State of Maine
Department of Administration and Financial Services
PROPOSAL COVER PAGE
RFP# 201508142
LiDAR Data Acquisition

Bidder's Organization Name: **Quantum Spatial, Inc.**		
Chief Executive - Name/Title: **Michael B. Shillenn, CP / Vice President**		
Tel: **(610) 344-0890**	Fax: **(859) 277-8901**	E-mail: **mshillenn@quantumspatial.com**
Headquarters Street Address: **4020 Technology Parkway**		
Headquarters City/State/Zip: **Sheboygan, WI 53083**		
(provide information requested below if different from above)		
Lead Point of Contact for Proposal - Name/Title: **Jennifer Whitacre / Contract Administrator**		
Tel: **(925) 217-1221**	Fax: **(859) 277-8901**	E-mail: **jwhitacre@quantumspatial.com**
Street Address: **523 Wellington Way**		
City/State/Zip: **Lexington, KY 40503**		

LiDAR Acquisition Services: ☒	LiDAR QA/QC Services: ☐
Small Area per Square Mile Cost	$ **193.54**
Medium Area per Square Mile Cost	$ **170.26**
Large Area per Square Mile Cost	$ **165.42**
The proposed costs listed above are for reference purposes only, not evaluation purposes. In the event that the cost noted above does not match the Bidder's detailed cost proposal documents, then the information on the cost proposal documents will take precedence.	

- This proposal and the pricing structure contained herein will remain firm for a period of 180 days from the date and time of the bid opening.
- No personnel currently employed by the Department or any other State agency participated, either directly or indirectly, in any activities relating to the preparation of the Bidder's proposal.
- No attempt has been made or will be made by the Bidder to induce any other person or firm to submit or not to submit a proposal.
- The undersigned is authorized to enter into contractual obligations on behalf of the above-named organization.

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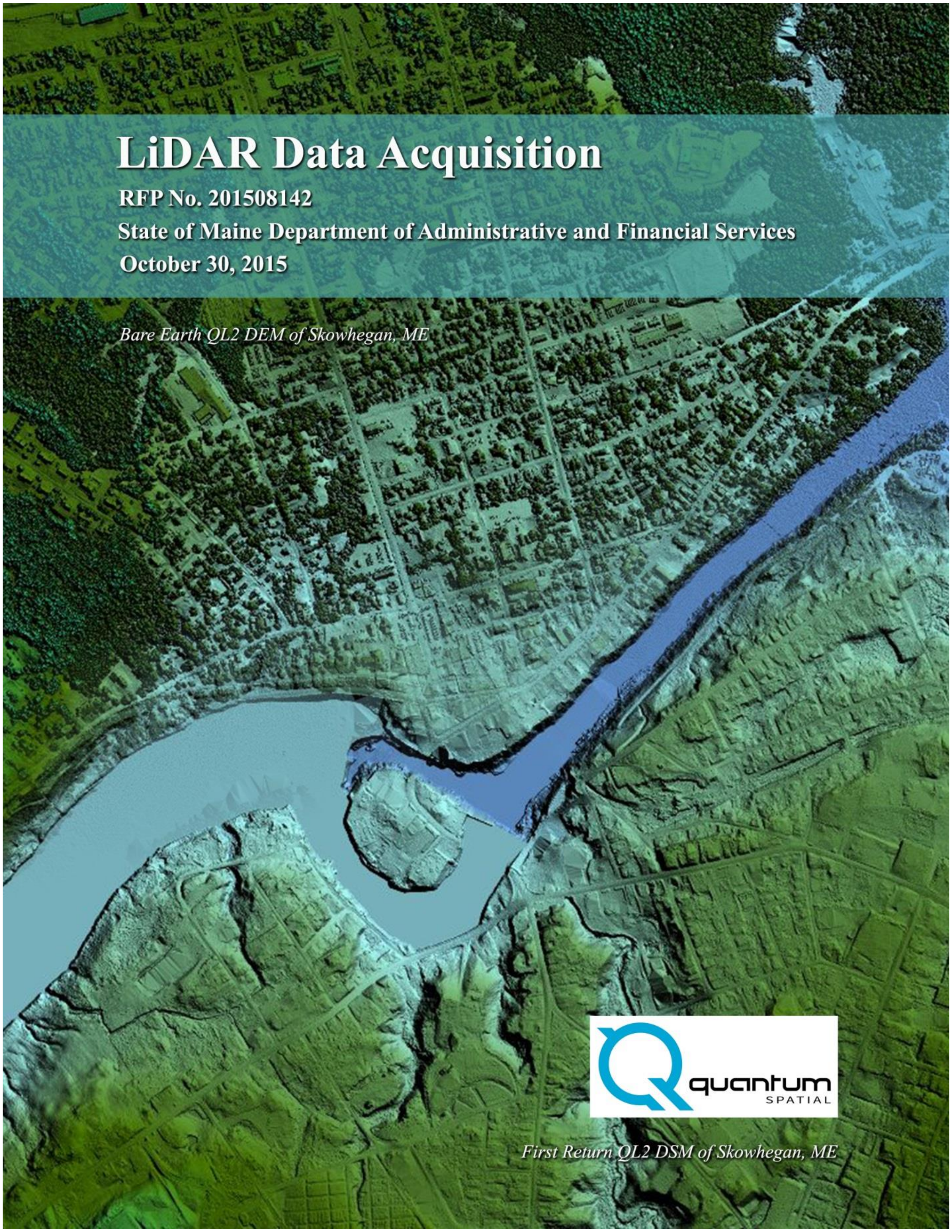
RFP No. 201508142
State of Maine Department of Administrative and Financial Services
October 30, 2015



1. ORGANIZATIONAL QUALIFICATIONS AND EXPERIENCE

1.1. Overview of the Organization

Quantum Spatial Inc. is pleased to respond to the State of Maine's LiDAR Data Acquisition Request for Proposal (RFP#201508142) to provide Aerial LiDAR acquisition services on an "as required" basis over a five year contract duration supporting Maine's primary objective of completing LiDAR for the remaining 20,000 mi^2 of the State.

1.1.1. Introduction

Quantum Spatial offers a portfolio of experience and technical competency in LiDAR acquisition and processing that perfectly aligns with the State of Maine's requirements and provides for substantial enhancements. Our Team offers extensive national, as well as, Maine specific experience in providing quality geospatial solutions that include airborne LiDAR acquisition and processing, ground based mobile LiDAR, GPS ground control surveys, forest analytics and related services.

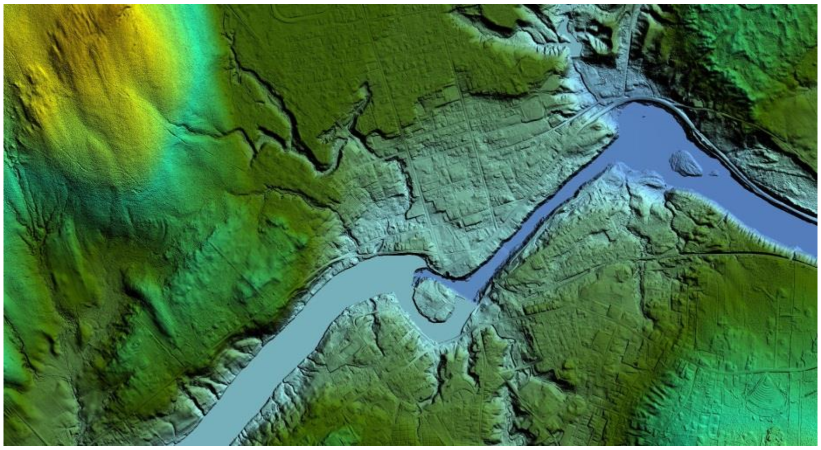


Figure 1: Hydroflattened bare Earth DEM of Skowhegan, ME with the Kennebec River. Currently, Quantum Spatial is completing a USGS 3DEP BAA task order providing QL2 LiDAR mapping covering 2,882 mi^2. Additional details regarding this project are located in Proposal Subsection 1.4: Description of Experience with Similar Projects.

The Quantum Team also provides the State with an unique opportunity to employ newer LiDAR acquisition technology which optimizes acquisition efficiencies by substantially reducing collection times while offering the option to process higher point densities to support applications that exceed QL2 (2 ppsm) dataset specifications. Quantum also recognizes the positive economic impact and critical operational importance of maximizing the involvement of Maine-based mapping and surveys firms to support both control and data processing phases, as well as, providing specific forest management analytical capabilities based on decades of knowledge and experience for hundreds of thousands of acres of forest across the State of Maine. To that end, our Team has also secured a commitment from the University of Maine's Cooperative Forestry Research Unit (CFRU) to collaborate with the mutual goal of improving the access, analysis, and use of LiDAR data for improved forest management in the state.

1.1.2. Quantum Spatial

Quantum Spatial, Inc. is a full-service geospatial firm with a staff of 500 highly qualified geospatial experts specializing in spatial data collection, generation, integration, and analysis for clients worldwide. With a mapping and survey heritage dating back to 1969, the unification of Photo Science, Watershed Sciences, and AeroMetric, Quantum Spatial Inc. is the largest, most innovative, and competitively positioned geospatial services, products and solutions provider in North America. Quantum Spatial is dedicated to embracing its legacy traits of flexibility, creativity, innovation, responsiveness, partnership, client satisfaction, and on time, first time right products, which has defined our success. With offices strategically distributed throughout the U.S., we provide local expertise for most any location while collectively providing a broad and diverse geographic base of expertise.

Through all phases of a project, from planning and data acquisition to processing and final delivery of datasets, we adhere to techniques and practices that ensure our products meet or surpass industry standards and meet the client's needs. It is our strong-held philosophy to make sure our clients receive quality data with high utility, and we regularly recommend team collaborations, sensor specifications, and specific methodologies that will ensure the delivery of such data.

1.1.3. Team Composition

Quantum Spatial will serve as the prime contractor and is submitting its proposal to the State of Maine for the "LiDAR Acquisition" contract opportunity identified in the RFP. Quantum will provide overall contract and project management, overall quality assurance/quality control, linear mode LiDAR data acquisition, LiDAR data post processing, bare earth editing, breakline development, derivative product development, and will support optional forest analytics services. All applicable LiDAR related work will be done in full compliance with RFP requirements including adherence to USGS LiDAR Base Specifications v1.2 for QL2 data. As prime, Quantum will be solely responsible for the successful execution of all contractual, technical, and performance requirements outlined in the final contract issued by the State.

