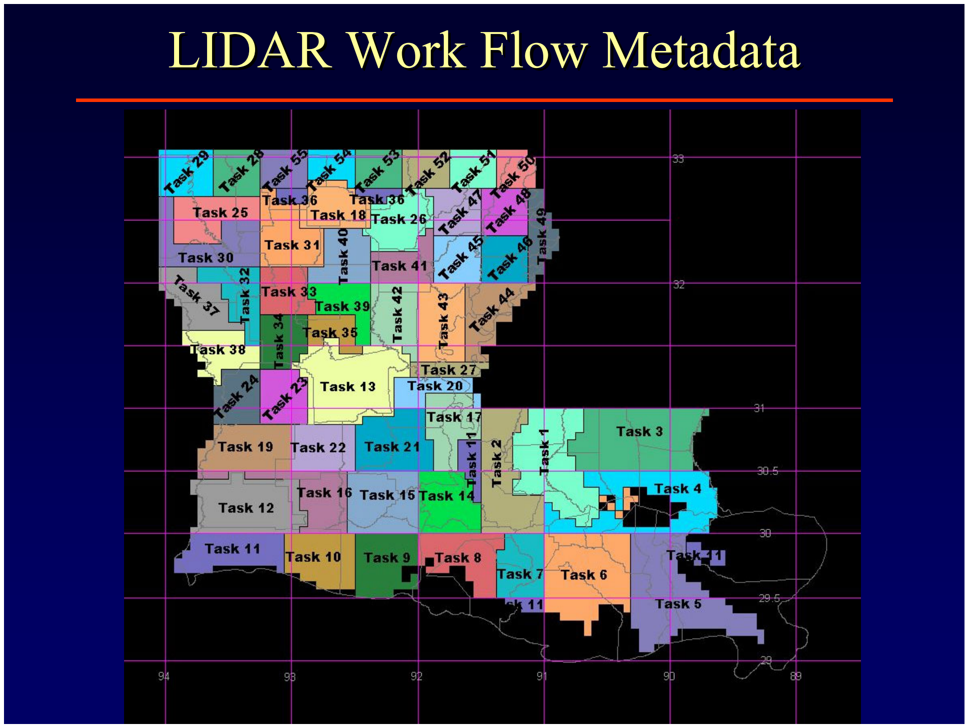


Figure 9 – Work Flow Metadata

In addition, multi-dimensional spatial metadata could show what areas are collected by terrestrial lidar, photogrammetric methods, ground surveys, traditional bathymetric surveys, bathymetric lidar, etc. For example, Lafayette Parish government provided the state with cross-sectional data to be integrated with the lidar based terrain surface. Traditional methods of metadata documentation may require some revision when documenting a complete contiguous national terrain surface.

Finally, pictures are more effective communication tools for legislators and policy makers rather than rows and columns. Using multi-dimensional spatial metadata could be helpful in communicating to Congress about the overall progress on the project.

Storage & Retrieval Issues

bb) Processing

Powerful computer systems are required to retrieve and process lidar data. For example, hurricane storm surge modeling requires super computing capability in order to provide timely surge predictions before hurricane landfall.

cc) Disk Storage

Petabytes of on-line storage will be required to host the lidar-derived national terrain surface in a [meaningful] fast, accessible way.

dd) Connectivity

The computer science community has developed massively parallel computers. Now massively parallel storage and retrieval architecture will be required to move lidar terrain surfaces into powerful computer systems required to perform regional simulations and modeling.

Distribution Issues

ee) Data Structure

A formal data structure allowing efficient storage of lidar based terrain data must be developed at a national level.

ff) Data Format

Data format must be addressed as part of data delivery.

gg) Delivery Mechanism

Delivery mechanism must be addressed before collection of a national lidar data set begins. In Louisiana, long before lidar products actually existed, we developed a map type interface to deliver data to the end user. We decided to have the deliverables "canned" into quarter-quadrangle tiles. Perhaps a means of dynamically selecting an area and product type (point cloud, bare earth, etc.) would be in order.

Summary

The above discussion attempts to address the major aspects encountered in acquiring and utilizing Louisiana statewide lidar-based elevation data and translating those lessons learned into a national approach. In the five major issues described above, many detailed aspects would need to be addressed in a business plan before a formal plan is completed. From the Louisiana perspective, the notion of "Elevation for the Nation" as described by the National Research Council report "Base Map Inputs For Floodplain Mapping" would be far more appropriate in describing the acquisition of a national terrain model, because elevation could potentially come for several sources, such as terrestrial lidar, photogrammetric methods, ground surveys, traditional bathymetric surveys, bathymetric lidar, etc.

Pennsylvania Perspective

The Pennsylvania Lidar project is managed under the PAMAP project which started in 2001. It is a Federal, State and local partnership, and is part of *The National Map.* In 2006, the Pennsylvania Department of Conservation and Natural Resources (DCNR) began providing lidar as part of the PAMAP project. Lidar is to be collected for one-third of the state each year for 3 years. The data is being collected to meet FEMA specifications (1.4-meter specs, 2-meter average post spacing). The lidar is to be used as the DEM for the orthophotos. A digital terrain model (DTM) and 2-foot contours are the main deliverables, but the raw and processed data are also available. **Figure 10** shows the planned acquisition of the lidar in Pennsylvania.

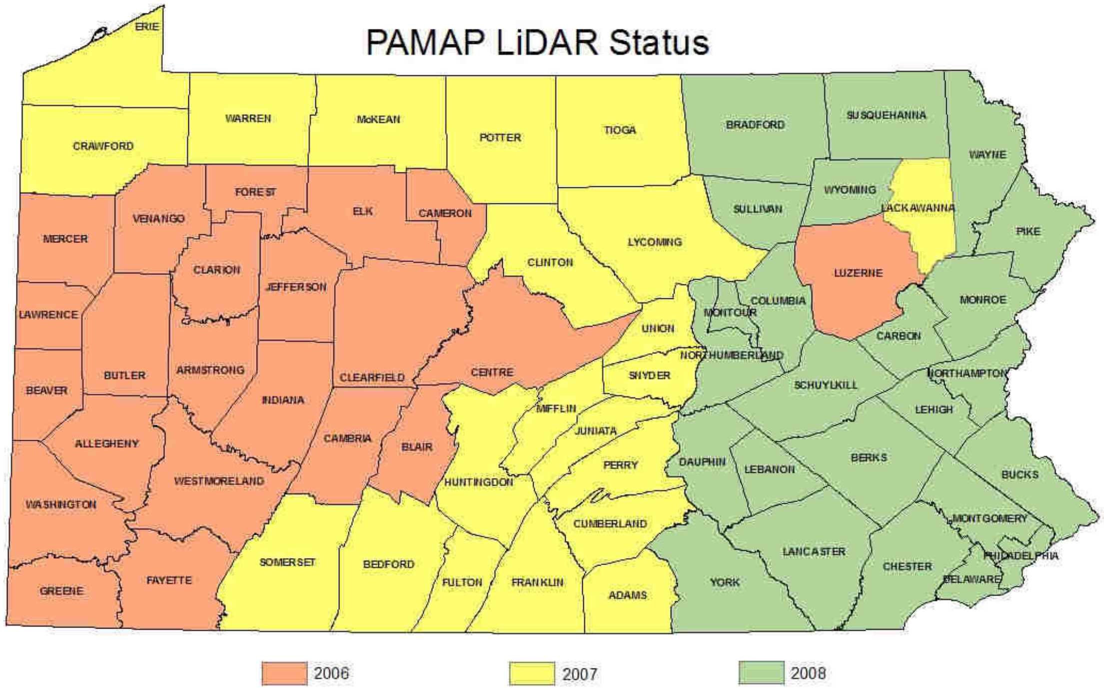


Figure 10. PAMAP Lidar Status

Although Pennsylvania is already in the process of acquiring statewide lidar, State agencies are still interested in participating in a National Lidar Initiative because of issues such as future carbon studies and monitoring. A final opinion is that lidar for the nation should take priority over other national programs, such as Imagery for the Nation, and especially highways.

Ohio Perspective

The Ohio Statewide Imagery Program (OSIP) provides 1-foot resolution color digital orthophotography and DEM data derived from lidar across the entire State of Ohio. The color imagery and DEM data will be captured and delivered in two phases. The northern half of the State (51 counties- 23,000 sq. mi.) will be flown in 2006 with final delivery to the State by the first or second quarter of 2007, and the southern half (37 counties- 17,000 sq. mi) will be flown in 2007 and delivered to the State by 2008 **(Figure 11).**

Figure 11. OSIP collection plan

In addition to the statewide coverage, county governments have been given the option to "buy-up" to 0.5-foot resolution digital orthoimagery and/or breakline reinforcement of the lidar DEM and generation of two-foot contours. Thus far, 25 of the 88 counties have decided to participate in the buy-up program. The combination of imagery and lidar appears to be a big draw for users **(Figure 12).** Financial support is provided primarily by the Ohio Department of Transportation (ODOT) but also include the USGS, the Ohio DNR and several Ohio counties.

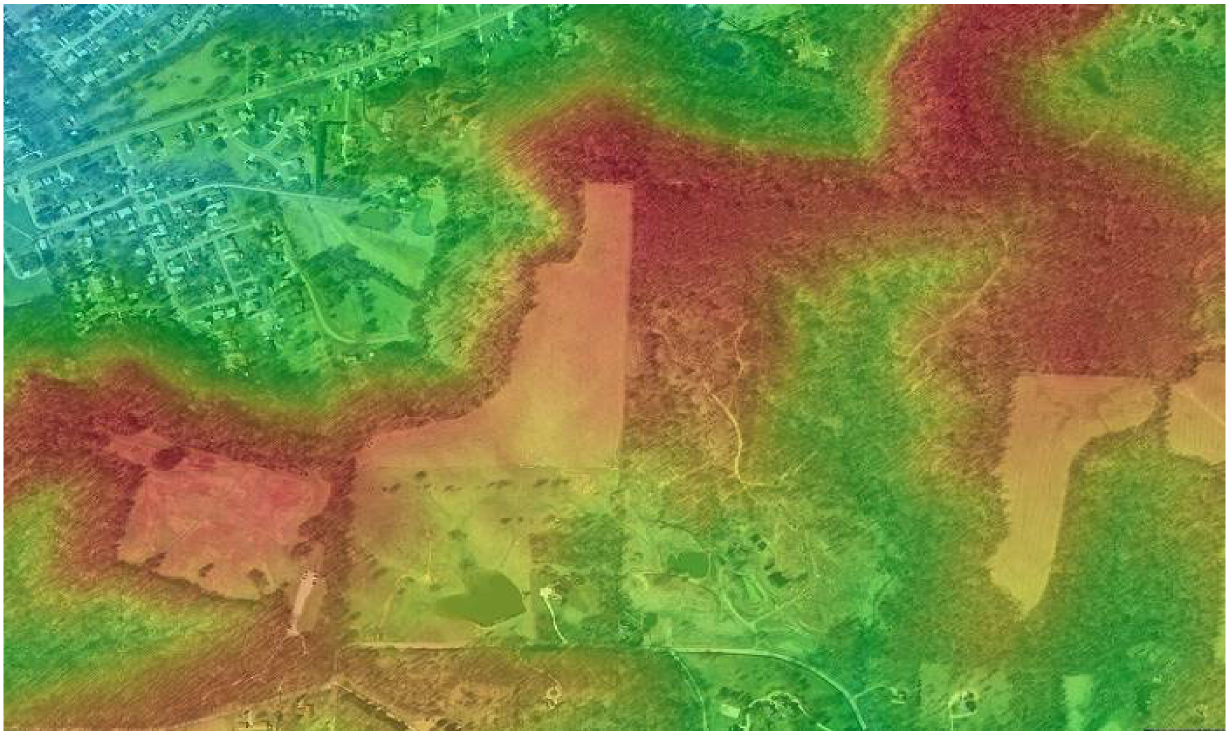


Figure 12. Imagery and Lidar Overlay in Ohio

Considerations & Lessons Learned

1. **The Champion and Managing Agency –** For any program to succeed there must be a "Champion". To support programs of this type in the State of Ohio, the Ohio Geographically Referencing Information Program (OGRIP) was created under the Ohio Department of Information Technology. The strategic goals defined by OGRIP are:
    - Develop a comprehensive program plan for geographic data development and usage for Ohio
    - Support and facilitate geographic data sharing among state and local governments, the private sector, academia, and the pubic in Ohio
    - Foster meaningful and continuing communication for Geographic Information Systems (GIS) in Ohio
    - Encourage enterprise-wide perspective among the public and private participants of the GIS community in Ohio
    - Promote GIS as an analytical tool supporting problem solving and decision making in Ohio.
2. **Determine the Objectives and Priorities –** Know who you want to serve and their needs. OGRIP has held monthly forum meetings that are well attended and promote the interaction of local, State and Federal government, educational institutions and private sector. The OGRIP Forum formed an Imagery/DEM task force to determine the needs within the state and develop an action plan. The use of a Profile Questionnaire was an invaluable tool used to determine the needs of the counties.
3. **Determine Specifications that Meet the Objectives –** Determine currency of data, density of data, and accuracy and format requirements that meet the needs of the majority.