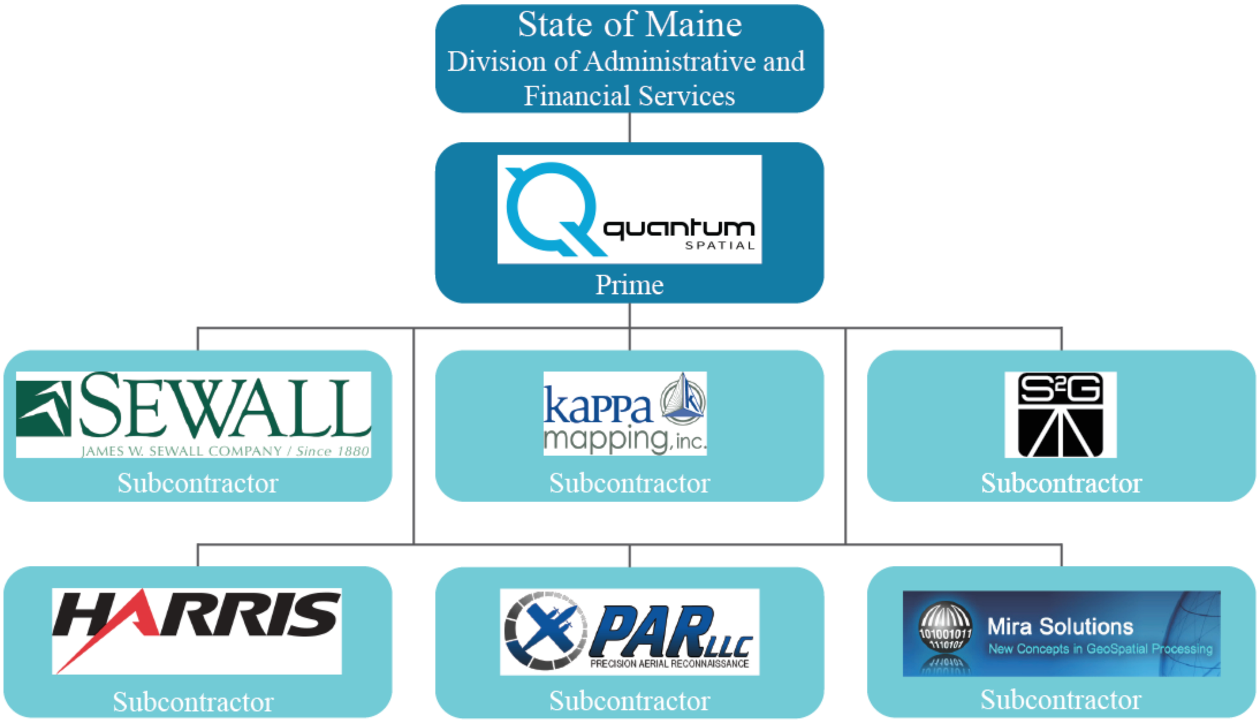


Figure 2: Quantum Spatial Team Organizational Chart

Quantum Spatial has assembled a team of professional and technology subcontractors that further enriches and extends its own capabilities. We are joined by three preeminent Maine mapping and surveying firms: James W. Sewall Company, Kappa Mapping Inc., and Shyka, Sheppard & Garster Land Surveyors. These firms' local experience knowledge and capabilities will provide invaluable support and efficiency to our Team in performance of control surveys, LiDAR data processing and forest analytics over the life of the contract. These firms have also been leading geospatial advocates in the State of Maine and have well-established records of performance, knowledge and relationships with Maine's broader geospatial community that can be harnessed to advance the State's LiDAR Program.

Harris Corporation has joined our team to provide the State with the innovative opportunity to use Geiger Mode LiDAR technology to support data acquisition at QL2 and/or higher point densities. Geiger-mode technology enables the faster collection of LiDAR data at higher resolutions and from higher elevations. The use of Geiger-mode LiDAR is further presented below, in Section II, Proposed Services, and Section II Cost Proposal.

Also joining our team is Precision Aerial Reconnaissance LLC (PAR), a trusted linear mode LiDAR acquisition surge support partner providing additional acquisition resources should they be needed to mitigate variables such as collection window compressions due to poor weather and ground conditions or to bolster Quantum's acquisition capacity to support accelerated scheduling. See Proposal Subsection 1.3: Organizational Experience for an organizational chart that illustrates our Team's key personnel structure.

Lastly, we will be utilizing Mira Solutions, Inc., a trusted geospatial data processing firm with offices located in both Union City, CA and Harbin, China. Quantum Spatial has been working with Mira Solutions for over 10 years on projects ranging from LiDAR bare earth clean-up and breakline generation to orthorectification and planimetric support. With facilities in China, Mira has the ability to offer Quantum Spatial high quality, cost effective production support resources. Quantum will be sending approximately 45% of the bare earth clean-up work to Mira

The Quantum Spatial's Team composition and contact information are provided in Figure 3.
Team Member/Contact

Team Member / Contact / Title	Address	Phone/Email	Business Type
Quantum Spatial Inc. Michael Shillenn, CP Vice President	1055 Andrew Drive, Suite D West Chester, PA 19380	(610) 724-7661 mshillenn@quantumspatial.com	LB
James W. Sewall Company David Edson, LF President/CEO	136 Center Street Old Town, Maine 04468	(207) 827-4456 edson@sewall.com	SB / HUBZone
KAPPA Mapping, Inc. Claire Kiedrowski, CP President	6 State Street, Suite 301 Bangor, ME 04401	(207) 942-5200 claire@kappamap.com	ME DBE
Shyka, Sheppard & Garster Land Surveyors Stevenson Sheppard, PLS, President	6 State Street, Suite 301 Bangor, Maine 04401	(207) 942-1955 ssheppard@ssgsurvey.com	SB
Harris Corporation Mark Romano Geospatial Product Manager	150 S. Wickham Road Melbourne, FL 32902	(321) 984-6182 mroman02@harris.com	LB
Precision Aerial Reconnaissance (PAR) Ken Comeaux, CP, GISP, Operations Manager	P O Box 72357 Bossier City, LA 71172	(318) 658-9818 ken@precisionaerialrecon.com	SDVOSB
Mira Solutions, Inc. Steve Wang, CP Chief Executive Officer	29300 Kohoutek Way, Union City CA, 94519	(510) 487-9688	SB

Figure 3: Quantum Spatial Team's contact information

The Quantum Spatial Team's unique qualifications and experience are further summarized below:

Professional Competence

Quantum Spatial's Team of professional staff includes 9 professional engineers, 38 licensed land surveyors including 10 that are licensed in Maine, 25 ASPRS Certified Photogrammetrists, 17 certified GISP, 14 PMI certified PMP's and 7 PhDs in supporting disciplines.

Technical Competence

The Quantum Spatial Team fields an impressive national footprint of 20 geospatial data production facilities in the Nation, and our aircraft mobilize from hangers throughout the US with an extraordinary equipment profile that includes 25 aircraft equipped with ABGPS/IMU, 18 airborne Linear-mode LiDAR sensors, 3 Geiger-mode LiDAR sensors, an Optech Lynx M-1 Mobile Mapping System, 55 survey equipment (GPS, receivers, levels, etc.), and 491 LiDAR processing hardware and software.

Specialized Experience

Quantum Spatial Team has an unparalleled ability to support all of Maine's airborne LiDAR requirements using both linear-mode and Geiger-mode technologies. We routinely acquire and process over 35,000 mi^2 of airborne LiDAR per year at various point densities (QL0, QL2, and QL3) and in many cases in full compliance with USGS LiDAR Base Specifications (currently v1.2). Quantum Spatial has direct experience collecting and processing 6,275 mi^2 of airborne LiDAR over the last 4 years in the State of Maine. Other recent statewide and large regional LiDAR tasking for federal, state and local agencies includes thousands of square miles of QL2 or better acquisition in the states of New Hampshire, Massachusetts, Vermont, New York, Pennsylvania, New Jersey, North Carolina, Kentucky, Georgia, Colorado, California, Oregon, and Washington. Our Optech Lynx M-1 Mobile Mapping System has successfully completed over 60 mobile LiDAR projects across the Nation for State DOT's and their consultants in New York, New Jersey, Pennsylvania, Maryland, Virginia, Florida, Mississippi, Kentucky, Tennessee, Georgia, and California for those state's DOT and/or their engineering consultants.

Local Knowledge & Economic Impact

With the addition of the James W. Sewall Company, Kappa Mapping Inc. and Shyka, Sheppard & Garster Land Surveyors, the Quantum Spatial Team affirms its commitment to make a direct and positive economic impact to Maine's economy and public revenues while promoting the State's LiDAR Program through its extensive network of Maine clients and partners. Quantum's commitment to meaningful and significant roles for these partners throughout the life of the contract enhances our local knowledge, increases opportunities for closer collaboration with the State and its geospatial community, and will result for greater cost efficiency based on proximity to project tasking. The resulting benefit beyond theses specific unique contract qualifiers will be the positive impact to the State's economic health by creating/sustaining jobs, generating tax revenue and licensing fees and fostering innovation that will be reinvested into growing their businesses and opening up new market opportunities.

Innovation

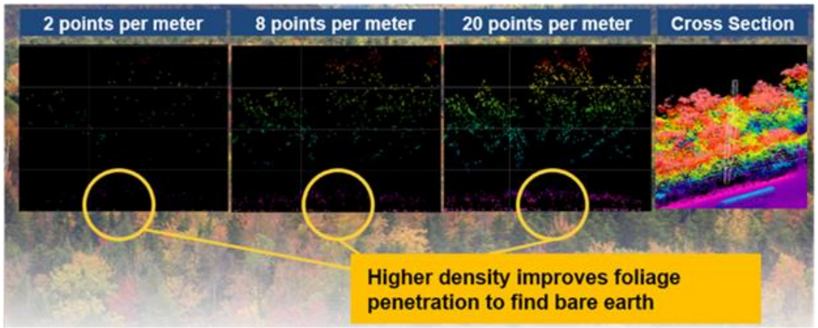


Figure 4: Only Quantum Spatial team offers Geiger-mode LiDAR to the State of Maine. The image above highlights one of the many benefits of Geiger LiDAR, which is further discussed in Proposal Section 2: Proposed Services.

Quantum Spatial is constantly exploring and implementing emerging LiDAR technologies that best fit our client's needs like our newest linear-mode LiDAR system, the Leica ALS80, or Harris's new commercially available Geiger-mode LiDAR system. Currently, USGS is evaluating Geiger-mode LIDAR to validate that it is fully capable of meeting USGS LiDAR Base Specifications (v1.2) for QL2 data. Results of that testing are expected later this year. Both platforms afford significant improvements in the rate of acquisition while easily achieving increased point densities over older linear-mode LiDAR systems. As such, Quantum has assembled a team that is capable of fielding both advanced systems and is committed to working with the State of Maine to select and deploy the best possible solution to meet both the base density requirement for QL2 data and enhanced datasets that start at QL1 (8 ppsm) expandable to 20 ppsm with efficiency and economy. Affordable higher density data sets open the door to enlist the participation of public and private stakeholders that require increased utility. Typical applications that would likely benefit from increased point densities greater than QL2 include vegetation and forestry classification, utility asset inventories, infrastructure mapping, and enhanced floodplain modeling among many others. Additional discussions and pricing options on the use of linear-mode and/or Geiger-mode LiDAR can be found in Proposal Subsection 1.3: Organizational Experience, Section 2: Proposed Services, and Section 3: Cost Proposal.