4. **Determine the Amount of Resources** available to meet objectives in the desired timeframe
5. **Determine the Funding** necessary to meet objectives – How will the program be funded? Who will participate?
6. **Determine Who** will perform the various functions and duties.
    - Contractor or government agency?
    - Consider capability and experience
    - Develop selection process and contracting mechanisms
7. **Determine How** the data will be collected, processed, stored, and distributed during the production process.
    - Collection/processing priorities and schedules
    - Production task areas
    - Data transfer method (between State and vendor)
    - Data storage requirements
8. **Develop an Effective and Cost-Efficient Quality Control Procedure**
    - Determine reasonable expectations
    - Educated Quality Control Team
    - Maintain consistency
9. **Determine the Software and Equipment** needed to distribute and archive data
    - County Deliverables (firewire)
    - Imagery & ASCII Bare-earth DEM available via internet download
    - LAS Format Distribution (tools to view and analyze)
    - Develop a plan to handle preliminary requests for data
10. **The Education Process – Communication** is **The Most Important Factor** of the program
    - OGRIP Forum Meetings – interaction with local, State and Federal government, educational institutions and private sector.
    - Regional Workshops – educate participants on the status of the program and how to use the data.
    - Conference Presentations

Iowa Perspective

Iowa Perspective

A handful of lidar datasets have been collected in Iowa since 2000. In 2005, five watersheds were flown at a cost of over $1 per acre, including breaklines, DEMs, and 2-foot resolution color orthophotos. The data was at a nominal post spacing of 1 meter, with 15 cm RMSE vertical accuracy. After the Mid-American GIS Consortium Lidar workshop at EROS in August 2005, Iowa was able to use a Commercial Services Contract (CSC-2) through the USGS that generated lidar at standard specifications that meet FEMA standards. These standards include 1.4-m nominal postings, 18.5 RMSE at 95% confidence, with 37-cm RMSE in vegetated areas. The deliverables include ASCII x,y,z,I text files, and LAS all-return binary files. The contract price for this statewide effort has dropped to $75-85 per sq. mi (11 to 13 cents per acre). Instead of a $20 million project for the entire state, it dropped to a $4 million project.

A few of the justifications Iowa used to sell this idea to partner agencies included cost effectiveness. Lidar can be used for planning topographic surveys (2-foot contours). They estimate roughly 1% to 3% savings on large construction projects. The magnitude of potential 1% savings can be estimated from the $100 million a year that the Natural Resources Conservation Service (NRCS) spends on conservation projects, and the $1 billion per year the Department of Transportation spends on road construction projects. Likewise the Iowa Department of Natural Resources estimates potential savings of about $400,000 per year for planning surveys used in land acquisitions, boat dock and other construction projects.

Iowa is using its state revolving fund to finance purchase of the statewide lidar. Normally the state revolving fund is used to finance water quality improvement projects. The Iowa DNR applied for a $2 million, 20-year loan from this fund. This allowed them to leverage enough money to get the entire state collected. The acquisition is to be spread over two years. Lidar products for 19 counties will meet FEMA guidelines, and 80 counties will get the standard product. The acquisition started in fall/winter of 2006, and may extend until the spring of 2008 **(Figure 13).**

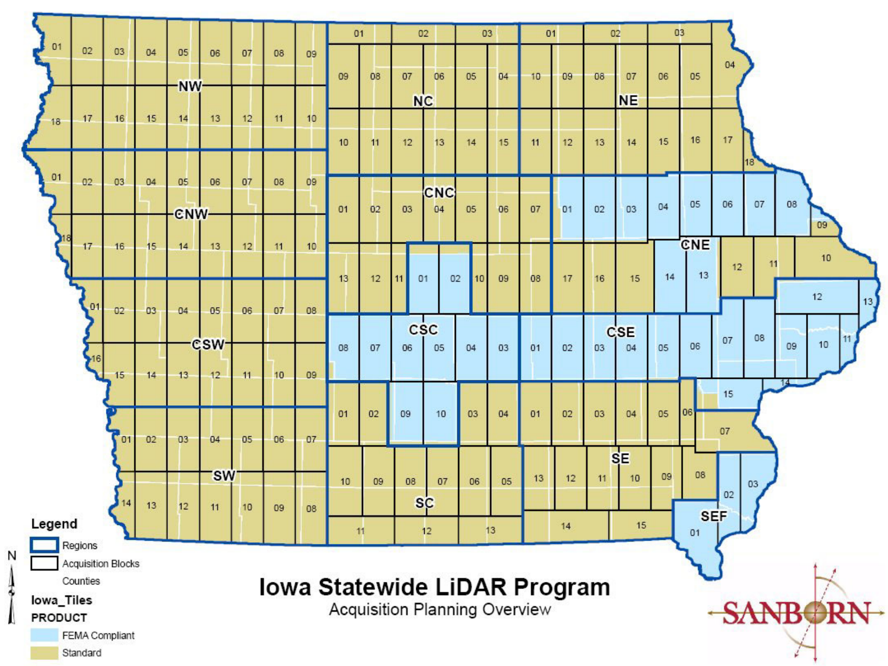


Figure 13. Iowa Acquisition Status

Puget Sound Lidar Consortium Perspective

The Puget Sound Lidar Consortium (PSLC) is an informal buying club for lidar data, with city, county, State, tribal, and Federal governments, and NGOs contributing funds to buy lidar data from the same vendor with the same specifications. All data are public domain. The master purchase contract is managed by Kitsap County; staff at the USGS and Puget Sound Regional Council helped write data specifications, evaluate vendor proposals, and provide quality control and data management. Formation of the Consortium was initiated by USGS researchers—who were looking for recent earthquake fault scarps—working with local government emergency managers and GIS staffs who were interested in improving public safety and addressing land and water management issues.

The PSLC has been collecting data since 2000 and has surveyed a large part of the Pacific Northwest **(Figure 14)**. Data layers include the all-return point cloud with attributes that include GPS time stamp, return number, return classification and intensity, a character-format (ASCII) list of ground points, and 6-foot resolution bare-earth and first-return DEMs.

The PSLC has created a robust three-part procedure to evaluate data accuracy, completeness, and conformance to format specifications. 1) The final bare-earth DEM is tested against ground control points (GCPs), although this has limited utility. Typically one cannot afford enough GCPs to fully evaluate a lidar data set and many unacceptable errors have a high probability of not being detected. 2) Large-scale (circa 1:12,000) shaded-relief images of the bare-earth DEM are carefully inspected. Most problems with a data set are visible to a trained eye. 3) A subsample of data tiles is analyzed through an automated routine that separates all-return data into its constituent swaths, constructs single-swath surfaces for both first-return and ground-return data, and then calculates the differences between these surfaces.

Results of the automated analysis include image-maps of swath-to-swath differences; by-tile and by-survey averages of differences; an analysis of the dependence of first-return Z differences on local slope, from which both Z and XY measurement errors can be extracted; and measures and maps of fraction swath overlap, pulse density, and ground-return density. Automated analysis is an effective check that files conform to format and naming specifications.

As lidar technology has improved, the cost to acquire data of a given quality has decreased. The PSLC has opted to remain at the same price point, about $500/mi^2, and buy data of better quality. Internal reproducibility of lidar measurements is now typically 5 cm (RMS Z). Standard data density has increased from 1 pulse/m^2 in 2000 to 8 pulses/m^2 in 2007. Year 2000-quality data now cost about $150/mi^2. Where public safety is an issue, legal concerns suggest that the best possible data are the most cost effective.

The PSLC experience demonstrates the strengths of a lidar acquisition program with a regional focus. Close ties to local collaborators produce strong political support for the program. Collaborators have a strong sense of owning the data, leading to early and widespread use of the data. Contracting is outside the USGS, which avoids the resistance of local partners to paying

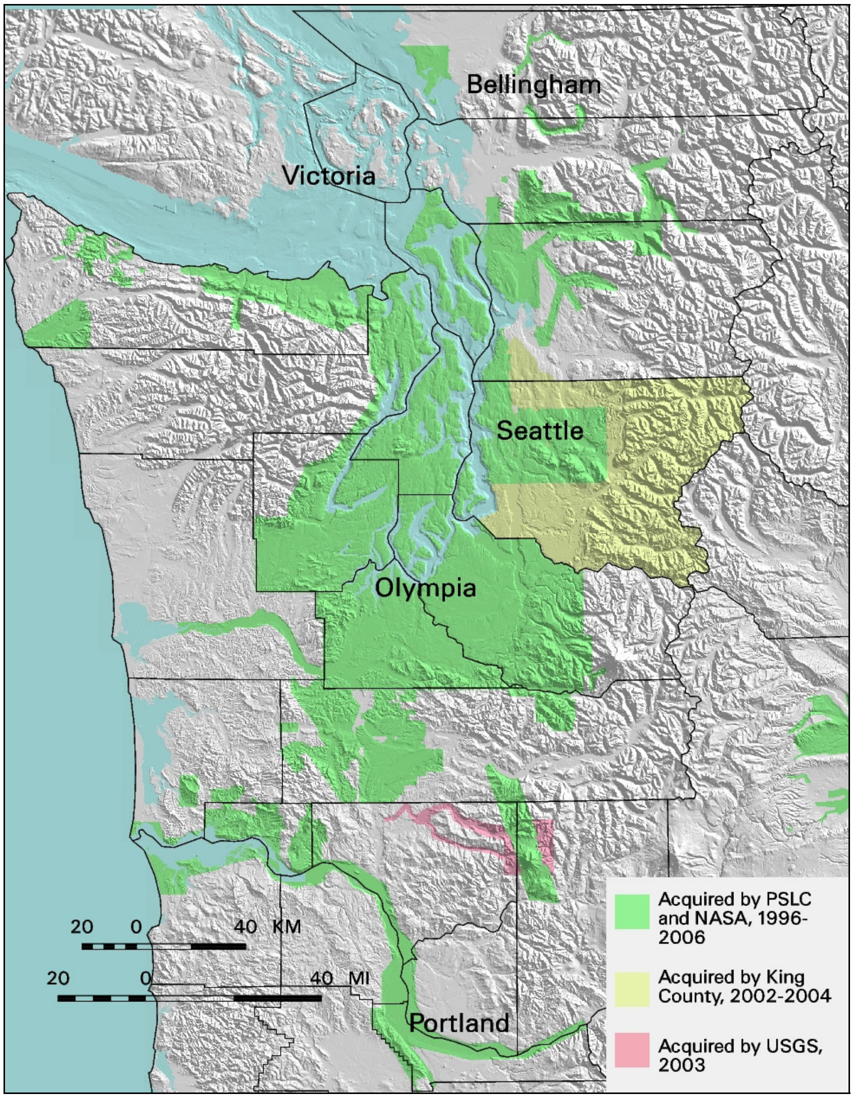


Figure 14. PSLC Acquisition Status

USGS overhead, facilitates effective vendor competition on quality and price, and provides short communication channels that make it easy to fix problems when they arise. Data standards are responsive to local needs. For instance, heavy forest cover requires a higher pulse density than has been contemplated for similar efforts elsewhere. Regional importance of forest resources dictates retaining the complete point cloud for description of the forest canopy. The PSLC has been adamant about leaf-off data collection. Data are delivered and archived in Washington State Plane projection and coordinate system, which has been deemed the most useful for most users.

Federal presentations

The federal presentations were given by Jason Stoker, SAIC (contractor to the USGS), Paul Rooney for FEMA, Hans-Erik Andersen for the U.S. Department of Agriculture Forest Service, and Steve Nechero for the Natural Resources Conservation Service (NRCS), Kirk Waters for the National Oceanic and Atmospheric Administration (NOAA), and Eddie Wiggins for the U.S. Army Corps of Engineers. Amar Nayegandhi provided information on the NASA Experimental Advanced Airborne Research Lidar (EAARL) system. Benjamin Jones provided some useful opinions on the potential of lidar in Alaska. Karen Schuckman and Dave Maune presented the findings from the recent National Research Council's Floodplain Mapping Report, entitled "Base Map Inputs for Floodplain Mapping." Dave Harding presented his ideas and developments on the NASA's work in designing a sensor that will be able to collect lidar at high altitudes over large areas. Bryon Ellingson presented the National Digital Elevation Program perspective, George Lee presented on Imagery for the Nation, and Tim Saultz presented about the USGS Geospatial Products and Service Contracts.

USGS Perspective

The USGS has a long tradition of collecting topographic data for the nation, starting in 1879 when USGS initiated surveying and mapping of the United States. In the 1930s, in cooperation with the Tennessee Valley Authority (TVA), the USGS began using aerial photographs in mapping and collecting photogrammetric data. In 1975, the USGS created the first digital elevation model, and in 1990, every 1:24,000 scale topographic map had been completed for the conterminous United States. In 1997, the seamless National Elevation Dataset (NED) was completed, and in 2003, NED began incorporating lidar source data into its multi-resolution framework. In 2005, the USGS initiated Web-based applications that perform GIS applications using seamless national data. The future of NED is trending towards not just bare earth elevation, but the elevation of things, such as natural (trees) and man-made structures.

The USGS is using lidar remote sensing data for a myriad of applications in every discipline and every region of the bureau. High-profile applications include using lidar to detect fault geomorphology and volcanic activity, and lidar is being used in biological and hydrologic applications as well as in multi-temporal applications **(Figure 15).**

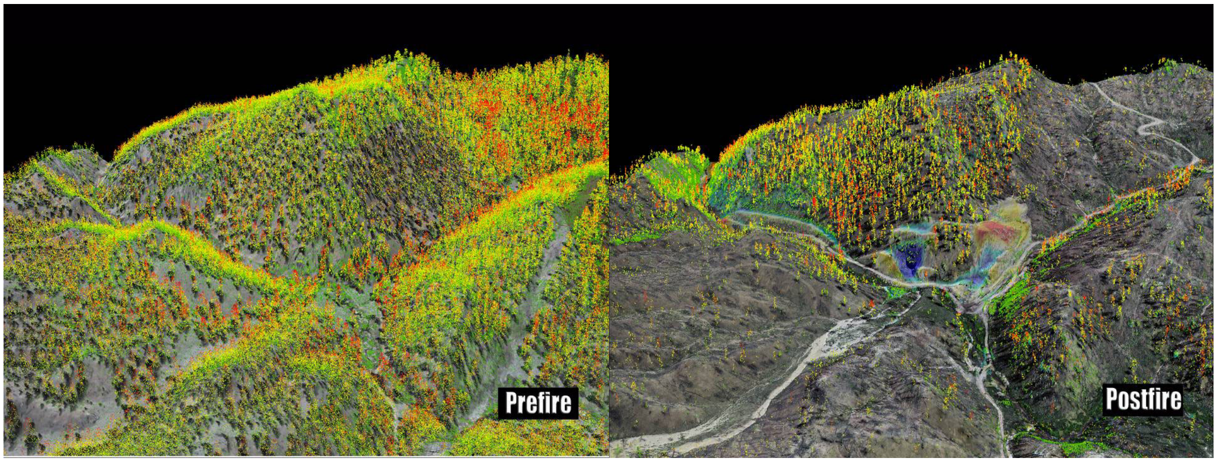


Figure 15. Multi-temporal, bare and non-bare earth applications using lidar in one project

Most bare earth lidar data are being incorporated into the NED and resampled at three resolutions: 1 arc second, 1/3 arc second, and 1/9 arc second (**Figure 16**). Unfiltered point cloud data are being delivered to the USGS Center for Lidar Information Coordination and Knowledge (CLICK) for use in scientific non-bare earth applications.

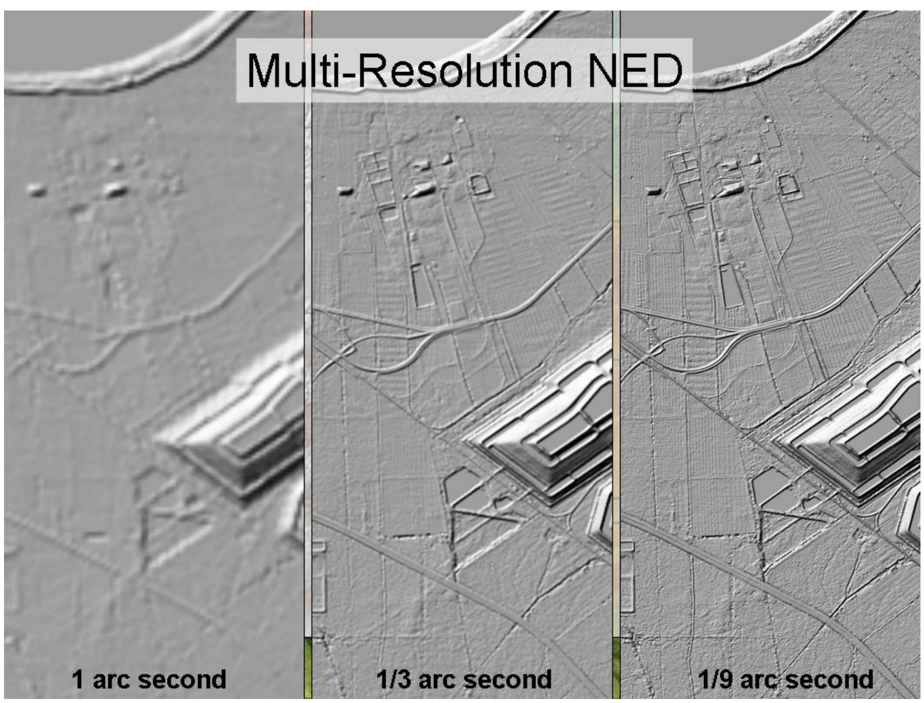


Figure 16. Multi-resolution elevation data in the National Elevation Dataset

The goals of incorporating lidar into national-scale datasets and applications are the primary drivers for NED and CLICK. There are several difficulties with using a bottom-up approach to consolidate disparate datasets into a cohesive national database, including differences in resolution, map projections, file types, file sizes, accuracies, system attributes, timing of collections, and metadata. All of these can complicate a seamless integration. **Table 1** details the advantages in a bottom-up approach versus a top-down approach in lidar collection for the nation.

Table 1. Bottom-up versus Top-down approach

Bottom-up Approach	**Top-down Approach**
Local dollars	Synoptic view
Local knowledge and enthusiasm	Seamlessness
Local needs addressed: project specific specs	Consistency
Less bureaucracy	Standards
Less overhead	More oversight
Higher resolutions and accuracies	More possible users and uses of the data
Focused problems	Better public data access
More intensive use of the data	Better coordination
Better chance of repeatability	Wider resource pool

In preparation for this meeting, in January, 2007 the USGS held a Bureau-wide conference call to coordinate all lidar users and discuss their applications. Some interesting findings from this call included:

1) It was not possible to determine the actual expenditures by USGS on lidar because of an inconsistent funding approach, and because of the difficulty of determining a monetary value for in-kind contributions to data analyses.

2) Lidar is being used in all regions and all disciplines.

3) All projects had major non-USGS sponsors that generally paid for the majority of the data collections. USGS expertise was the main contribution to these multi-partner efforts, not funding for the acquisition.

4) There is a high interest in ground-based and bathymetric lidar.

Federal Emergency Management Agency (FEMA) Perspective

The primary use of lidar for FEMA's Flood Hazard Mapping Program is to provide bare-earth information as the basis for the modeling and analysis of flood hazards and delineation of the boundaries of the special flood hazard areas. FEMA also uses lidar for preparedness activities for significant national events, in disaster response situations, and in other hazard analyses.

FEMA provided an overview of the recent National Academies report on mapping technologies used by FEMA's Flood Hazard Mapping Program. The report concludes that all flood maps should show the predicted water surface elevation for the base flood and that lack of accurate national elevation data is one of the principal reasons that these elevations are not computed and shown everywhere. The Academies report recommends a national program to develop accurate elevation beyond the scope of FEMA's Flood Map Modernization Program. FEMA agrees that the flood elevations are critical information for floodplain management. Development of new or updated flood elevations is a priority for the mapping program. However, FEMA must balance expected flood risk for an area mapped with the cost of the hazard analysis and other priorities. The FEMA strategy to complete the current modernization effort was explained in the Mid-Course Adjustment report to Congress in 2006.

FEMA provides tools and guidance to communities that have elected to participate in the National Flood Insurance Program (NFIP) to assist them in determining the flood elevations where they are not published by FEMA. FEMA has implemented an online application process that provides fast results for map amendments when homeowners feel their house was inadvertently included in the special flood hazard area due to inaccurate elevation data. FEMA has also strongly supported the National Digital Elevation Program, a voluntary partnership of Federal agencies working together to cooperate on improving the national elevation data holdings.

The report also observed that the new digital maps are correctly identifying the special flood hazard areas, that FEMA is finding good local elevation data in high risk areas to improve the flood maps and efforts to refine existing floodplain boundaries using the best available elevation data are an improvement upon previous approaches.

The last year of planned funding for the current Map Modernization is FY2008, with production continuing through FY2010. The NFIP will continue to need flood maps, the flood map inventory will require maintenance, and elevation data will be needed to update specific flood maps. However, until the scope and strategy for flood map maintenance is better defined, the specific flood mapping needs for elevation data are unknown and the benefits of a national Lidar effort for flood mapping cannot be quantified.

FEMA responded to the questions presented by the USGS from the perspective of a national program meeting many needs, not based on expected future needs for FEMA. FEMA recommended 3-meter post spacing, right now, for finished products if a single standard is used nationwide, but agreed that multiple resolutions of 1 meter, 3 meter and 5-10 meters might be the best solution (vertical accuracies 40 cm, 80 cm and 120 cm NSSDA). It is important to not add costs for detail that does not provide meaningful benefits. For a national program, higher standards will translate into higher costs even though sensor capabilities and collection densities continue to soar. However, technology is improving rapidly, so the program should assess these standards frequently and take advantage of improvements that truly have no, or very little extra cost.

Rather than a separate horizontal specification, FEMA suggests eliminating quality assurance (QA) rules that avoid areas where horizontal displacement will result in large vertical errors. Instead, testing comprehensively for vertical accuracy using a methodology similar to the current published FEMA Lidar QA specifications is recommended. National calibration might be helpful, but QA of all projects is needed. The USGS should be the national steward for the data and manage it at the Center for Earth Resources Observation and Science (EROS). Distribution through State clearinghouses should be encouraged and allowing States that meet specific criteria to serve as the authoritative stewards should be considered.

A five to seven year program with the work being done by the industry and funding provided by Federal, State and local contributors who can quantify the benefit of these data to their missions is the most likely scenario. Program priorities should be set, based on a vote by the funding partners with votes proportional to funding provided. The Federal contribution should be limited to encourage State and local buy-in. States should be required to bundle local contributions to avoid the program becoming unmanageable at a national level.

For the Flood Hazard Mapping Program, hydrologically treated, bare earth surface referenced NAVD88 or successor and the original point cloud with ellipsoidal heights are the most important products. A targeted refresh strategy for these data would be the most cost effective with a means to identify and update just the areas of change. Technological improvement will likely drive the next nationwide refresh, probably 15-20 years after the start of the first national effort.

Forest Service Perspective

The Forest Service is using lidar to estimate forest inventory information, such as stand height, mean diameter, volume and biomass, basal area, stand density and deciduous/coniferous discriminations. They are also using lidar for wild land fuel assessments to calculate canopy bulk density, canopy base height, and fuel volume in fire behavior predictions. Wildlife habitat assessments include percent cover, vertical structure, and species and diameter class. Finally, multi-temporal lidar is helping foresters monitor canopy change by estimating height growth, detecting blowdown and mortality, as well as areas that have been harvested. On forest lands, the Forest Service is using lidar for specific applications such as DEM production and corridor mapping, watershed mapping and flood risk protection, landslide hazard assessment, stream channel mapping, and geological mapping.

Multiple return lidar is needed by the Forest Service in order to create many of these forest characteristic estimations (**Figure 17**). Many systems record the amount of energy reflected by the target objects as intensity, and this information can also be useful for discriminating between deciduous and coniferous vegetation as well as stand and tree health. Plot-level lidar metrics are used to estimate forest inventory parameters, such as dominant height, basal area, stem volume, biomass and canopy fuel variables.