3DEP Program Knowledge & Advocacy

As a USGS Geospatial Products and Services Contractor (GPSC), Quantum Spatial possesses in depth knowledge and experience supporting the 3DEP program, a collaborative initiative between federal, state, local and private sector stakeholders that if fully realized will result in nationwide LiDAR coverage within eight years. Quantum Spatial's advocacy of USGS's 3D Elevation Program (3DEP) implementation has assisted state, regional and local LiDAR stakeholders in New Hampshire, Pennsylvania, New Jersey, New Hampshire, Wisconsin, Michigan, and Oregon to prepare and submit grant applications seeking federal matching funds through a Federal Broad Agency Announcement (BAA) process. In 2014, the BAA process resulted in 29 cost share awards, seven of which resulted in direct tasking to Quantum Spatial totaling nearly 19,000 mi^2. This includes the BAA award to the Maine Geolibrary to collect and process 2,882 mi^2 of QL2 LiDAR in the greater Bangor area. Quantum Spatial is well prepared to support and assist the State of Maine in future BAA cycles.

Forest Analytics

Quantum Spatial and Sewall together have extensive national and Maine specific forest management experience and knowledge working with public and private landowners. This includes appraisal and inventory, management planning, and modeling; and natural resources mapping and information systems. Quantum Spatial has mapped tens of millions of acres of forestland across the US, including Maine, these data have supported forest inventory and assessments for both public and private lands ownerships. Sewall has been actively working with point cloud data for over seven years developing a long resume of successful projects totaling over 5 million acres in the Eastern United States and Maritime Canada. Together, Quantum Spatial and Sewall will work closely with the Cooperative Forestry Research Unit (CFRU) and the University of Maine in Orno, to ensure that we are tied into the latest research and need of the forestry landowners in Maine.

Figure 5: The CFRU and the University of Maine will work with the Quantum Spatial Team on forestry analytics ensuring that all Maine stakeholders have accurate data

Quality Commitment

Quantum Spatial's Quality Management System (QMS) fully complies with the underlying principles of ISO 9001-2008 quality standards and is reflected in numerous professional excellence awards for LiDAR projects including USGS's "LiDAR for the Northeast" project which covered 2,893 mi^2 of coastal Maine.

1.2. Organization Location and Licensure

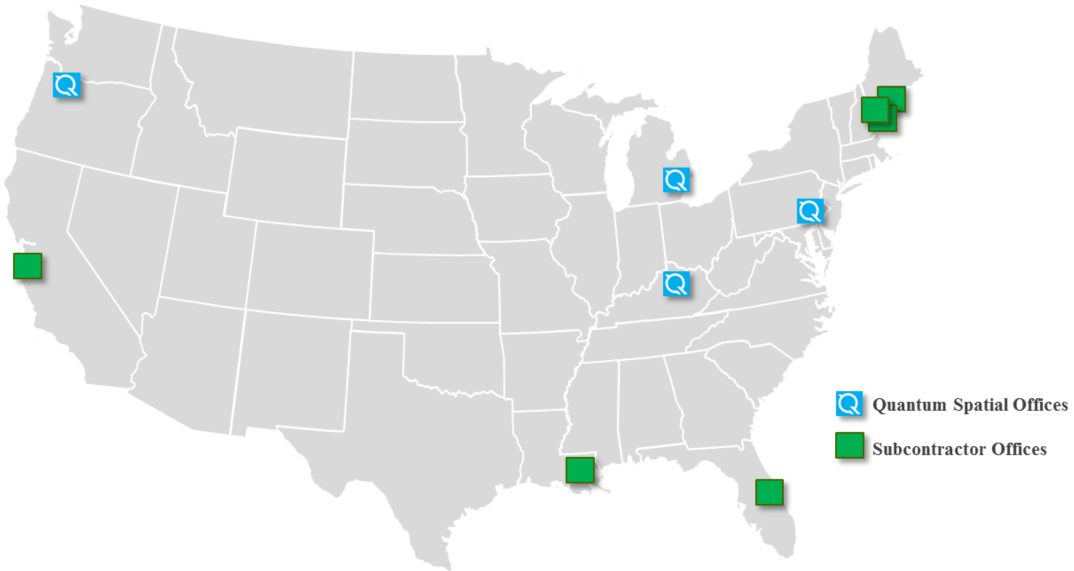
1.2.1. Location of Corporate Headquarters

Quantum Spatial's corporate headquarters are located at 4020 Technology Parkway in Sheboygan, Wisconsin 53083.

1.2.2. Location where Services will be Performed

The Quantum Spatial Team has identified centers of excellence within our own corporate structure, which will be providing services on the State of Maine contract. We have identified those below as well as the locations of our subcontracts that will be performing work on this contract. We have strategically identified three Maine-based firms who will participate on this program and with our contract management office located in Pennsylvania, we can ensure timely communications with the State for the entire duration of the contract.

Quantum Spatial Team
Maine Program Office Locations



Maine – James W. Sewall
136 Center Street
Old Town, Maine 04468
LiDAR Processing, Control Surveying & Forest Analytics

Maine – KAPPA Mapping
6 State Street, Suite 301
Bangor, ME 04401
LiDAR Processing

Maine – SSG Land Surveyors
6 State Street, Suite 301
Bangor, ME 04401
Control Surveying

California – Mira Solutions
29300 Kohoutek Way
Union City, CA 94587
Offshore LiDAR Processing

Florida – Harris Corporation
1025 W NASA Blvd
Melborne, FL 32919
Geiger LiDAR

Louisiana – PAR
P O Box 72357
Bossier City, LA 71172
Supplemental LiDAR Acquisition

Kentucky – Quantum Spatial
523 Wellington Way
Lexington, KY 40503
Project Management,
LiDAR Acquisition (Linear & Mobile),
LiDAR Processing, QA/QC

Michigan – Quantum Spatial
315 West Huron St., Ste. 260
Ann Arbor, MI 48103
Forestry Analytics

Oregon – Quantum Spatial
517 Southwest 2nd
Corvallis, OR 97333
Forestry Analytics

Pennsylvania – Quantum Spatial
1055 Andrew Drive, Ste. D
West Chester, PA 19380
Contract Administration

Figure 6: Location where services will be performed.

1.2.3. Maine Licensure Requirements

Quantum Spatial is a certified foreign business by the State of Maine Department of the Secretary of State. We have included on the following pages a copy of our certificate demonstrating that we are authorized to perform work in the State. Additionally, following our business certificate are the licenses for our team's Maine land surveyors: John Allen, PLS, Stevenson Sheppard, PLS, Robert Garster, PLS, and Glenn Griswold, PLS.

State of Maine

Department of the Secretary of State

I, the Secretary of State of Maine, certify *that according to the provisions of the Constitution and Laws of the State of Maine, the Department of the Secretary of State is the legal custodian of the Great Seal of the State of Maine which is hereunto affixed and of the reports of qualification of foreign business corporations in this State and annual reports filed by the same.*

I further certify *that QUANTUM SPATIAL, INC., a WISCONSIN corporation, is a duly qualified foreign business corporation under the laws of the State of Maine and that the application for authority to transact business in this State was filed on November 12, 2013.*

I further certify *that said foreign business corporation has filed annual reports due to this Department, and that no action is now pending by or on behalf of the State of Maine to forfeit the authority to transact business in this State and that according to the records in the Department of the Secretary of State, said foreign business corporation is a legally existing business corporation in good standing under the laws of the State of Maine at the present time.*

In testimony whereof, I have caused the Great Seal of the State of Maine to be hereunto affixed. Given under my hand at Augusta, Maine, this twenty-eighth day of September 2015.

Matthew Dunlap
Secretary of State

Authentication: 4651-251 - 1 - Mon Sep 28 2015 12:47:35

State of Maine

DEPARTMENT OF PROFESSIONAL & FINANCIAL REGULATION

BOARD OF PROFESSIONAL LAND SURVEYORS

License # PLS2311

Be it known that: **JOHN H. ALLEN**
has qualified as required by 32 MRSA Chapter 121 and
is licensed as a

PROFESSIONAL LAND SURVEYOR

ISSUE DATE
Jan 01, 2014

Anne L. Head

Director, Office of Professional & Occupational Regulation

EXPIRATION DATE
Dec 31, 2015

State of Maine

DEPARTMENT OF PROFESSIONAL & FINANCIAL REGULATION

BOARD OF PROFESSIONAL LAND SURVEYORS

License # PLS2086

Be it known that: **STEVENSON WIGHT SHEPPARD**
has qualified as required by 32 MRSA Chapter 121 and
is licensed as a

PROFESSIONAL LAND SURVEYOR

ISSUE DATE
Jan 01, 2014

Anne L. Head

Director, Office of Professional & Occupational Regulation

EXPIRATION DATE
Dec 31, 2015


State of Maine

DEPARTMENT OF PROFESSIONAL & FINANCIAL REGULATION

BOARD OF PROFESSIONAL LAND SURVEYORS

License # PLS2047

Be it known that: **ROBERT J. GARSTER, JR**

has qualified as required by 32 MRSA Chapter 121 and is licensed as a

PROFESSIONAL LAND SURVEYOR

ISSUE DATE
Jan 01, 2014

Anne L. Head

Director, Office of Professional & Occupational Regulation

EXPIRATION DATE
Dec 31, 2015

State of Maine

DEPARTMENT OF PROFESSIONAL & FINANCIAL REGULATION

BOARD OF PROFESSIONAL LAND SURVEYORS

License # PLS2405

Be it known that: **GLENN GRISWOLD**
has qualified as required by 32 MRSA Chapter 121 and
is licensed as a

PROFESSIONAL LAND SURVEYOR

ISSUE DATE
Jan 01, 2014

EXPIRATION DATE
Dec 31, 2015

Director, Office of Professional & Occupational Regulation

1.2.4. Certificate of Insurance

Included on the following page is a copy of our certificate of insurance documenting proof of adequate general liability, professional liability, and workers compensation. Per the specifications outlined in the solicitation, this information is presented in a standard Acord form.

ACORD®

CERTIFICATE OF LIABILITY INSURANCE

4/1/2016

DATE (MM/DD/YYYY) 4/1/2015

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AFFIRMATIVELY OR NEGATIVELY AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW. THIS CERTIFICATE OF INSURANCE DOES NOT CONSTITUTE A CONTRACT BETWEEN THE ISSUING INSURER(S), AUTHORIZED REPRESENTATIVE OR PRODUCER, AND THE CERTIFICATE HOLDER.