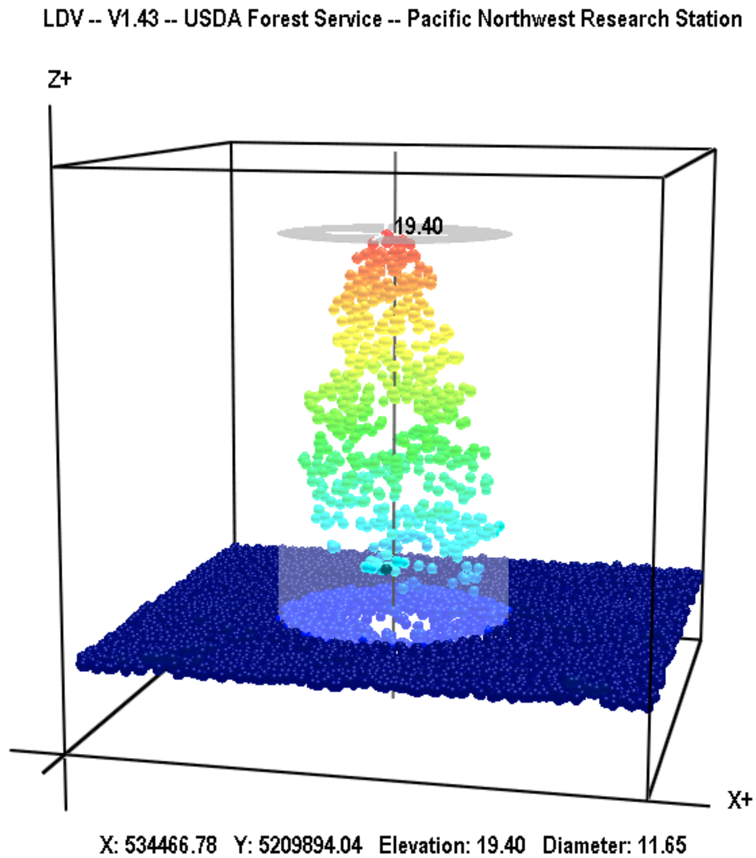


Figure 17. Lidar-based measurement of individual tree height within a Ponderosa pine stand, Fort Lewis Military Reservation, WA

Multiple regression models are used to make the comparisons to the plot-level metrics. Recent studies have shown that lidar performs well compared to field estimations of forest parameters. However, accurate measurements of tree heights require higher density than what is traditionally used for bare earth applications (greater than one pulse/m^2). The required density will depend on management objectives, but detection does degrade with decreasing density (**Figure 18a-b**).

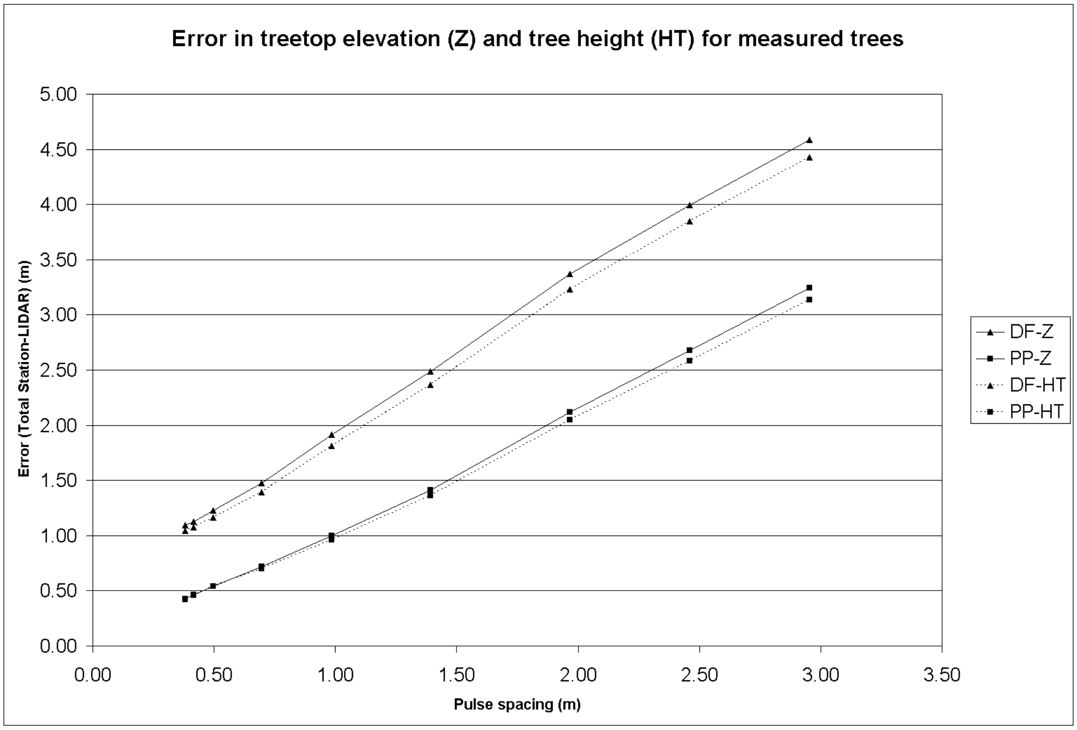


Figure 18a. Narrow-beam density and error (PP= ponderosa pine; DF= Douglas-fir)

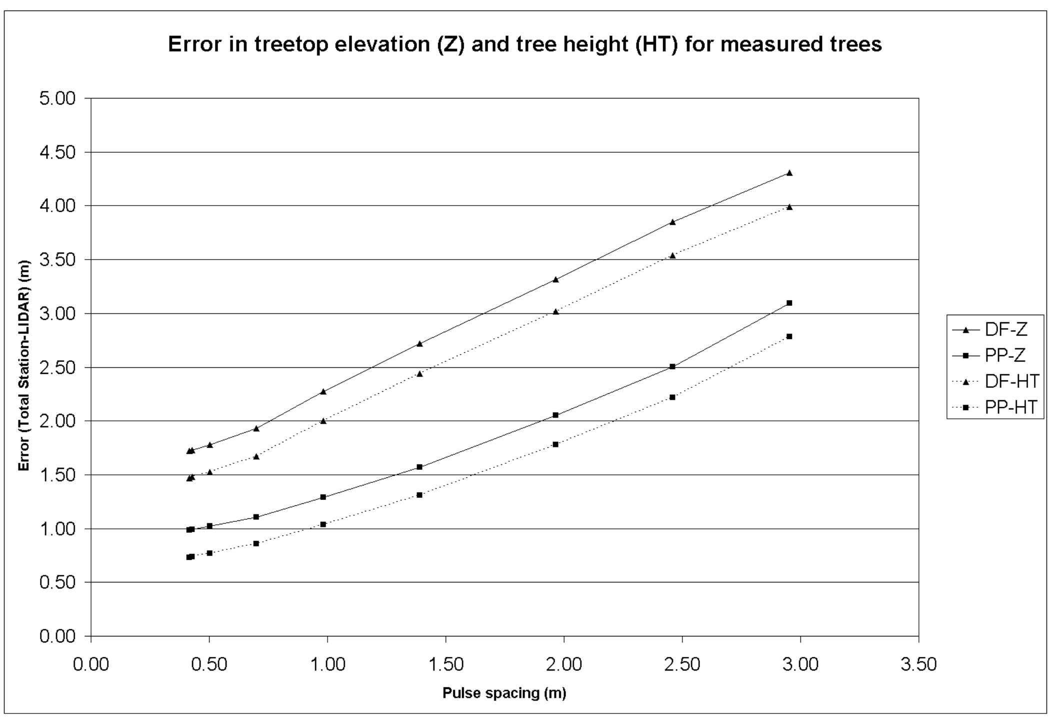


Figure 18b. Wide-beam density and error (PP= ponderosa pine; DF= Douglas-fir)

An informal survey carried out by the Forest Service Remote Sensing Applications Center (RSAC) and the PNW Research Station in September 2006 found that there are lidar projects underway in 6 regions and all research stations. Lidar data have been tested and used on a pilot basis in most resource planning and monitoring applications where terrain or vegetation structure is needed. They conservatively estimate that the Forest Service has been involved in lidar collection or use on 1 million acres of public land.

Natural Resource Conservation Service (NRCS) Perspective

The NRCS use of lidar is increasing in conducting their soil surveys. The soil survey provides essential information for making land use decisions and treatments to control soil erosion, manage water quality, and maintain high quality forage, crop, and timber productivity. They identify sensitive areas of concern for land use planners and determine eligibility in government programs. Soil survey interpretations predict soil behavior for specified soil uses and under specific management practices. Spatial Soil Data are produced by soil scientists making on-site observations and using remote sensing techniques to represent the geographic extent of soils that have the same properties, characteristics and behavior under different land uses. Soil scientists must understand the soil/landscape relationship. Topographic properties such as slope gradient and soil shape are essential in understanding these relationships. Lidar provides an excellent tool for determining soil properties. In fact, for many areas, traditional lidar data density may be more than what is needed for soil scientists. Other issues include the reduced accuracy and density of bare earth slope estimates because of vegetative characteristics.

National Oceanic and Atmospheric Administration (NOAA) Perspective

NOAA mission goals include studies of ecosystems, climate (weather and water), and commerce and transportation. Lidar is important in NOAA's mission because it is used in coastal hazards and flooding, coastal uplands and ecosystem management, hydrography, shoreline mapping, storm modeling, coastal erosion and assessing benthic habitats. NOAA uses lidar in an end-to-end fashion, from research and development to a complete operational mapping program. Primary mapping operations include bathymetry, fusion of topography and bathymetry, and coastal upland mapping. Bathymetric lidar augments NOAA's acoustic surveys, and is used in nautical charting, benthic habitat mapping and coastal resource management and conservations. The topo/bathy mapping is an operational data acquisition and dissemination program, and is part of the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) partnership between U.S. Army Corps of Engineers, Navy, and NOAA. NOAA distributes the data collected via the web using their Lidar Data Retrieval Tool (LDART). Topo/bathy applications include hazard mitigation, shoreline delineation, beach change, tsunami inundation mapping and sea level rise. The coastal uplands mapping effort is using topographic lidar primarily to collect data in coastal counties and immediate coastal watersheds. The current focus of this program is the Gulf of

Mexico and the East coast, although the program is national in scope. NOAA has created partnerships with industry to provide a wide distribution of these data. Key coordination groups include FEMA, the National Digital Elevation Program (NDEP) and the National States Geographic Information Council (NSGIC). Coastal applications include watershed and ecosystem management and planning, watershed modeling of water quality, stream flow, pollution loading and erosion potential, and visualization.

The resolutions required by NOAA are application dependent. They currently use 4 meter for bathymetry, 2 meter for benthic rugosity, and certain standards for charting. They require between 1 and 5 meters for ecosystem management and floodplain mapping, 1 meter or less for feature extraction, and 2 meters or less for shoreline delineation. The LDART system allows users to specify the resolutions of the outputs. Interestingly, the vast majority of requests made are at the defaults (**Figure 19**). This highlights the importance of dataset-dependent default specifications for future data dissemination programs for multiple applications.

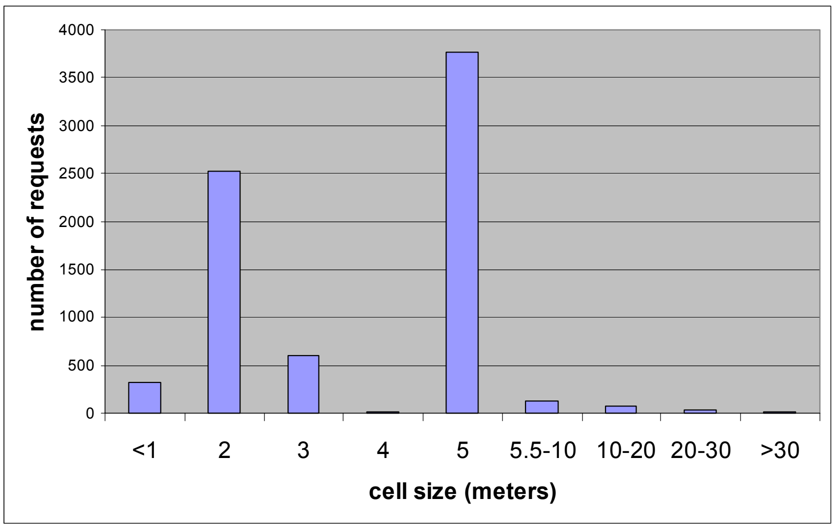


Figure19. Requests versus cell size

NOAA is concerned about several issues regarding a national-scale lidar program. The true vertical accuracy needs may be difficult to assess, and are often model- and terrain-dependent. Many coastal management users have the need for 1-foot contours. Also, relative accuracy may be more important than absolute accuracy, particularly for water flow applications. Some other considerations include the possibility of using a full-waveform lidar instead of discrete return systems, as they provide much more information. The LAS format is acceptable for points, although it does have some timestamp limitations, and is not very bathymetric-friendly. Many users may not want the point cloud, but may only want the data in a grid or as contours. The timings of the collections are critical for shoreline delineation, as well as leaf-off conditions to model water flow. Also, low turbidity is important for bathymetric work. NOAA agrees that updates will clearly be needed, but expects that the timing is location dependent. Cheaper technologies, such as land cover products or IfSAR, may be usable to detect areas of change requiring updates. A full repeat cycle of 10-20 years may be sufficient if targeted updates can be made. Also, updates in the Geoid model may cause errors in change detection if we aren't careful in documentation. It may be wise to store data in ellipsoid heights.

U.S. Army Corps of Engineers (USACE) Perspective

JALBTCX is part of the USACE, and flies the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) lidar system, owned by the Naval Oceanographic Office, to perform its coastal mapping work. CHARTS is an integrated lidar system that collects topography, bathymetry, and imagery from a single platform. The extent of data collection using the CHARTS system is from the waterline out 1,000 meters at 4 m point spacing for hydrologic data, and from the waterline inland 500 meters at 1 meter spacing for topographic data. CHARTS also collects imagery simultaneously at 20 cm resolution.

Data and products include elevations in XYZ text files, with land at 1 m by 1 m resolution and hydro at 4 m by 4 m. This equates to average files sizes of about 250 MB per mile. The data also includes orthometric RGB imagery in GeoTIFF format, a 1-meter elevation grid for GIS uses, shoreline vector (the 0 line in NAVD88), building footprints, bare earth, bottom reflectance and the hyperspectral cube when applicable (**Figure 20**).

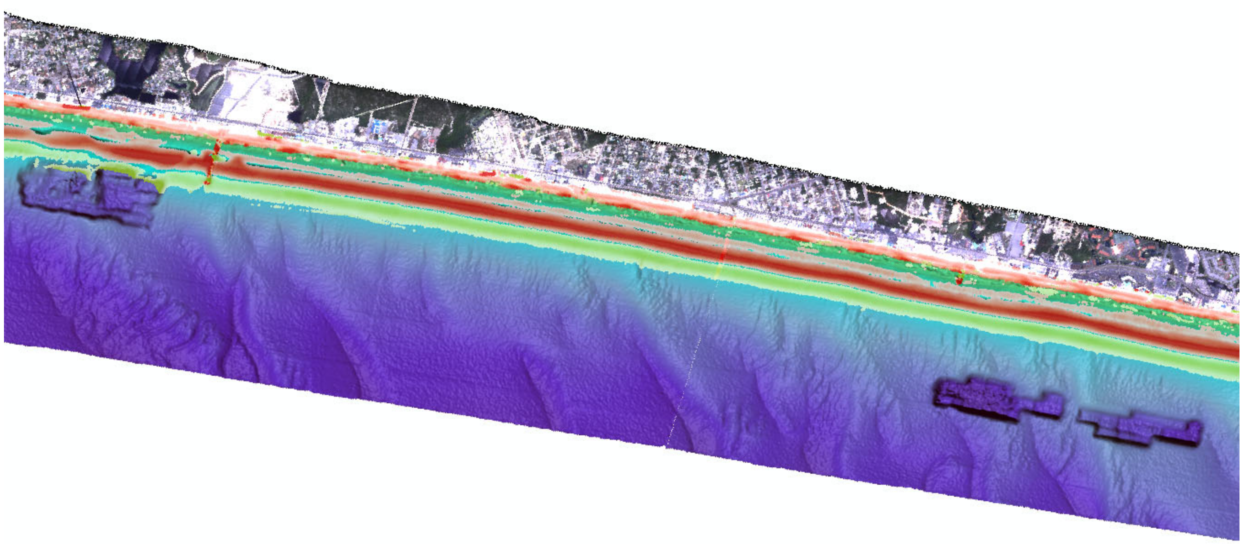


Figure 20. CHARTS example

The JALBTCX made the following recommendations. Data collection should be prioritized based on hazards and areas with no data that are highly susceptible to short-term change. In addition, we should build on existing QC/QA standards rather than creating completely new standards. Metadata must be thorough and accurate. Standard file formats must provide all the information necessary for the end user. There is a need to mix record types in a file. For example, topo produces intensity, whereas bathy produces reflectance. We need free tools available to access the data in the desired formats.

NDEP Perspective

The National Digital Elevation Program (NDEP) is a consortium of agencies coordinating the collection and application of high-resolution, high accuracy elevation data. The NDEP consists of:

- Bureau of Land Management
- Federal Emergency Management Agency
- U.S. Fish and Wildlife Service
- National Aeronautic and Space Administration
- National Geospatial-Intelligence Agency
- National Oceanic and Atmospheric Administration
- National States Geographic Information Council
- USDA Natural Resources Conservation Service
- U.S. Army Corps of Engineers
- U.S. Census Bureau
- USDA Forest Service
- U.S. Geological Survey

NDEP was established to promote the exchange of accurate digital land elevation data among government, private, and non-private sectors and the academic community and to establish standards and guidance that will benefit all users. Its goals are to enhance data sharing among Federal, State, and local agencies, the private sector and academia, minimize redundant data production, leverage resources to satisfy multiple requirements, develop flexible standards that meet the needs of most users, and to ensure the availability and accuracy of digital topographic data.

The NDEP has created "Guidelines for Digital Elevation Data" v. 1.0, which specifies vertical accuracy testing and reporting approaches in data collection contracts. NDEP also has a project tracking system online that shows areas where digital elevation data has been collected (**Figure 21**).

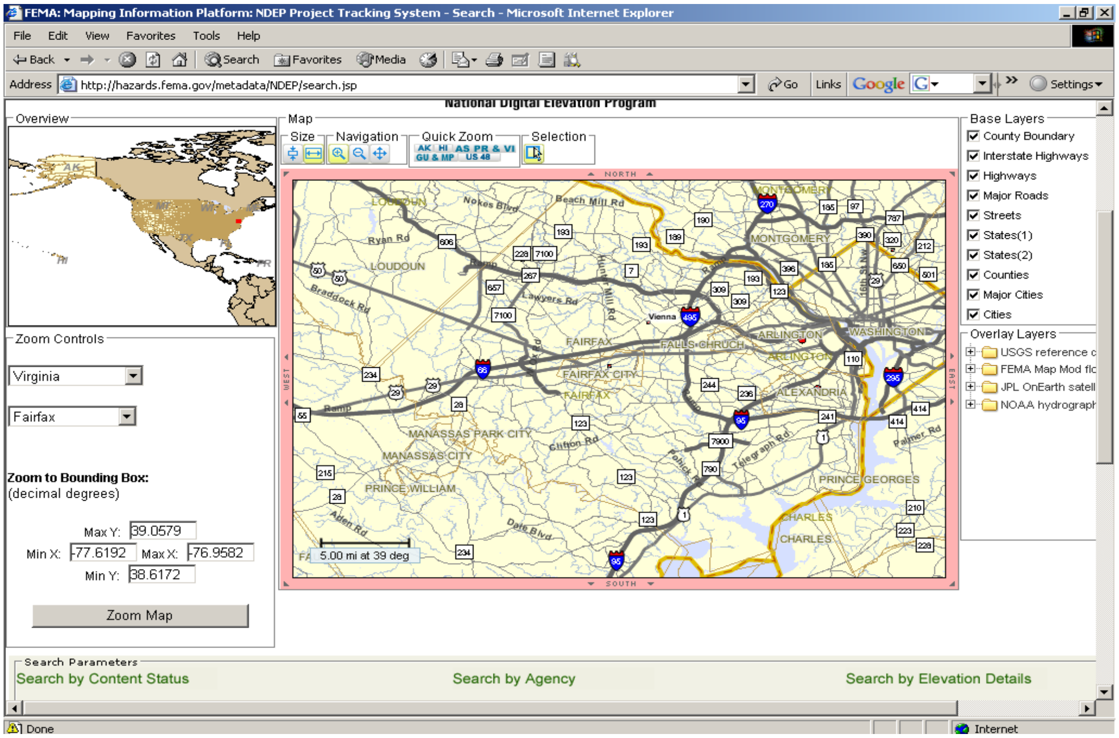


Figure 21. NDEP Project Tracking Viewer

The lidar specifications that would satisfy NDEP guidelines are as follows:

- 1.4-meter average point spacing, Vertical Bare earth 18.5 cm RMSE
- 15-cm RMS in open terrain
- Vertical in Vegetation 37 cm RMSE
- Horizontal 1-m RMSE
- All product quality per FEMA guidelines and Specifications for Flood Mapping Partners
- No data voids due to system malfunctions or lack of overlap
- Dense vegetation data voids minimized by automatic removal process
- Instrument calibrated for every mission
- Flight plans are parallel flight lines with at least one cross flight line to assure positional accuracy.
- Flight plan considers requirements for point density, terrain, PDOP, and KP index
- Uses ONLY automated filtering for lidar products with minimum performance for bare earth models
- All data and products associated with contract deliverables will meet or exceed relevant NSSDA standards and fully comply with FGDC metadata format standard

- Deliverables will be submitted to customer in digital format according to requirements outlined in FEMA guidelines
- Standard coordinates, projections, and datums available.
- No Independent field verification.

Current Lidar industry estimates are that nation-wide lidar coverage could be done for about 200 million dollars. This Lidar product would meet or exceed the standard that meets NDEP guidelines. Given the number of sensors currently being flown, estimates are that this effort would take approximately 5 years to complete. Given a 5-year collection cycle, costs would be about 40 million dollars per year.

Imagery for the Nation Comparison

Imagery for the Nation is an organized effort to acquire imagery over the entire United States. It is a multiple-resolution effort (6-inch, 1-foot, 1-meter), with a repeat cycle of 3-5 years. All imagery stays in the public domain. There are consistent national standards. States can manage part of the program through developments of business plans, but the Federal government funds the program. There are several buy-up options that localities can purchase, and they vary according to product type. Some of these options include color infrared, increased frequency, increased footprint, increased horizontal accuracy, sampling to lower resolutions, increased resolution (6-inch to 3 inch and 1-foot to 6-inch), improved elevation data products, and creation of "true orthos", which remove building lean. More information on Imagery for the nation can be found at: http://www.nsgic.org/hottopics/imagery_forthe_nation.pdf

From April through July 2006, the National States Geographic Information Council (NSGIC) conducted a national survey on Imagery for the Nation. It included input on survey questions from other stakeholders. In total, 1,887 people responded to the survey. The survey was designed to take a pulse on local and state government with regards to Imagery for the Nation. Some observations of this survey include:

- Local Government is more likely to contract for new imagery and depend less on public domain sources than state government.
- State Government is more likely to acquire and process imagery "in-house" than local government.
- The entire group of respondents, including Federal, tribal, private, academic, and public are more dependent on public domain than licensed sources of imagery.
- Surprisingly, State government showed a greater interest about increased frequency of acquisition.
- As expected, local government showed a greater interest in True Ortho production to remove building "lean" in their imagery.
- State government showed a surprising interest in sampling high resolution products.
- State government showed a significantly greater interest in 4-Band, CIR, and improved elevation products.

Beginning in October 2006, the U.S. Geological Survey and U.S. Department of Agriculture are jointly funding a comprehensive cost benefit analysis. The draft results are due in March, 2007 and final deliverables are due in June, 2007. The goal is to develop a comprehensive Imagery for the Nation (IFTN) business case that accurately communicates program goals, objectives, benefits, and other value propositions.

Geospatial Products and Service Contracts

The USGS Geospatial Products and Service Contracts (GPSC) comprise a suite of contracts providing flexibility and tools for the future. Contracts are awarded based on Qualifications Based Selections (QBS) procedures. Task orders are awarded based on quality, timeliness, and efficiency. They perform negotiations with one contractor at a time toward an agreement on "Level of Effort". The contractor and the USGS work together as partners, and risk is shared between the contractor and the Government. Two awards were made in January, 2007 to Aerometric and Dewberry and Davis, and two more awards were made in February, 2007 to Sanborn and Woolpert. Negotiations are currently taking place with a fifth prime contractor.

Part 15 of the contract defines the term "Best Value": Best value means the expected outcome of an acquisition is that which, in the government's estimation, provides the greatest overall benefit in response to the requirement. This permits tradeoffs among cost and non-cost factors. As a result, the government may accept an offer other than the lowest cost proposal. A negotiated procurement allows for technical discussions prior to the award. If the requirement is clearly defined and the risk of non-performance is low, then cost or price may play a dominant role in contractor selection. If the requirements are less defined and the performance risk is greater, then past performance and technical considerations are dominant in the selection. To date, 21 lidar task orders have been completed with five different prime vendors (1 in FY03, 5 in FY04, 5 in FY05, and 10 in FY06). These orders had several specifications and products, and involved many Federal and State partners. In total, over 66,000 square miles of lidar have been collected with just under $7 million dollars in total funding.

National Research Council Report: "Base Map Inputs for Floodplain Mapping"

This summary is from the National Academies Report Executive Summary, and can be found at: *http://books.nap.edu/execsumm_pdf/11829.pdf*

The committee concludes that the nation's base map information for land surface elevation is inadequate to support FEMA's Flood Map Modernization and that new national digital elevation data collection is required. The committee proposes that this program be called *Elevation for the Nation* to parallel the existing *Imagery for the Nation* concept. The committee recommends the following:

1. *Elevation for the Nation* should employ lidar as the primary technology for digital elevation data acquisition. Lidar is capable of producing a bare-earth elevation model with 2-foot equivalent contour accuracy in most terrain and land cover types; a 4-foot equivalent contour accuracy is more

cost-effective in mountainous terrain, and a 1-foot equivalent contour accuracy can be achieved in very flat coastal or inland floodplains. A seamless nationwide elevation database created at these accuracies would meet FEMA's published requirements for floodplain mapping for the nation. The first focus of this program should be on remapping the elevation of the 65 percent of the nation that contains 92 percent of its population, where flood risk justifies the required data collection. The program can use newly acquired data or existing local and regional data if the existing data are reasonably up-to-date.