IMPORTANT: If the certificate holder is an ADDITIONAL INSURED, the policy(ies) must be endorsed. If SUBROGATION IS WAIVED, subject to the terms and conditions of the policy, certain policies may require an endorsement. A statement on this certificate does not confer rights to the certificate holder in lieu of such endorsement(s).

PRODUCER Lockton Companies
1801 K Street NW, Suite 200
Washington DC 20006
(202) 414-2400

CONTACT NAME:
PHONE (A/C, No, Ext):
FAX (A/C, No):
E-MAIL ADDRESS:

INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A : The Phoenix Insurance Company	25623
INSURER B : Travelers Property Casualty Co of America	25674
INSURER C :	
INSURER D :	
INSURER E :	
INSURER F :	

INSURED Quantum Spatial, Inc.
1363847 4020 Technology Parkway
Sheboygan WI 53083

COVERAGES CERTIFICATE NUMBER: 12276927 REVISION NUMBER: XXXXXXX

THIS IS TO CERTIFY THAT THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.

INSR LTR	TYPE OF INSURANCE	ADDL INSD	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	X COMMERCIAL GENERAL LIABILITY	N	N	6309C655806	4/1/2015	4/1/2016	EACH OCCURRENCE	$ 1,000,000
	CLAIMS-MADE [X] OCCUR						DAMAGE TO RENTED PREMISES (Ea occurrence)	$ 1,000,000
							MED EXP (Any one person)	$ 10,000
							PERSONAL & ADV INJURY	$ 1,000,000
	GEN'L AGGREGATE LIMIT APPLIES PER:						GENERAL AGGREGATE	$ 2,000,000
	POLICY [X] PRO-JECT [ ] LOC						PRODUCTS - COMP/OP AGG	$ 2,000,000
	OTHER							$
B	AUTOMOBILE LIABILITY	N	N	8109C655806	4/1/2015	4/1/2016	COMBINED SINGLE LIMIT (Ea accident)	$ 1,000,000
	X ANY AUTO						BODILY INJURY (Per person)	$ XXXXXXX
	ALL OWNED AUTOS / SCHEDULED AUTOS						BODILY INJURY (Per accident)	$ XXXXXXX
	HIRED AUTOS / NON-OWNED AUTOS						PROPERTY DAMAGE (Per accident)	$ XXXXXXX
								$ XXXXXXX
B	X UMBRELLA LIAB X OCCUR	N	N	CUP9C655806	4/1/2015	4/1/2016	EACH OCCURRENCE	$ 5,000,000
	EXCESS LIAB CLAIMS-MADE						AGGREGATE	$ 5,000,000
	DED X RETENTION $ 10,000							$ XXXXXXX
B	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y/N		N	UB9C655806	4/1/2015	4/1/2016	X PER STATUTE / OTH-ER	
	ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH) [N]	N/A					E.L. EACH ACCIDENT	$ 1,000,000
	If yes, describe under DESCRIPTION OF OPERATIONS below						E.L. DISEASE - EA EMPLOYEE	$ 1,000,000
							E.L. DISEASE - POLICY LIMIT	$ 1,000,000

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (Attach ACORD 101, Additional Remarks Schedule, may be attached if more space is required)
Evidence of Insurance

CERTIFICATE HOLDER

12276927
Evidence of Insurance

CANCELLATION

SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS.

AUTHORIZED REPRESENTATIVE

ACORD 25 (2014/01)

1.3. Organizational Experience

1.3.1. Quantum Spatial

Quantum Spatial, Inc. (formerly Aero-Metric, Inc., Photo Science, and Watershed Sciences, Inc.), delivers professional services and solutions for clients across all industry verticals with specialized expertise in energy, transportation, utilities, environmental, mining, national security, federal agencies, state and local government, and commercial applications. Quantum Spatial plans to invest significantly to enhance its solutions, as well as expand its newly launched family of cloud-based, enterprise-wide, operational solutions. As a result of this merger, Quantum Spatial's domestic and international clients benefit from enhanced capabilities and solutions. In addition, clients benefit from accelerated research and development through significant investments to create new solutions that address the evolving challenges faced by each end market. Clients also have complete access to the creativity and knowledge of the firms' expanded core capabilities and resources.

Quantum Spatial, founded in 1969 as Aero-Metric, Inc., is one of the nation's largest and most experienced full-service geospatial/information technology (IT) firms. We provide comprehensive Mapping, Acquisition, IT and GIS services. Our client base includes local, county, state, regional, and federal agencies; public utilities; airports; and many of the top engineering and industrial firms in North America. We have completed projects in all 50 states and in over 30 foreign countries including Canada.

Quantum Spatial has been an active stakeholder in the Maine geospatial community working with Federal, State and local agencies to partner in the use and production of aerial LIDAR, orthophotography, and related photogrammetric services across the State. Quantum Spatial (as Photo Science) has been an active participant in the Maine GIS Users Group (MEGUG) and was a gold level sustaining member. Quantum Spatial staff including assigned Principal-in-Charge, Michael Shillenn, CP, have made educational presentations on LiDAR technology at MEGUG sponsored events. Additionally, Quantum Spatial (formerly Photo Science) maintained an office space in Old Town, Maine to better support our Maine clients when project requirements dictated.

Working with our subcontractor Sewall from 2003-2005, Quantum Spatial (as Photo Science) was the prime consultant who developed the State's first ever full color, higher resolution, digital orthophotography dataset. This $2.3 million dollar project was successfully accomplished by Quantum Spatial (as Photo Science) using its USGS Cartographic Services Contract (CCS), and the successor contract, the Geospatial Products and Services Contract (GPSC), in partnership with the Maine GeoLibrary Board. Additionally, since 2005, Quantum Spatial (as Photo Science) has provided mapping and surveying services to the Maine Department of Transportation and holds a current open end contract through the balance of 2011.

In the fall of 2009, Quantum Spatial (as Photo Science) and its sub consultant, Sewall, were tasked by tasked by USGS to provide 1,245 mi^2 of high-resolution natural color orthoimagery covering the City of Portland, Maine and vicinity in support of the National Geospatial Intelligence Agency's (NGA) Urban Area 133 City initiative.

In 2010, Quantum Spatial (as Photo Science) was tasked again by USGS in cooperation with the State Planning Office (SPO) and the Office of GIS (MEGIS) to leverage and enhance LiDAR data acquired by our firm for FEMA Region 1 in support of FEMA's Risk Mapping, Assessment, and Planning (Risk MAP) program in Androscoggin County, Maine.

Figure 7: LiDAR DEM in Androscoggin County, ME collected for the USGS and MEGIS.

In 2011, Quantum Spatial (as Photo Science) captured over 2,800 mi^2 of LiDAR imagery along the coast of Maine in support of the MEGIS and the USGS North East LiDAR program. Our subcontractor, Sewall's survey crews provided all ground based control surveys to support the processing and validation of the LiDAR data. Quantum Spatial's professionalism, integrity, and achievement in client satisfaction for the North East LiDAR project was recognized in the receipt of a Geospatial Products and Excellence Award in 2012.

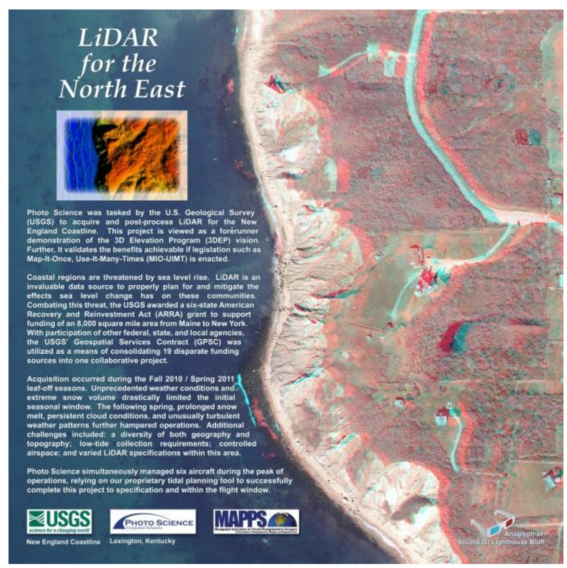


Figure 8: 3D Poster of the award-winning LiDAR for the North East project, which included 2,800 mi^2 *of data captured in Maine.*

Currently, we are actively working with USGS and the Maine Office of GIS/Maine Geolibrary resulting from a 2015 3DEP BAA LiDAR task order award covering a 2,882 square mile area in the vicinity of Bangor. The task order includes the acquisition, control, processing and delivery of a fully compliant QL2 dataset adhering to USGS Base LiDAR Specification v1.2. Both Sewall and PAR, USGS approved subcontractors, are working with Quantum to complete this latest Maine project.

Quantum Spatial is comprised of some of the most practiced and highly credentialed staff in the geospatial profession. While our resources have expanded beyond that of our competitors, our success is defined by our legacy traits of quality, flexibility, responsiveness, partnership, and client satisfaction.

1.3.2. Subcontractors

The Quantum Spatial team includes a group of leading subconsultants that are strategically located in Maine and the surrounding region. Their capabilities allow us to deliver efficient mobilization in support of various geospatial requirements to the State and its constituents. Our close partnership and documented accomplishments with our subconsultants will mitigate any risk involved in the subcontracting process. Quantum Spatial has current working relationships with most of its team members.

James Sewall Company

Founded in 1880, Sewall provides integrated engineering and forestry consulting services with attendant geospatial capabilities to clients in government and industry. Sewall is the oldest continuously operating forestry consulting firm in North America with a long history of providing forest modeling services to a wide range of private and public-sector clients. Their staff is expert at using the Remsoft Spatial Planning System and is a consulting partner with Remsoft.

With 135 years' experience in surveying and mapping, 65 years' in aerial photogrammetry, and a legacy in accurate geospatial data, the company has built strong capabilities in geospatial data conversion, LiDAR Processing, GIS, and software application development. The company is organized to implement innovative systems and processes for sharing resources and technologies across business units. These innovations enable them to deliver multidisciplined solutions that integrate their expertise in engineering, survey, natural resources, aerial imaging and photogrammetry, and information systems to meet specific client needs.

As a member of the Cooperative Forestry Research Unit (CFRU) and as a consultant on geospatial services and forest biometrics to virtually all large private forest landowners in Maine, James W. Sewall Company (Sewall) has performed mapping of roughly one million acres per year and been involved in inventory efforts of at least an equivalent additional amount each year. Sewall is currently working on a research and development project to generate forestry analytics/metrics derived from data produced by an innovative new photon counting LiDAR sensor for Baxter State Park- Scientific Forest Management Area (BSP). LiDAR data acquisition and pre-processing will be carried out by a third party aerial vendor and provided to Sewall by BSP. The results of this experiment will make a significant contribution to the CFRU in the form of data sharing to help inform decisions about next steps with this technology.

The derivation of inventory metrics from LiDAR data is based on building statistical models between traditional forest inventory data and metrics derived from the LiDAR data that are used to predict the inventory attributes across a study area. Sewall will use existing inventory data provided by BSP as the training (modeling) and validation datasets. All inventory data will be grown forward using an appropriate regional growth and yield model to standardize the data and bring it up to date with the timing of the LiDAR acquisition. These data will then be summarized to provide plot level estimates of meaningful inventory metrics such as basal area (BA), average height, volume, stem density, and stem size. The metrics can be calculated for both overall and merchantable stems, with a merchantability threshold being specified by BSP.

Sewall will use its custom software to extract data from the point clouds for an area that matches the area of the inventory plot, centered on the plot location provided by BSP with the inventory data. Sewall will use modern statistical data analysis methods to reduce the initial set of LiDAR input metrics to a core group that makes a meaningful contribution to the resulting models by identifying and removing correlated, redundant and non-contributing metrics. The final models will be evaluated using standard statistical techniques and then applied to the full dataset to provide geospatial data products for the full project area.

Sewall assists clients in developing full life-cycle GIS from strategic planning and needs assessment to geodatabase design, systems integration, and application development. To reduce the cost of technology entry and maintenance, Sewall offers web hosting, on-line data maintenance, and a secure geoportal for the collection and distribution of geospatial data. With their established web site/web mapping hosting facility, clients access their data with only a current web browser and a reliable Internet connection. The Sewall staff has expertise in industry-leading technologies including ESRI, Intergraph, Cartegraph, and Autodesk; Sewall is a business partner with ESRI and Cartegraph, and part of the developer network for AutoDesk.

As client-focused firm, Sewall is committed to understanding client needs and business drivers and the needs of client constituencies. Our core services in engineering and natural resources with respective geospatial capabilities can be integrated in any combination to further client success:

- **Engineering**. Civil, environmental, and traffic engineering; utilities infrastructure mapping and asset management; and surveying services
- **Natural Resources**. Appraisal and inventory; forest management, management planning, and modeling; and natural resources mapping and information systems

Embedded in these core services, they offer:

- **Geospatial Solutions**. Geospatial data acquisition and development, GIS development, mapping and applications, and web services

A privately held firm under management ownership, Sewall continues to grow to meet their clients' evolving needs. Sewall currently has seven offices nationwide, 80+ staff, and ever broadening capabilities. Sewall's headquarters are located at 136 Center Street, Old Town, Maine 04468; telephone: 207 827 4456. Regional offices are located in Caribou, Maine; International Falls, Minnesota; Milledgeville, Georgia; Port Charlotte, Florida; Summerville, South Carolina; Thetford, Vermont and Tuscumbia, Alabama.

Sewall manages approximately 1,000 projects a year, ranging in size from a few hundred dollars to several just shy of a million. We perform project work in 14 countries on 5 continents, and in 40 states and most Canadian provinces. Our clients range from smaller local municipalities and firms to some of the largest cities and retail organizations in the country. They service public, private, governmental and non-profit organizations.

Kappa Mapping

In December 2003, KAPPA Mapping, Inc. purchased a well-established aerial mapping firm located in downtown Bangor, Maine. KAPPA took over the existing equipment and facilities, and retained all of the staff and most of the purchased company's clientele. A good part of that original staff is still working at KAPPA, and has a combined experience of over 120 years in photogrammetry and orthophoto services, LiDAR editing and classifying, tax mapping, GIS, and other mapping services.

Now in its twelfth year of operation, KAPPA has three ASPRS certified photogrammetrists on staff, all of whom have managed a wide variety of photogrammetric mapping, LiDAR processing and orthophotography projects from start to finish. Their experience with project planning and management provides clients with realistic estimates and schedules, effective workflows, superior quality assurance, and on-budget, on-time delivery of products.

KAPPA has edited and reviewed over 10,000 mi^2 of LiDAR data, mostly for federal & state projects, which are funded by multiple stakeholders. Duties usually include enforcement of lakes, ponds, and double line drains (with directionality). Their LiDAR editors typically edit and classify LiDAR data starting after automated bare earth routines and the end result is usually for 1 ft. or 2 ft. contour interval projects. During the classification process, editors use TINs and/or contours along with Google Earth imagery to interactively classify and edit the data. The Google Earth imagery provides additional context for the LiDAR data.

KAPPA's Mapping Analysts and GIS Specialists assist clients with GIS production services for mapping, including quality control for our final deliverables. Their Photogrammetric and GIS Technicians are highly proficient with a variety of hardware and software production equipment, including state-of-the-art workstations specifically configured for orthophotograph production, GIS, tax mapping, softcopy vector collection, and LiDAR editing and classification.

KAPPA takes an active role in the various mapping communities, by attending both the spring and fall American Society of Photogrammetry & Remote Sensing (ASPRS) conferences to stay current with photogrammetric mapping technologies; participating in Maine GIS User Group (MEGUG) sessions, by exhibiting and attending the Maine Municipality Association (MMA) and Maine Association of Assessors Officers (MAAO); and by exhibiting at the Maine Department of Transportation conference held each year in Augusta. This active involvement helps KAPPA stay up-to-date with the mapping technologies and allows them to keep abreast of what is happening within Maine's communities.

KAPPA Mapping, Inc. is a woman-owned business and is certified as a Disadvantaged Business Enterprise (DBE) by the State of Maine.

KAPPA Mapping, Inc. owns and maintains a collection of state-of-the-art systems specifically configured for orthophoto and softcopy vector collection, including high-capacity hard drives, 3D-displays and fast processors. Mapping software packages are also maintained, such as the latest versions of ArcView, and other related mapping software, as well as hardware suitable to operate these applications.

KAPPA's local project references include providing true color & CIR ortho-imagery for the Town of Bar Harbor, locating lobster buoys for the Maine Department of Marine Resources, and providing traditional engineering-grade mapping services for the Maine Department of Transportation. KAPPA also supports a number of Maine municipalities such as the City of Gardiner, Town of Vassalboro, and City of Belfast with yearly tax mapping and GIS services. This past year, KAPPA has updated GIS basemaps for the Cities of Auburn & Lewiston, working as a team partner with Sewall Company. Prior mapping services also include supporting the Cities of Portland, Bangor and Brewer with basemap and parcel updates.

KAPPA's role, as Team Member to Quantum Spatial, is to manage their portion of the project, provide manual editing and classification to the bare earth deliverables, develop and/or coordinate project reporting and metadata development, and to provide quality assurance on all deliverables.

Shyka, Sheppard & Garster (SSG)

Shyka, Sheppard & Garster Land Surveyors (SSG) provides a full range of surveying services and uses the latest surveying technologies to produce accurate, timely, and cost-effective survey and spatial information for a variety of industry sectors including engineering, architecture, construction, land development, public utilities, and local, state and federal government agencies.

SSG is based in Bangor, Maine and was originally founded in 1994 as "Sheppard & Garster Land Surveyors, Inc". by Stevenson W. Sheppard & Robert J. Garster, Jr. In 1998, Sheppard & Garster acquired the records and assets of Andrew J. Shyka, PLS and became Shyka, Sheppard & Garster Land Surveyors (SSG). Acquisition of the Shyka records provided project records dating back to 1964 and a substantial archive of historic documents.

Now in its twenty-first year of operation, SSG has four licensed surveyors with extensive experience in managing a wide variety of surveying projects from start to finish. SSG's experience with project planning and management provides clients with realistic estimates and schedules, effective workflows, superior quality assurance, and on-budget, on-time delivery of information products. SSG's Licensed Surveyors and Survey Technicians are highly proficient with a variety of terrestrial, GPS, and scanning data collection technologies including Leica Robotic, Nikon and Sokkia total stations and electronic data collection systems and Trimble and Leica GNSS and Leica 3D laser scanners. Deliverables are prepared using current, networked Autocad Infrastructure Design Suite, Trimble Business Center and Leica Geo Office capabilities to provide accurate information quickly and efficiently. Always keeping service in mind, SSG provides geo-referenced deliverables using client specified CAD and GIS standards.

Shyka, Sheppard and Garster is always prepared to provide tailored services for unique project requirements as well as offering a wide variety of services, including:

- Boundary Surveys
- Topographic Surveys
- Engineering Surveys
- GPS Control Surveys
- Hydrographic Surveys
- Construction Layout and Monitoring
- As-Built Surveys
- Expert Witness Testimony
- 3D Laser Scanning
- Utility Surveys
- GIS Data Collection (GPS Sub-Meter)
- FEMA Surveys (Flood Elevation Certificates)
- Letter of Map Amendment (LOMA) Applications.
- Subdivision Design
- ALTA/ACSM Land Title Surveys

Harris Corp.

Harris Corporation provides advanced, technology-based solutions to our government and commercial customers' most complex challenges. From wideband-networking tactical radio systems for defense and security forces to secure telecommunications networks for air traffic control, customers trust Harris to deliver mission-critical situational awareness. Our company has approximately $8 billion in annual revenue and about 23,000 employees—including 9,000 engineers and scientists—supporting customers in more than 125 countries.

For 25 years, Harris has created geospatial information solutions that meet the exacting—and often unique—needs of government and commercial customers. They supply imagery processing, foundation data, mapping and charting production, and production management for U.S. government programs, including the Foundation GEOINT Content Management contract (FGCM). For this major contract, Harris is creating, managing, and delivering on-demand geospatial data for two-thirds of the globe. Harris differentiates ourselves in commercial and international markets through our established preferred-reseller agreements with most of the commercial space companies and with many aerial partners differentiate us. By finding the best data to address our customers' needs and then applying our advanced geospatial processing capabilities, they are able to meet even the most unique requirements.

Today, through our IntelliEarth™ Geospatial Solutions, Harris is making it easier and more cost effective to visualize the physical environment for a wide range of applications. Harris' new IntelliEarth™ Geiger-mode LiDAR sensor and tool suite for cost-effective, large-area topographic mapping can provide engineering-grade base maps for multiple geospatial applications and for generating integrated enterprise geospatial information and situational knowledge products to benefit customers and stakeholders.

Harris' topographic LiDAR mapping technology offering includes sensors, processing tools, and analytics born from Harris' 15-year Geiger-mode LiDAR legacy within the U.S. government and transitioned to bring the next big leap in production efficiency to the broader international and commercial marketplace. Their topographic mapping solution uses Harris-developed Geiger-mode LiDAR that maps land features at high point densities (from 2 points/m2 to greater than 20 points/m2) at area collection rates greater than 1000 km2/hour. It penetrates foliage better to map the underlying ground and structures and to detect utility wires and other fine structures of critical importance for city/infrastructure planning, utility management, disaster management, transportation, water resource management, and other geospatial applications.