2. A seamless nationwide elevation model has application beyond the FEMA Map Modernization program; some local and state governments are acquiring lidar data at the same accuracies or better. For example, in 2007, the Florida Division of Emergency Management will be acquiring lidar data satisfying 1-foot equivalent contour accuracy of shorelines for storm surge modeling and hurricane evacuation planning. As part of *Elevation for the Nation*, Federal, State, and local mapping partners should have the option to request data that exceed minimum specifications if they pay the additional cost of data collection and processing required to achieve higher accuracies.

3. The new data collected in *Elevation for the Nation* should be disseminated to the public as part of an updated National Elevation Dataset.

4. The *Elevation for the Nation* database should contain the original lidar mass points and edited bare-earth surface, as well as any breaklines required to define essential linear features.

5. In addition to the elements proposed for the national database, secondary products including triangulated irregular networks, hydrologically corrected digital elevation models, and hydrologically corrected stream networks and shorelines should be created to support FEMA floodplain mapping. Standards and interchange formats for these secondary products do not currently exist and should be developed. Comprehensive standards for lidar data collection and processing are also needed. Professional societies and Federal agency consortia are appropriate entities to lead development of these standards; funding to support these efforts should be considered as part of a nationwide effort.

The committee reached its conclusion that *Elevation for the Nation* is needed for two main reasons – first, that for the nation as a whole, the existing elevation data are so old, and the gap between their accuracy and the accuracy required for floodplain mapping is so great, that the need for new elevation data is clear; and, second, that the required elevation mapping technology exists and has been commercially deployed such that implementing *Elevation for the Nation* is technically feasible. Regardless of whether "best-available" elevation data are used or new elevation data are being acquired for a flood study, informed judgments must be made about the appropriateness of these datasets and their influence on the flood data computations. The committee recognizes that *Elevation for the Nation* will involve significant expense, perhaps as large as the existing Flood Map Modernization program. It is for Congress and others to determine whether this expense is justified in the context of national spending priorities.

Certainly the data arising from *Elevation for the Nation* will have many beneficial uses beyond floodplain mapping and management. The current study was conducted in a short time to address very specific questions about the mapping technologies used to produce floodplain maps. As such, the committee did not have the resources or scope to examine in detail many important issues related to flood map accuracy.

The committee suggests, for example, that an analysis of a selection of updated flood maps could be useful to compare the quantitative effects of using lidar versus using conventional 10-meter or 30-meter NED information derived from USGS topographic maps to provide the elevation base map data. In a new, two-year study, beginning in early 2007, FEMA has separately requested the National Academies to undertake a distinct evaluation of flood map accuracy, including an examination of the whole range of uncertainty in flood mapping arising from uncertainty in flood hydrology and hydraulic modeling, as well as uncertainty in land surface elevation. The committee hopes that the present report provides solid input to this upcoming study and helps to further objective examination of the most cost-effective methods needed to support the nation's floodplain mapping and management.

NASA EAARL Coastal Mapping Perspective

The NASA Experimental Advanced Airborne Research Lidar (EAARL) is a lidar system with cross-environment topo/bathy capabilities. It is a small-footprint waveform-resolving green wavelength lidar. It was designed to collect detailed topography of shallow marine substrates and vegetated canopies. In addition to the lidar system, EAARL also collects digital multi-spectral imagery. One of the main advantages of the EAARL system is that it is a waveform digitizing system versus the traditional commercial discrete-return systems. Many USGS projects are using EAARL data, such as Advanced Remote Sensing Methods for Coastal Science and Management, Decision Support for Coastal Parks, Sanctuaries and Preserves, the Coral Reef Program, and National Assessment of Coastal Change Hazards. The system has been able to create submarine topography maps at high resolution over areas such as Biscayne National Park (**Figure 20**). Some of the issues from a coastal mapping perspective include:

- Should lidar bathymetry mapping be part of the National Lidar Initiative?
- If so, how deep or offshore should we map?
- Accuracy: Flat, dynamic terrains need higher accuracy than sloping, static terrains.
- Repeatability: Should repeat surveys in coastal zones be done at higher temporal frequency (5 year time scale?)
- Waveform-digitizing vs. multiple return data? ("dead zone" effect)
- Better understanding of lidar error sources
- GPS, IMU, ranging, filtering, datum conversion
- Definition of "raw" data availability?
- Focus on data dissemination and visualization
- Google Earth or similar application

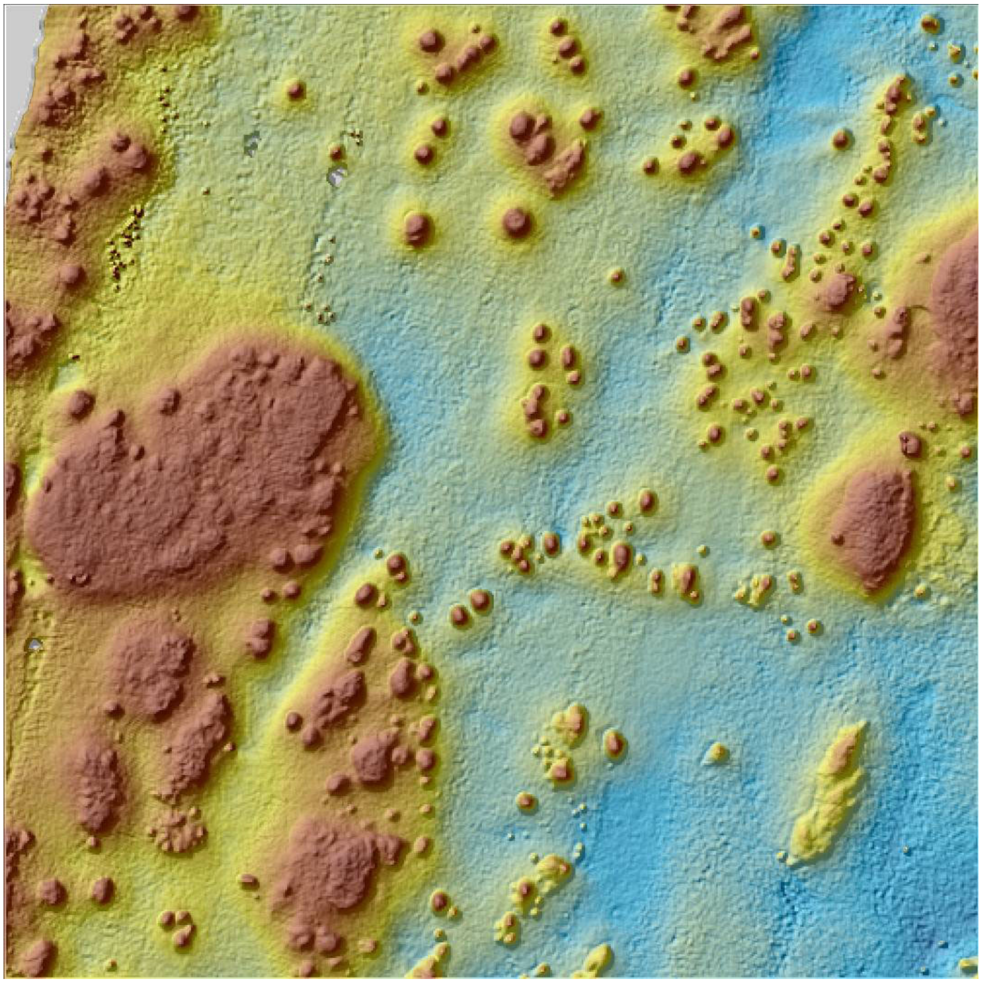


Figure 22. EAARL Coral reef mapping example

NASA Perspective

In consultation with the USGS and AASG, NASA has formulated an advanced-technology, wide-swath, high-altitude lidar mapping concept for the National Lidar Mapping Initiative. The concept draws upon NASA expertise in airborne and spaceflight laser altimetry instrumentation, space geodesy and altimetry data processing. The approach is envisioned as a State-Federal-commercial partnership establishing an infrastructure, to be operated commercially, that would provide seamless, consistent, public domain national lidar data in a cost-effective and timely manner. This is envisioned as not only a one-time mapping of the United States, but an ongoing program for monitoring of topographic and land cover change.

The airborne lidar mapping industry was only in its infancy ten years ago. Therefore, what will be achievable 10 years from now is not known, but will assuredly be better than today. The National Lidar Mapping Initiative must have a structure that not only accommodates those improving capabilities, but should be a driving force for those improvements. We need to look at national and global scale data collection and distribution efforts for lessons learned, and not only at existing lidar surveys. Doing some simple calculations, the scope of the effort looks like this:

- Land area of United States = 9,161,923 sq km
- Assuming:
  - 2 laser pulses per sq m
  - an average of 1.5 returns per pulse
  - 35 data bytes per return
- = 1 x 10^{15} bytes of point cloud data
- = 1 petabyte = 1,000 terabytes

For comparison, that is 3 times more data than produced by all the instruments combined on NASA's flagship Earth Observing System Satellite, Terra, over the course of a full year.

There are two NRC reports that were published in January, 2007 that provide motivation for a comprehensive lidar mapping program. The first "Base Map Inputs for Floodplain Mapping" is discussed above. The second comes from the Committee on Earth Science and Applications from Space, which was requested by NASA, NOAA, and the USGS to provide recommendations on Earth observing satellite needs in the coming decade. It advocates 3 laser altimeter spaceflight missions be implemented:

- ICESat-II for ice sheet height changes
- DESDynI for vegetation canopy structure
- LIST for global land surface topography

NASA's Goddard Space Flight Center has been a leader in the development and scientific utilization of airborne and spaceflight laser altimeter systems. There is a diversity of approaches used in those systems to acquire the laser ranging data (**Figure 21**). The efficiency of photon-counting laser ranging, as compared to more traditional analog detection methods, provides a means to achieve high-resolution lidar mapping over wide swaths from high altitudes.

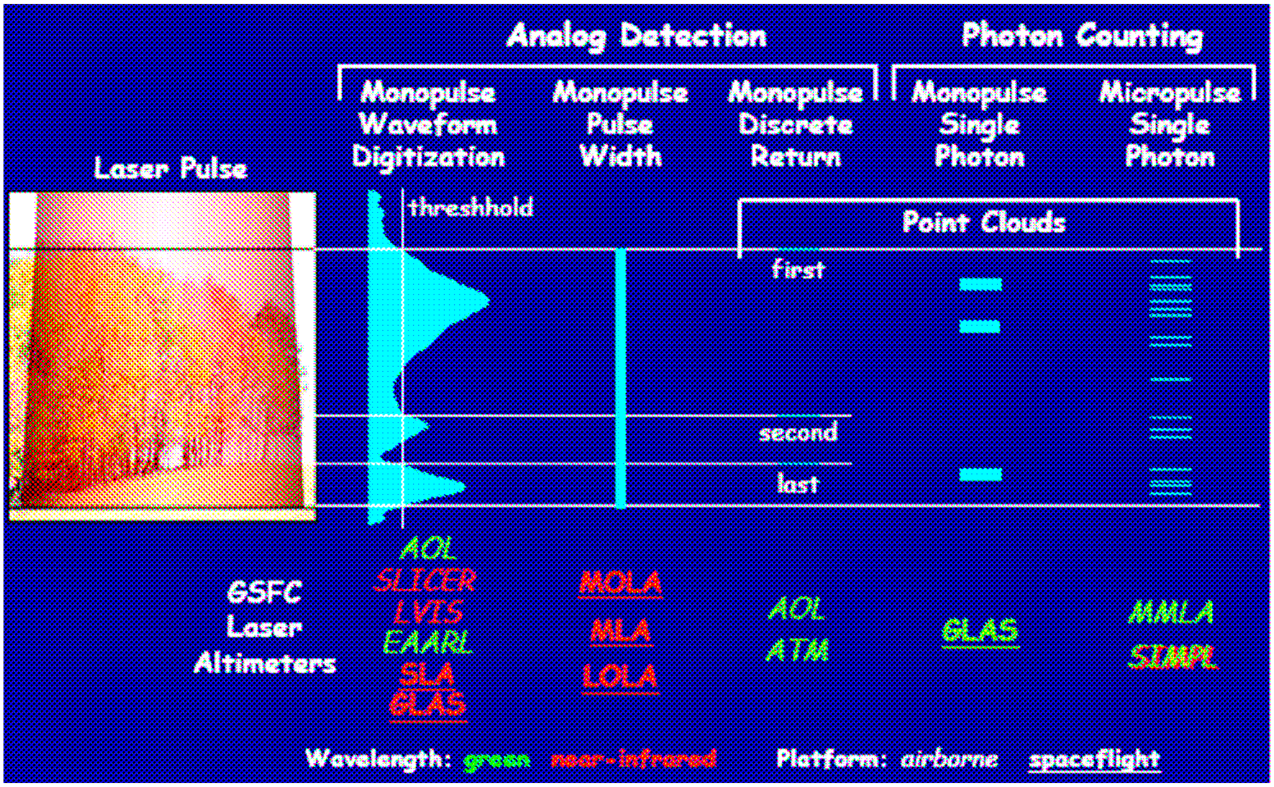


Figure 23. NASA approaches to lidar collections

An instrument funded by NASA's Instrument Incubator Program, the Swath Imaging Multi-polarization Photon-counting Lidar (SIMPL), is in development to demonstrate components and measurement approaches needed for a space-based swath-mapping laser altimeter. An adaptation of that approach is the basis for an airborne, high-altitude mapping capability for the National Lidar Mapping Initiative having these attributes:

Implementation Approach

- Long-duration, long-range aircraft (e.g., ER-2, Gulfstream V)
- High-altitude flights at 50,000 to 60,000 ft above commercial airspace
- Aircraft cruise speed = 200 m/sec (~ 800 km/hr)
- Cross-track scanned bush-broom laser altimeter
- NASA-developed based on spaceflight approach
- 10 km wide swath & products with 3 m grid posting
- Nationally uniform data acquisition and processing

- Technology transferred to commercial sector
- Potential for complementary instrumentation
  - Airborne gravity for improved geoid model
  - Airborne magnetics for crustal structure
  - Multispectral or hyperspectral optical imaging
  - Dual-wavelength SAR Interferometry
- Fly to and map regionally cloud-free areas
- Continue low-altitude, higher-resolution (≤1m) commercial lidar mapping
  - for urban areas and other high-priority locations
  - for cal/val of national mapping products in selected areas

Multiple-beam bush-broom scanned cross-track ("bush-broom" or "push-broom"?)

- 36 beams x 3 m beam spacing = 108 m scan width
- ± 18° scan = 10 km wide along-track swath
- 2 Hz scan rate = 8% along-track scan overlap

400 KHz fiber laser array transmitter

- 20 transmit pulses / cross-track meter / beam
- Short pulse-width (1 nsec), plane-polarized, 532 nm (± 1064 nm)
- 40 pulses simultaneously in-flight per beam = 375 m range ambiguity for transmit & receive pairs

Photon counting receiver

- 4.3 million single photon surface ranges per second (@ nominal 30% probability of detection)
- 6 detected photons / cross-track meter / beam = 2 detected photons / square meter
- 18 detected photons per 3 m pixel
- Parallel & cross-polarized channels for surface type differentiation
- Narrow band-pass etalon filter for solar background rejection

High-precision, event-timing ranging electronics

- 10 cm range precision per detected photon

Aircraft Trajectory

- Precision point positioning Global Differential GPS (GDGPS) solution
- RMS vertical accuracy ~ 10 cm

Optical Bench Attitude

- High-end gyros + star camera + GDGPS (e.g., ICESat)
- Total-angle pointing knowledge:

- 0.003° = 10 arc sec (3x WORSE than ICESat)
- = 10 cm flat-surface range error at scan mid-point (± 9°)

Geolocation of Photon Returns in Point Cloud and Performance

- Simultaneous solution of pointing, timing, and trajectory errors using GSFC Geodyn range-residual, least-squares method applied to along-track swath overlaps
- 10 cm range precision per single photon (due to short pulse & high precision timing)
- Sqrt (18 photons) per 3 m pixel = 2 cm range precision for flat, non-vegetated pixels
- Elevation accuracy = 14 cm RMSE

  - At mid-points from nadir to swath edges

  - Better at nadir but less good at swath edges

NASA's intent is not to conduct operational mapping for a National Lidar Initiative. Rather, NASA seeks to partner with States, other Federal agencies and the commercial sector to accomplish the goals of this initiative, providing technical expertise and capabilities that enhance the collection of lidar data for the nation. The potential partner roles could look like this:

USGS:

- project management

Local, State, and Federal agencies:

- requirements for national lidar data & products meeting their mandates

NASA:

- fabricate and test high-altitude airborne lidar instruments
- implement processing methods & infrastructure
- provide instrumentation and infrastructure to commercial sector

Commercial Sector:

- acquire and process high-altitude, nationwide data
- acquire and process low-altitude, higher-resolution data for high-priority areas and for

QC/QA

- apply point cloud classification & feature extraction
- generate TINs, DTMs and DSMs (I don't think TIN or DSM have been spelled out yet – do so here.)
- produce national lidar map products
- create and market value added products

Local, State and Federal agencies:

- QA and utilize data and map products for their specific mandates

USGS:

- Archive and distribute “raw” data, TINs, DTMs, DSMs and national map products

Alaska Perspective

When considering a National Lidar Initiative, we must not forget about Alaska and Hawaii. Alaska is one-fifth the size of the continental United States (**Figure 22**), with an area of 650,000 square miles, over 34,000 miles of coastline, 39 mountain ranges, with 17 of the 20 tallest peaks in the United States. Five percent of Alaska's land surface is covered by glaciers, and these are contributing more to sea level rise than any other source on Earth. There are 40 historically active volcanoes, with 4 volcanoes located across the inlet from the majority of the state’s population. This area is critical for international transport of cargo.

Figure 24. Alaska compared to conterminous 48 States in areal extent.

There is a need for better elevation data in Alaska. Currently the best available is at the 2 arc-second resolution (60 m). This resolution is not adequate for studying natural hazards, and flood zone delineations in relation to ice jams, storm surges, and tsunamis. There are many changes occurring across the landscape in Alaska. Glaciers are thinning and retreating, permafrost temperatures have warmed and thermokarsting has increased, coastal erosion has increased, and forest fires and insect infestations have increased. In 2004 and 2005, 18,000 square miles were burned, which is roughly twice the size of Maryland.

Should the collection of elevation data in Alaska be a Federal initiative? Sixty percent of Alaska is Federally owned, with 28% state lands, 12% native lands, and less than 1% private land. From Alaska's perspective, here are the answers to the 20 questions:

Resolution

Horizontal:

- 2 to 3 meters sufficient for most earth science needs, but higher would be better for engineering projects
  - These areas could be delineated rather easily in Alaska
  - Possibly an 80/20 split
  - Accuracy
  - 1 to 2 meters and better than 5 meters

Vertical:

- Relative accuracy between pixels - ~10 cm and no worse than 20 cm in steep or heavily forested areas
- Absolute accuracy - ~ 1 meter
- Recommend common global ellipsoid datum

Q/C

- Most important component of initiative next to metadata archiving
- Recommendations
- Data needs to be validated by a third party (NGTOC or contractor)
- Users can further qa/qc if they want
- Require all data to be in public domain not just final product
- Raw GPS and ALSM observations
- All overlapping data and cross lines
- UAF is in the process of acquiring its own aircraft and lidar system and they could play a leading role in cal/val work for Alaska

Data storage

- USGS EROS
- Local and regional data holdings

What roles do NASA and other agencies play?

- Sensor design and development
- Use Lidar acquisition to cal/val some of their spaceborne sensors
- Potential source of funding

Timetable

- The sooner the better

Prioritize orders of collection

- In Alaska - AGDC
- Urban areas (Cities and towns)
- Roads, transportation corridors, hydrants, sewer line
- Semi-rural
- Native allotments
- Pipeline corridor
- Airstrips
- Wilderness
- No concentrated centers of population

Derivatives and Deliverables

- Any and all data collected should be archived and made available
  - All returns
  - Bare earth
  - Intensity or relative return signal strength
  - Extracted features
  - GPS and ALSM observations
- LAS ok but GeoTIFFs preferable

Cost sharing

- Nationally funded mandate with state and local partnerships
- Kenai Peninsula Watershed Forum is attempting to acquire lidar for entire Kenai Peninsula (10,000 sq. miles)
  - Partners:
    - Forest Service, Fish and Wildlife Service, Kenai Peninsula Borough, EPA, USGS, State?
  - If national initiative takes off, why duplicate this effort if it meets desired specs
    - Invest time and money into inventorying data already collected

Incorporate into NED?

- Yes and No
- This initiative should do a better job of documenting and archiving data than NED
  - Metadata
- Leave NED as is (NED 1.0) and with lidar initiative create NED 2.0
- NED is a living dataset that is updated bimonthly
- For this reason, researchers and modelers have issues of repeatability

Technology Issues

Martin Flood provided expertise on Lidargrammetry as well as some project management advice, and finally Ayman Habib shared some of his research work as an example of what might be used for a consistent QA/QC national program.

Lidargrammetry

Legal Note: The techniques discussed here are based on algorithms developed by GeoCue Corporation and implemented in their GeoCue software suite. GeoCue Corporation has a patent pending on its imaging techniques, including lidar stereo or 'lidargrammetry' and related 'synthetic stereo' generation methods.

Lidargrammetry is a specific example of a new tool that is impacting overall production efficiency for lidar data producers. It demonstrates the benefits of integrating two distinct workflows to improve throughput and scalability of established techniques. Traditionally in normal stereo vision systems a pair of two-dimensional images, each taken from a slightly different perspective is used to derive three-dimensional object space points. Or, by creating a second image from an orthorectified source image and an elevation model, an inferred stereo pair can be created. However, with lidar data, there is no true image; the source data consists of actual 3D points in object space. The 3D object space points may have additional attributes that can be used to create a pseudo-image from the lidar point data. The most common attribute recorded is the intensity, or more correctly, the amplitude of the return pulse measured by the sensor. Using the intensity attribute, a pseudo-grayscale image can be created of the point data. This intensity image then forms the basis for lider stereo or 'lidargrammetry'. Lidargrammetry works by reversing the traditional stereo modeling process, taking 3D object space points and rendering an inferred pair of 2D images from the intensity attribute. The inferred images are generated as if captured at positions determined via a pseudo base-height parameter and related parameters of the data set. The object information being used to generate the image, the intensity or any other object attribute such as point class, determines the value of the pixel. Current applicationsfor lidargrammetry include breakline delineation for terrain modeling, planimetric feature delineation, and classification QA/QC. The advantages of this hybrid technique is that is removes the need for separate imagery collections. Using lidargrammetry, lidar data can be viewed as a stereo model in standard photogrammetric software. Production technicians can use established viewing measurement and compilation techniques.

In a production framework sense, there are problems with the current geospatial data production management techniques if we were to scale it up to a national level:

- Addresses numerous end-user applications.
- Uses a wide variety of software tools.
- Has dynamic workflows.
- Is difficult to effectively manage over large or numerous projects (who works on what and when).
- Is generally workstation-centric, data-flow oriented, not process-driven
- Producers are building one-off project management systems that are difficult to scale, not extendable, and becoming cost-prohibitive compared to industry expansion.

The solution for large production efforts is an integrated production framework that:

- Encompasses all workflows in common framework.
- Is standardized on best practices and procedures.
- Combines disparate input data into a managed program data set.
- Reuses existing software tools.
- Provides easy integration of new tools.
- Remains vendor neutral for both software tools and hardware capabilities.
- Is inherently multi-user.
- Optimized for large volume, multiple technician, multiple product geospatial data production
- Graphical.
- End-user customizable.
- Affordable to deploy and maintain.

A national production framework integrates all tasks into a single efficient, manageable environment. It is a framework that supports technology growth by integrating current production tools, is extensible to future software solutions, and allows dynamic integration of ad-hoc tools.

Some important observations on a national program from a production management point-of-view:

- What we are doing today, we will not be doing tomorrow.

- A common production infrastructure is as beneficial as a common technical specification.

- Scalability, extensibility, interoperability are not just buzz words.

•Production of geospatial data uses workflow tools and management methods that are outdated compared to other commodities.

Quality Control Measures

In order to completely understand the output of a lidar sensor, we must be able to understand the error budget that is inherent in the system. The error budget is the sum of the errors from the various system components, but it is not the interaction with different terrain and ground cover types. Some of the error sources include the bore-sighting offset error, the bore-sighting angular error, the laser range error, the laser beam angular error, the laser range noise, the GPS noise, the IMU noise, and the laser beam angular noise. We would like to show the effect of biases in the lidar measurements on the reconstructed object space. These effects are derived through a simulation process. The effects will be shown through the difference between the reconstructed footprints and the simulated surface (i.e., ground truth). Systematic biases may or may not be dependent of flight characteristics (**Table 2**).