Precision Aerial Reconnaissance (PAR)

Precision Aerial Reconnaissance (PAR) is a client focused, quality driven small business that specializes in LIDAR and aerial image acquisition, LiDAR processing, geospatial and infrastructure products and solutions. Our areas of expertise include surveying and mapping, remote sensing, GIS, and related software products. PAR is a Service-Disabled Veteran-Owned Small Business whose clients include federal, state, and local government agencies, as well as private sector companies. Our company's professional solutions are designed to exceed client expectations through premium customer service, provided by sincere personal attention, and careful consideration to the needs of its clients.

Mira Solutions Inc.

Founded in 1997, Mira Solutions is a geospatial services provider specializing in large scale topographic and planimetric mapping, digital orthophotography, LiDAR production, remote sensing, and geospatial analysis. Headquartered in Union City, California, Mira Solutions has a proud record of performance delivering innovative geospatial solutions to government and private sector markets. In addition to their Union City office, Mira maintains an affiliated production facility located in the City of Harbin located in the Peoples Republic of China where they have highly skilled and trained staff utilizing state-of-the-art technologies.

Mira Solutions collects and converts information about the earth's surface into spatially accurate mapping and engineering products for surveyors and engineers and other land information management environments.

Their highly experienced team consists of certified photogrammetrists and software engineers with years of experience in digital photogrammetry and lidargrammetry, softcopy photogrammetric software development and remote sensing. This expertise combined with our emphasis on superior quality and service, provides Mira Solutions the ability to offer exceptional and cost effective solutions to meet the mapping needs of their clients.

Mira Solutions is a privately held company incorporated in Colorado in 1997 and operating in California since 2002. Directly and through partnerships with mapping industry leaders, such as Quantum Spatial, BAE Systems, etc., Mira Solutions has provided quality geospatial services to federal, state, county and city government agencies, such as Caltrans, and private industries as well.

1.3.3. Team Equipment List

Quantum Spatial has the experience, personnel, equipment, and facilities available to meet the future geospatial service needs of the State of Maine. Our capacity includes a large highly trained staff, the latest equipment, and processes in place (project management, technical procedures, and quality control) to meet any needs of the State. We have also assembled a subconsultant team of industry experts to complement our abilities and provide surge capacity as needed. Figure 9 provide the specifics of our team's resources, including personnel, equipment, and hardware/software.

Quantum Spatial Team Equipment			
Resource Type	Quantum Spatial	Team Surge Resources	Total Team Resources
Personnel – qualified and trained	525	236	761
Aircraft – FAA/ICAO certified	20	4	24
Linear LiDAR Sensors	17	1	18
Geiger LiDAR Sensors	0	3	3
Mobile LiDAR Sensors	1	0	1
LiDAR Processing Hardware/Software	433	58	491
GIS / CADD Data Analysis Hardware/Software	208	60	268
Survey equipment (GPS receivers, levels, etc.)	30	25	55

Figure 9: Quantum Spatial Team Equipment Capacity

1.3.4. Key Personnel

Quantum Spatial is proud of the quality of our staff and the staff of the subconsultants we have teamed with for this contract. We understand that our success is based on our most important resource, i.e., our staff. Each of the key personnel selected for the Quantum Spatial Team for this program has extensive relevant experience and outstanding professional qualifications. We have previously worked with most of our team members and are well organized to provide exceptional project management and technical support to provide aerial and mobile LiDAR services. Our team is comprised of industry leading geospatial firms with highly qualified experts that specialize in all aspects of professional geospatial services. With an average of 22 years of experience, our staff members are dedicated to the geospatial profession. Many are licensed, certified and very active in professional societies such as the American Society for Photogrammetry and Remote Sensing (ASPRS). Resumes for all of the staff listed in the organizational chart are included in Appendix B of this response.

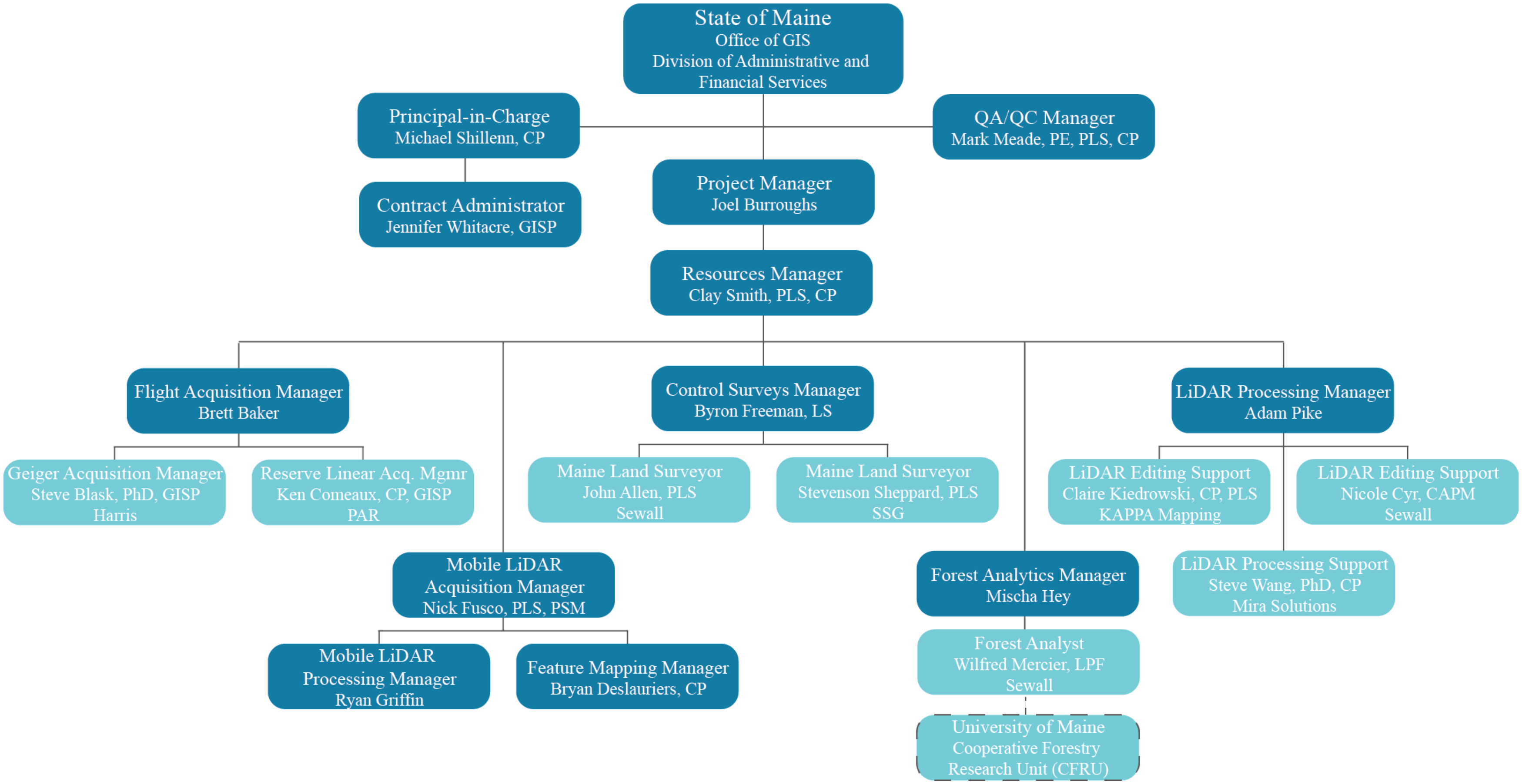


Figure 10: Quantum Spatial Team Organizational Chart

Contract Management Team

We have assembled a contract management team consisting of skilled, senior personnel who are experienced in delivering services with the State of Maine. Listed below is the Quantum Spatial management team dedicated to this contract. Each of them are currently managing relating contracts and projects, all have years of experience in the geospatial industry as well as project management. Full resumes are included in Appendix B of this response.

Mike Shillenn, CP – Principal-in-Charge

Mike Shillenn, CP – Principal-in-Charge. Mike will be responsible for overseeing the contract and milestones as well as their successful implementation. Mike has been with Quantum Spatial for over a decade, and he is a proven leader having managed numerous LiDAR programs throughout the US including the current USGS task order in Bangor, ME.

Jen Whitacre, GISP – Contract Administrator

Jen's administrative, contractual, and technical experience enhances the management team, which makes her most suitable for supporting Mike in executing program management roles, responsibilities, and contract duties. Jen has been with Quantum Spatial for over eight years, and she is the currently serving in the same capacity on several other LiDAR programs.

Joel Burroughs – Project Manager

Joel will serve as Quantum Spatial's project manager on this program and will be responsible for project planning, cost estimation, scope management, client reporting, and invoicing. Joel has extensive experience in managing multiple projects that range in scale from small mapping projects to large regional and statewide programs. Joel has a BS in Business Management and 9 years of experience.

Mark Meade, PE, PLS, CP – QA/QC Manager

Mark will be responsible for the implementation of Quantum Spatial's Quality Management System (QMS) by establishing the Quality Policy and Objectives. Mark has a strong management background with extensive experience serving as a technology advisor on numerous large-scale and complex contracts with Quantum Spatial. Mark also serves as our Chief Technology Officer, and he will support bringing new and innovative technologies to the State. He is a highly skilled professional who has authored numerous publications on innovative technologies in the geospatial field for Point of Beginning Magazine.

Clay Smith, PLS, CP – Resources Manager

As a resource manager, Clay will be responsible for monitoring Quantum Spatial's resources – including personnel and equipment – to ensure that we continue to work at a steady capacity while accounting for auxiliary resources to respond to no-notice or rapid response geospatial projects such as emergency tasks.

Technical Staff

The Quantum Spatial Team has an unparalleled staff of geospatial professionals to provide the services required by the State of Maine. The Quantum Spatial Team implements ASPRS standards, guidelines, and best practices for mapping, data accuracy, formats, and reporting, in most of its production workflows. Quantum Spatial LiDAR acquisition projects routinely implement the USGS base specifications for LiDAR acquisition and product development, widely accepted across the geospatial industry. Below are mini biographies for the key subject matter experts on our team. Their resumes are included in Appendix B of this response.

Mischa Hey –Subject Matter Expert: Forestry Analytics

During his 20+ year career, Mischa has gain broad experience and technical skills in remote sensing analysis, in particular the development of feature extraction techniques using combined LiDAR and spectral datasets, including leveraging hyperspectral imagery to delineate land cover characterization of interest. He has been instrumental in developing processing workflows for specialty deliverables in unique landscapes, including hydro-flattening, intensity normalization, and point feature coding. Mischa received his MS in Wildlife and Fisheries Biology from the University of Vermont and his BS in Natural Resource Management from the University of Massachusetts.

John Allen, PLS – Subject Matter Expert: Control Surveying

John has more than 23 years' experience in mapping, drafting and land surveying. His duties have included supervision of field crews and survey department, project management and business development. Mr. Allen has significant experience working with town and state regulating agencies, subdivision design, road layout, boundary work, and deed research. In addition, he is familiar with Maine State, Land Use Planning Commission, and Department of Environmental Protection regulations.