Table 2. Systematic biases versus lidar flight characteristics

	Flying Height	Flying Direction	Look Angle
Bore sighting Offset Bias	Effect is independent of the Flying Height	Effect is dependent on the Flying Direction (Except ΔZ)	Effect is independent of the Look Angle
Bore sighting Angular Bias	Effect Increases with the Flying Height	Effect Changes with the Flying Direction	Effect Changes with the Look Angle (Except ΔX)
Laser Beam Range Bias	Effect is independent of the Flying Height	Effect is independent of the Flying Direction	Effect Depends on the Look Angle (Except ΔY)
Laser Beam Angular Bias	Effect Increases with the Flying Height	Effect Changes with the Flying Direction (Except ΔY)	Effect Changes with the Look Angle (Except ΔX)

- Assumption:
  - Linear Scanner
  - Constant Attitude & Straight Line Trajectory
  - Flying Direction Parallel to the Y axis.
  - Flat horizontal terrain

Random noise will lead to random errors in the point cloud. Some diagnostic hints include:

- GPS noise:
  - Similar noise level in derived point cloud.
  - Independent of the system parameters (height & look angle).
- Angular noise (IMU or mirror angles):
  - Planimetric coordinates are affected more than vertical coordinates.
  - Dependent on the system parameters (height & look angle).
- Range noise:
  - Mainly affects the vertical component.
  - Independent of the system height.
  - Dependent on the system look angle and flying direction

Systematic errors lead to systematic biases, and random noise leads to random errors. It is believed that random noise will not affect the relative accuracy. However, this is not the case for lidar systems. Random errors will affect the relative accuracy of the derived point cloud. Depending on the considered parameter, the relative effect of the corresponding noise level will not be the same. A lidar Error Propagation Calculator developed at the University of Calgary allows one to enter specific values for each of the fifteen input parameters for a certain lidar point and to enter the noise level for each of the parameters. The program then determines the accuracy of the ground coordinates of the point. Conversely, if the user requires a specific accuracy in the final ground coordinates, the program can be used to determine the accuracies that would be required for the input components, through a trial and error process.

Lidar Quality Assurance (Q/A) occurs before the mission. It is management activities to ensure that a process, item, or service is of the quality needed by the user. It deals with creating management controls that cover planning, implementation and review of data collection activities. The key activity in the quality assurance is the calibration procedure. Quality Control (Q/C) occurs after the mission. It provides routine and consistent checks to ensure data integrity, correctness, and completeness. It also checks to see whether the desired quality has been achieved. Lidar quality assurance is done by calibrating the system using a target function. By minimizing the normal distance between the laser point footprint and a known control surface, we can use the lidar equation to estimate the error parameters that minimize the cost of the target function. This is only possible if we are dealing with transparent system parameters. It is very difficult using current standards, such as the LAS file format. Lidar quality control is a post-mission procedure to ensure/verify the quality of the collected data. Quality control procedures can be divided into two main categories: External/absolute QC measures, where the lidar point cloud is compared with an independently collected surface; or Internal/relative QC measures, where the lidar point cloud from different flight lines are compared with each other to ensure data coherence, integrity, and correctness.

Q/C and Q/A procedures are essential for any spatial data acquisition system, but Q/A of lidar data is only possible for a transparent system. Q/C can be conducted by the end user. The derived quality control procedures take into account the irregular and random nature of the point cloud.

The British Columbia Base Mapping and Geomatic Services have developed lidar specifications. These can be found at: *http://ilmbwww.gov.bc.ca/bmgs/pba/trim/specs/*. This link also has the error budget calculator.

There was some disagreement as to the definitions of Q/A versus Q/C. We will need to come up with some consensus of the definition before we can proceed.

Discussion sessions

There were several breakout sessions conducted in order to have a free form discussion of specific topics. These topics were:

- Derivatives Discussion
- Data Dissemination Discussion
- Roles and Responsibilities
- Technical specifications
- Legal / Political Discussion

The following was reported from the discussions of each group:

Derivatives

- The point clouds are the primary deliverable- everything else is a derivative
- The uses are endless, and there are infinite possibilities
- There should be one level of collection regardless of terrain or vegetative density
- Hydrologic analysis tools are needed to remap the 'blue lines'
- Derivative product capability is dependent on the data quality of the original point cloud.
- Should deliver full swaths of data and not just individual tiles
- Need the classified point data, not just bare earth
- Software needs to be flexible to deliver multiple derivatives
- Mid-returns are important for lower level vegetative characterization
- DOI needs to get involved
- Leaf-on and leaf-off both needed for different project requirements
- Need to get academia involved
- Need more Federal research to resolve vegetative issues and derivatives

Data Dissemination

- Hardware Considerations:
    - Space (large files)
    - CPU speed
    - Band width (is it better to pipe/transfer large files or

run products on the fly?)

- Organization (includes file structure, naming conventions, database, data, metadata).
- Archiving and redundancy

- Archive Centers:
  - Distributed or centralized? per State/per region or ???
  - Develop common Web interface for distribution
  - Data synchronization

- Distribution:
  - Proprietary (such as QT Modeler files) or Open Source. Include documentation and viewer capability.
  - Methods of delivery - Internet (Web), DVD, Hard drive, etc. Develop an appropriate cost structure based on size of request.
  - How to handle sensitive data sets (i.e. military areas if restricted from distribution).

- Web Interface:
  - ArcIms, Google Earth or ??? - common Web interface.
  - Include disclaimers
  - Decide on standard products (datum, units, or option to choose)
  - Capability to produce products on the fly.
  - Provide software for product generation
  - How to manage historical and recent data sets
  - Presentation depends on level of sophistication of the end users:
    engineers
    general public
    planners

- Outreach and Education:
  - Inform users in community about what lidar is and how to use it.
  - Include Web tutorial

- Personnel:
  - Initial personnel to develop infrastructure
  - Personnel to operate and maintain

Roles and Responsibilities

1. This should be a Federal initiative with USGS as the lead agency. USGS also provides specs and standards.
2. There were two paradigms:
   a. Plan for the future, encourage a NASA solution and a short turnaround on completing coverage (2-3 years). This means there would be a consistent, uniform layer and it would be done in a politically acceptable time with respect to congressional elections, thus avoiding prioritizing the order in which things are done.
   b. Do it with existing technology and take about ten years, creating a patchwork.
3. With either model, industry will fly and process and check quality internally
4. USGS will do QA (or QC if you use the industry definition), checking on the quality of the delivered product
5. Use the National Agricultural Imagery Program (NAIP) model for buy-ins. A minority wanted money to go to the states directly; most thought it was important to have uniform collection and a Federal program.
6. We should be thinking of solutions which are ahead of the current technology

Technical Specifications

The group discussed the many aspects of what density lidar could be specified for a national scale collection. Several suggestions were; 1) specifications linked to land cover supported by literature citations; 2) collecting at 1-meter post spacing without regard to land cover and the data will become a repository for research; and 3) base the density specifications on the user needs by conducting a survey of what is wanted for all levels of government, resource management, and private industry. Additionally, the participants noted the need to include bathymetric lidar as part of any national elevation collection because of hazards and resource management requirements related to water through floods, hurricanes, sea-level rise, and tsunamis.

Data accuracy requirements were determined to be linked to data specifications. Accuracy testing should address what is achievable currently, recognizing the dynamic state of lidar technology and accuracy testing. Alternative methods should incorporate swath and interline consistency with current vertical point testing methods. Both vertical and horizontal accuracy must include coordination with NGS and help foster statewide virtual real-time networks in order to achieve a national elevation acquisition.

Legal / Political Discussion

- Need strategy to address challenge of implementing national program to meet local needs
- Need to address chicken-egg problem of elevation for the nation versus imagery for the nation
- Need to demonstrate need for and application of data across a number of Federal agencies (not just FEMA)
- Need standards and specifications for resolution that meet local needs as much as possible—don't want locals opting out of program and doing it themselves (and thus rendering national program less fundable)
- Need for funding strategy: 1 agency or many, but must be explicit. If across many agencies, how do you coordinate and fund?
- Need metadata, standards for quality, national certification to govern data and its collection,
- Need more and expanded forums: who was not here this week? Bring them in.
- MAPPS as possible vehicle to reach out to other sectors.
- Need more private sector participation, especially Google and Microsoft.

Conclusions

The meeting participants concluded that the idea of a National Lidar Initiative (NLI) is worth pursuing for the greater good of the country. While there are not other inarguable conclusions to report from this first meeting, the following are themes that carried throughout the meeting and were voiced by many as important issues and considerations. In the next National Lidar Meeting, discussions should derive some definitive solutions and develop a comprehensive strategy. The following were common themes seen through the meeting:

1. lidar dataset vs. terrain dataset:

   This is a fundamental question. There was general agreement that the National Lidar Initiative should focus on the lidar remote sensing aspect of this data, and as a result have the science and applications drive the resulting derivatives. There is complete agreement that the full lidar point cloud is needed and will become of increasing value for non-bare earth science needs.

2. Inclusion of non-lidar elements:

   Non-lidar elements such as breaklines and surveyed cross-sections are valuable for the development of advanced high resolution terrain datasets, and should have a central home. However, these should <u>not</u> be included in the core NLI. These are value-added products. Utilization of techniques such as lidargrammetry could completely replace the need for simultaneous imagery if taken advantage of.

3. Complete collect versus using existing data:

   There is too much variation in the resolution, accuracy, timing, and precision of existing data for a consistent national dataset to be developed from it. A new complete national collection will be required if we are to maintain consistency and repeatability. While existing lidar datasets are valuable in their own right, repeatability and consistency are important for monitoring purposes and national-scale applications

4. Coordinate Systems:

   While most lidar projects are using projected coordinate systems, a national program may also wish to store data in geographic coordinates to enable seamless access. As a result, software tools should be developed that can reproject this data on the fly to best accommodate users.

5. Q/A Q/C:

   Q/A tasks are the responsibility of the vendors and could also be the responsibility of highly-skilled, impartial Q/A contractors. These parties should be held accountable for delivering correctly processed data. There is some disagreement as to the need for the 'raw' sensor data, versus the processed final product. These data should be made available for independent research activities to perform independent Q/C.

6. File format standards:

   The present LAS file format is incomplete for the needs of the NLI. LAS 2.0 should be developed to easily handle additional requirements. NLI needs to work with the LAS group in order to ensure our needs are considered.

   At a bare minimum, the following LAS 2.0 attributes should be mandatory, with <u>all</u> sub-attributes fully and correctly populated:

   - X, Y, Z
   - Intensity
   - Return number
   - Return Attribute
   - Return Classification
   - Off-Nadir Scan Angle
   - Point Source ID
   - [GPS Week <u>and</u> GPS Second] **OR** [POSIX Time] with resolution to the nearest microsecond

7. Planning

   In planning for this dataset, we need to make sure that we design flexibility and dynamic changes while maintaining consistency. Lidar collected at the end of this project more than likely will be coming from a completely different system than lidar collected at the beginning of the project, so we must be able to incorporate legacy as well as changing and improving technology. We also need to take advantage of the innovations that will be driven by NASA and other agencies to make this a premier data product that can be used for mapping, monitoring, and national science applications.

8. Dissemination

   We need to improve and streamline how we disseminate these massive datasets. As computing power and storage improve, the processing issues we now have will not be as limiting, but we will have to constantly evolve how we deliver this data to the public as well as how we synthesize the data into informative products for derivatives.

9. Drivers

   It was agreed that scientific applications should be the primary driver of this collection, as the uses of this data are almost infinite and there is concrete evidence that lidar is a reliable and accurate technology. NLI supporters should show how many benefits are generated by the use of this data. Louisiana and Iowa are two states that convincingly showed extensive return realized on their investments of large area collections.

10. Metadata

   It was agreed that good metadata is essential for this effort, and the metadata need to be spatially referenced in order to detect differences in collections and temporal issues. The National Elevation Dataset employs a spatial metadata system that could be used as a model for this initiative.

11. Data ownership

   All of those who addressed data ownership said that all data from a national lidar initiative should be in the public domain.

The following table summarizes the desired resolutions of Federal partners and the resolutions at which the statewide collections are being or have been collected (**Table 3**):

Table 3. Participating Meeting Agencies versus desired or collected resolutions

Agency	Average Point Spacing Desired
USGS	1 meter for vegetation and structures, 3 meters for NED
FEMA	1 meter urban, 3 meter suburban, and 5-10 meters other
USDA-FS	< 1 meter
NRCS	3 meters
NOAA	1-5 meters for ecosystem management, 1 meter or less for feature extraction, 2 meters or less for shoreline
NDEP	1.4 m average post spacing
Army Corps of Engineers	4 meters for hydrologic, 1 meter for topographic
Alaska	2-3 meters for earth science, higher for engineering
NASA	Designing sensor at 3 meters resolution
State/Region	**Resolution of derived DEMs**
Louisiana	2-3 meters
Pennsylvania	1.4-2 meters
Iowa	1-2 meters
Ohio	2 meters
North Carolina	5 meters
Puget Sound Lidar	1 and 2 meters

The convenors would like to thank all of the people that attended this meeting and made the first National Lidar Initiative Meeting such a success, despite the weather.

Appendix

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