Steve Blask, PhD, GISP– Subject Matter Expert: Geiger LiDAR

Steve is Harris's chief scientist, guiding the overall design approach for Geiger mode and other LiDAR operations and image processing algorithm development. He has 28 years of experience in computer vision, computer graphics, image processing, and artificial intelligence, focusing on development of software systems for mobile robotics and unmanned vehicles, real-time machine vision for industrial robotics, tactical ISR payloads and ground processing, and space-based remote sensing. Steve has 24 publications and holds three patents in these areas. In the Purdue Robot Vision Lab, Steve developed geometric methods of classifying range data, low-level LiDAR range image processing, production systems for automatic recognition of hierarchical target models from noisy range images, methods and metrics for surface extraction from LiDAR images, and conducted automated target recognition (ATR) algorithm performance evaluation.

Nick Fusco, PLS – Subject Matter Expert: Mobile LiDAR

Nick is a Professional Surveyor in 13 states and has more than 40 years' experience in the surveying, mapping and photogrammetry field. He is the Program Manager for Quantum Spatial's Mobile Mapping clients. He is well versed in mapping issues ranging from aerial photography planning through advanced airborne applications involving photogrammetry, digital cameras, aerial LiDAR and mobile LiDAR acquisition and processing. Nick is a current member of the Florida Board of Professional Surveyors and Mappers. His experience includes project management on numerous mobile mapping, LiDAR, aerial photography, mapping, and related services contracts.

1.4. Description of Experience with Similar Projects

1.4.1. Aerial LiDAR Acquisition

Quantum Spatial is an industry leader in the acquisition and processing of LiDAR data at various point densities and accuracies and of varying sizes and flying heights for multiple Federal and State agencies meeting USGS LiDAR base specifications.

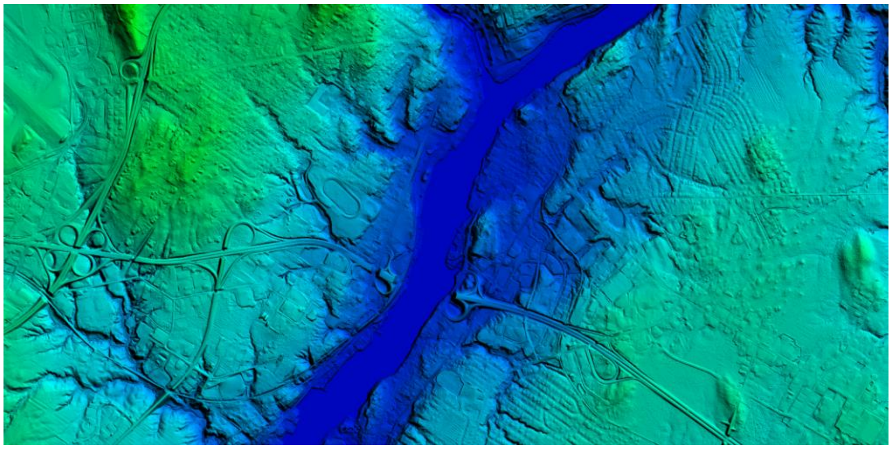


Figure 11: Hydro Flattened Bare Earth DEM of the greater Bangor Area acquired and processed in 2011-12 in support of the LiDAR for the Northeast Project.

Additionally, as a current USGS GPSC2 contract holder, Quantum Spatial has completed **44** LiDAR task orders for USGS and dozens more for other Federal and state agencies.

Client / Project	Period of Performance	Location	Size (Sq Mi)	Point Density	Meets USGS LiDAR Base Specifications
State of Maine/USGS: LiDAR for the NE	2011-2012	Coastal Maine	2,893	QL3	✓
State of Maine/USGS: 3DEP BAA	2015	Greater Bangor Area	2,882	QL2	✓
State of Maine/USGS / FEMA	2010	Androscoggin County	500	QL3	✓ hydro enforced
State of Vermont/USGS: 3DEP BAA Award	2010-2015	Various Tasking	5,227	QL2	✓ hydro enforced

Client / Project	Period of Performance	Location	Size (Sq Mi)	Point Density	Meets USGS LiDAR Base Specifications
State of New Hampshire / USGS: 3DEP BAA	2011-2015	Connecticut, Winnipesauke Watersheds & White Mountain	5,500	QL1 / QL2	✓
State of Massachusetts / USGS: 3DEP BAA	2015	Western Massachusetts	3,085	QL1 / QL2	✓
State of New York / USGS	2014	Clinton-Essex	2,669	QL2	✓
State of Delaware / Eastern Shore Maryland / USGS: Sandy Relief	2014	Statewide / 2 Maryland Counties	3,069	QL2	✓
Virginia/Maryland/DC/ USGS: Sandy Relief	2014	National Capital Region	2,002	QL2	✓
State of North Carolina: Yearly Tasks	2013-2015	Statewide	15,000	QL2	✓
State of Kentucky: Yearly Tasks	2011-2015	Statewide	13,750	QL3	State Specs
State of Kansas: Yearly Tasks	2012	Statewide	9,000	QL3	✓
State of Oregon/OLC: Yearly Tasks	2007-2015	Statewide	>28,000	QL1	State Specs
Delaware Valley Regional Planning Commission: 3DEP BAA	2015	8 Philly Metro Counties	3,260	QL2	✓

Figure 12: Completed past performance for airborne LiDAR acquisition & processing

1.4.2. Mobile LiDAR

Quantum Spatial understands that past performance is not just defined by the act of providing the service but more importantly, the quality and timeliness of the service or products provided. Since the acquisition of our mobile LiDAR system in 2010, Quantum Spatial has demonstrated our skill and expertise with providing high-quality DEM. In this short time, we have an extensive amount of experience working with State agencies throughout the country providing mobile LiDAR services (Figure 13).

Client / Project	Completion Date	Location	Size (miles)	Fee
New York Dept. of Transportation: Mobile Mapping in Stuben County	2013	I-86 / New York	6.5	$12,268
New York Dept. of Transportation: Mobile Mapping in Chocton County	2014	I-390 / New York	11.4	$34,393
Pennsylvania Dept. of Transportation: Multiple Mobile Mapping projects	2015	SR 322 / SR 144 / Pennsylvania	63	$183,244
Florida Turnpike/Wantman Group: Mobile Mapping in Orange/Osceola Counties	2013	Orange/Osceola Counties Florida	5	$10,000
KCI Technology: Mobile Mapping for Fiber Optics, Albemarle, Fairfax and Loudoun County, VA	2012	Virginia	28	$61,100
Georgia Transmission Corp: Mobile Mapping	2013	Ellijay-Roundtop Transmission Line in Georgia	17	$49,000

Figure 13: Completed Mobile LiDAR acquisition & processing projects

1.4.3. Project Narratives

On the following pages are extended narratives of some of the aerial and mobile LiDAR, as well as Forest Analytics project experience we have highlighted in Figures 12 and 13 above.

US Geologic Survey: Geospatial Production & Services Contract (GPSC)

Client
U.S. Geological Survey

Client Contact
Tim Saultz
(573) 308-3654
tsaultz@usgs.gov

Project Size
Nationwide

Dates of Service
GPSC2: 2010-Present

Value
GPSC2: $27.5M to date

RELAVENT DELIVERABLES:

- Fully complaint USGS v1.2 LiDAR datasets including raw and classified .LAS v1.4 files, gridded bare earth DEM, hydroflatten and hydro enforced breaklines, intensity imagery, topographic contours intensity imagery, FGDC metadata, and acquisition, QA and project reports.

Since 1997, Quantum Spatial (as AeroMetric and Photo Science) has provided USGS with comprehensive geospatial data acquisition, processing, exploitation and analysis services. It has held four consecutive USGS geospatial data production contracts (CSC, CSCII, GPSC, GPSC2) with over 375 total task order awards of which 120 task orders have been awarded to date under the GPSC2. Services provided under the current GPSC2 contract include imagery and LiDAR data acquisition and processing; surveying and control acquisition; photogrammetric mapping including aerotriangulation; orthophotography; image manipulation, analysis, and interpretation; map digitizing; data manipulations; thematic mapping; land characterization, GIS Services; ancillary data acquisition; metadata production and revision; and the production of geospatial products defined by formal and informal specifications and standards such as the USGS LiDAR Base Specification, v1.2. Some of our recent LiDAR mapping task orders are included below.

LiDAR for the Northeast

Quantum Spatial was awarded multiple task orders to collect and process LiDAR data of a coastal zone spanning six North Eastern states, including Maine, New Hampshire, Massachusetts, Connecticut, Rhode Island, and New York. This multi-stakeholder collaborative approach by USGS and participating federal, state and local agencies resulted in LiDAR acquisition and processing of over 8,000 mi^2 including multiple vertical accuracies (9.25 cm / 15 cm RMSEz), multiple post spacing requirements (1 meter / 2 meters NPS) and tide coordinated acquisition of selective areas/states. In order to retain small islands/rock outcrops (ground) along the coast (especially in Maine) that would have been classified as water in the hydro flattening process, Quantum Spatial developed a process by which water surface returns were also classified and incorporated into the bare earth DEM. This had the added benefit of allowing users to visualize the wave patterns at the time of acquisition. Services provided included **airborne LiDAR acquisition and processing, high-resolution topographic product generation, survey and control**

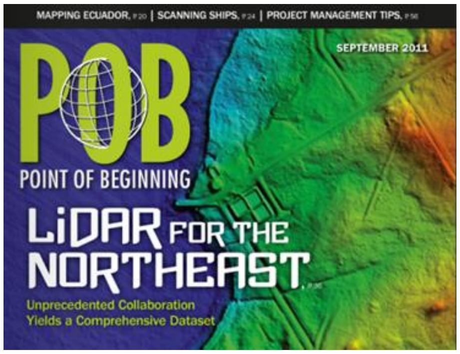


Figure 14: The LiDAR for the Northeast project was featured on the cover of POB Magazine

services, product generation, GIS services, acquisition of ancillary data, metadata creation, product validation, standard USGS raster and vector products. Project deliverables included all returns swath data, classified .LAS files, hydro-flattened, bare earth DEM earth, hydro breaklines, intensity imagery, FGDC metadata, and full adherence to **USGS Base LiDAR Specification v12**. The LiDAR for the Northeast Project won the **MAPPS Geospatial Products and Excellence Award** in 2012 and was the featured article in the September 2011 Point of Beginning (POB) Magazine.

3DEP BAA: Maine & Massachusetts QL1 & QL2 LiDAR

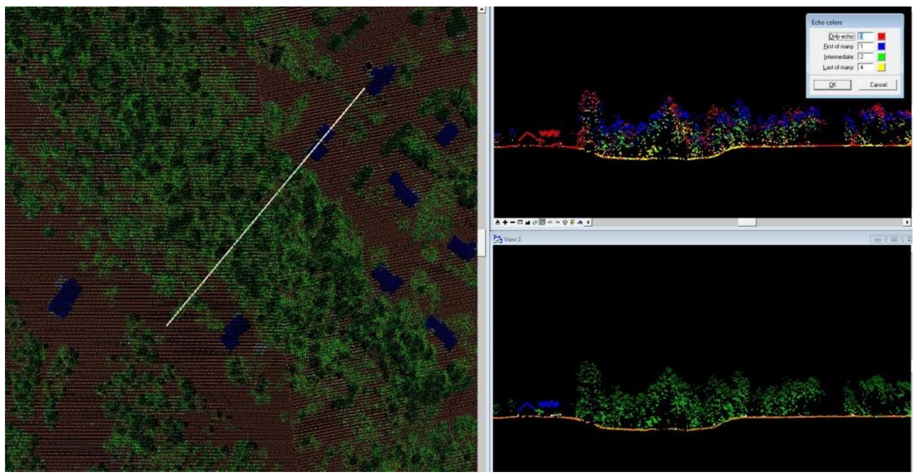


Figure 15: Top down & profile view of cross section of classified QL2 LiDAR point cloud near Showhegan, ME

In the spring of 2015, Quantum Spatial commenced acquisition, process and delivery airborne topographic LiDAR data covering specified Areas of Interest (AOI) located in Massachusetts and Maine totaling approximately 5,967 mi^2. LiDAR data is being collected at an aggregate nominal pulse spacing (ANPS) of 0.35 meters with a point density of 8 ppsm (QL1) for an 815 mi^2 AOI in MA and 0.7 meters ANPS with a point density of 2 ppsm (QL2) for the remaining 2,270 mi^2 AOI in MA, as well as, a 2,882 mi^2 AOI in ME. A non-vegetated, bare earth vertical accuracy (NVA) of ≤ 19.6 cm at the 95% confidence level (10 cm RMSEz) will be achieved for all AOIs. This high resolution LiDAR data will support both states' efforts regarding sea level rise and recurrent flooding in the identified area, and is a BAA funded proposal. Due to severely compressed spring window caused by persistent snow cover flowed by unseasonable warm temperatures, acquisition of the Maine AOI was suspended at 62% acquired and will resume in the fall of 2015 after leaf off. Supplemental ground control has been established by James W. Sewall survey crew, under subcontract to Quantum Spatial, to calibrate the LiDAR data. Additionally, a total of approximately 305 ground control quality check points have been established in various land cover categories and will be used by Quantum Spatial to validate NVA and VVA accuracies of the dataset. Quantum Spatial will adhere to "U.S. Geological Survey National Geospatial Program Base LiDAR Specification, v1.2. Quantum Spatial produced and delivered a pilot area(s) to validate data accuracy and classification. Quantum is also performing edge matching of the new Maine datasets to three existing LiDAR datasets using its customized 'feathering" approach that significantly reduces vertical stepping between new and old datasets while no compromising the overall accuracy of either dataset. Overall project deliverables will include raw point cloud data, classified point cloud data, hydro flattened, bare earth DEM, hydro break lines, intensity imagery, supplemental ground control and check points, metadata, and project/acquisition/processing reports. Deliverables for those portions of Maine and Massachusetts that have acquired and processed are scheduled for delivery to USGS on October 31, 2015.

3DEP BAA: Connecticut River Watershed & Winnipesaukee AOI QL2 LiDAR

Commencing in the fall of 2015, Quantum Spatial will collect and process high resolution QL2 LiDAR data covering over the Connecticut River watershed (4,437 mi^2) the Winnipesaukee River Watershed (486 mi^2) and portions of the White Mountain National Forest (WMNF) (181 mi^2) in New Hampshire. This high resolution LiDAR data covering a total of 4,923 mi^2 will support the state of New Hampshire, FEMA and the USFS's efforts regarding activities in the identified areas. The LiDAR data will be collected at an aggregate nominal pulse spacing (ANPS) of 0.7 meters and an aggregate nominal pulse density (ANPD) of 2 ppsm both for the Connecticut River and Winnipesaukee River watersheds. For the WMNF LiDAR data will be collected at an aggregate nominal pulse spacing (ANPS) of 0.58 meters and an aggregate nominal pulse density (ANPD) of 3 ppsm. Acquisition of LiDAR over Lake Winnipesaukee and Squam Lake will be targeted for mid-October to coincide with low water levels per Task Order requirements. Additionally, the western bank of the CT River will be acquired and included in breakline/hydro flattening process as part of DEM development. Additionally, a total of approximately 205 ground control quality check points will be established in various land cover categories and used by Quantum Spatial to validate NVA and VVA accuracies of the dataset. Quantum Spatial will adhere to "U.S. Geological Survey National Geospatial Program Base LiDAR Specification, v1.2" and meet NEEA QL2. Overall project deliverables will include raw point cloud data, classified point cloud data, hydro flattened bare earth DEM, hydro break lines, intensity imagery, supplemental and check point control data/report, metadata, and project/acquisition/processing reports.

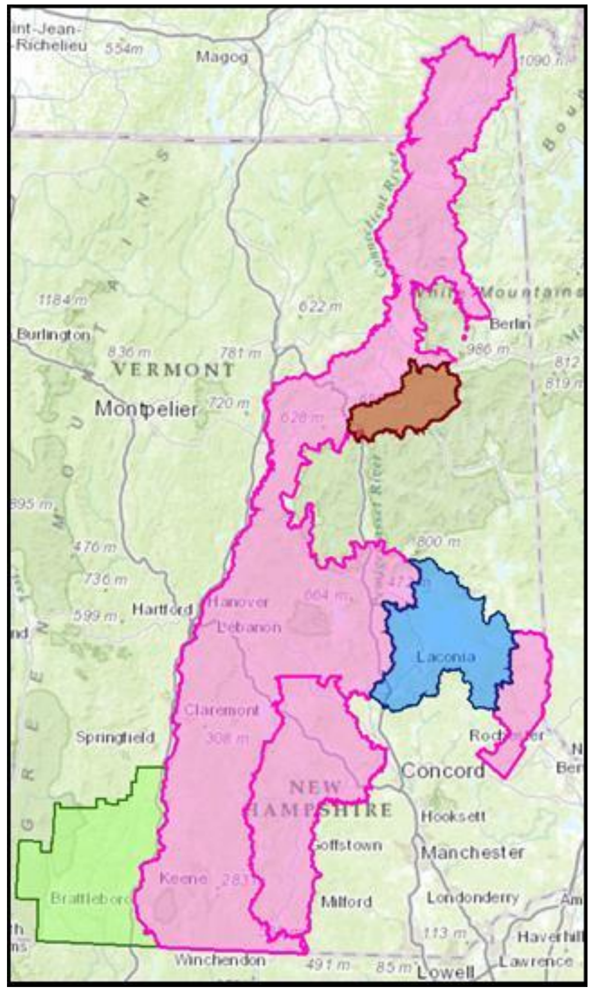


Figure 16: Map of the project area for the Connecticut River Watershed & Winnipesaukee USGS task order.

White Mountain National Forest, VT LiDAR

Three task orders spanning multiple years (2010, 2012, 2014) involving the planning, acquisition, processing and derivative products of LiDAR data at a point density of 3 ppsm covering 558 mi^2 of highly variable terrain. Services included airborne LiDAR acquisition and processing, high resolution topographic product generation, survey and control services, product generation, GIS services, metadata creation, product validation, standard and non-standard USGS raster and vector products.

Sandy Supplemental NCR (VA-MD-DC) QL2 LiDAR

Tasked by USGS, Quantum Spatial is collecting and processing spring 2014, leaf off, airborne topographic LiDAR of the greater National Capital Region (NCR) covering portions of northern Virginia, Maryland and the District of Columbia totaling approximately 2,002 mi^2. This data will assist in the evaluation of storm damage resulting from Hurricane Sandy. Flight operations and coordination involved the efficient prioritization and utilization of multiple LiDAR and imagery sensor types and crew in support of USGS and NOAA NGS Shoreline Mapping and Topo Bathy Projects. Challenging acquisition constraints included low tide collection along the tidally influenced portions of the Chesapeake Bay and Potomac Rivers within the project area. Additionally, Quantum Spatial applied and obtained FAA/TSA waiver to enter and operate in the DC Flight Restricted Zone (DC FRZ) and prohibited areas P-56A or P-56B which required additional clearances from the U.S. Secret Service, U.S. Capitol Police and U.S. Park Police including the coordination and presence of a security official in the aircraft during acquisition over these prohibited areas. The LiDAR data was collected at a planned density of 2.7 ppsm.

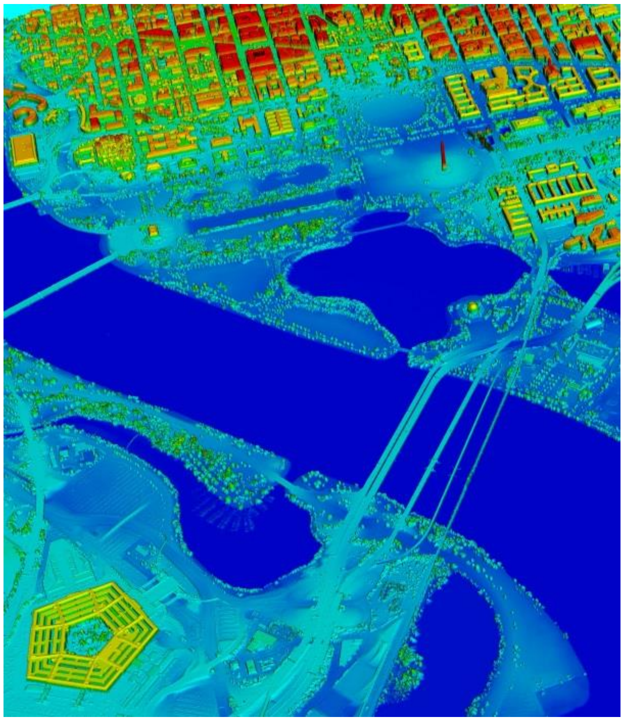


Figure 17: Shaded relief map of the Pentagon from the Sandy Supplemental NCR project.

On its own initiative, Quantum Spatial acquired LiDAR data over the District of Columbia at approximately 5 ppsm (50% sidelap) to support future derivative data development such as building extraction by stakeholders. Supplemental ground control was established to calibrate the LiDAR data. Additionally, ground control quality check points were established in selective land cover categories and used to validate the FVA, CVA and SVA accuracies of the dataset. Post processing, calibration, classification, editing, and hydro breakline development are complete. As required by USGS, Quantum's finishing process includes the modification of elevation values of selective sensitive areas to conform to security requirements. The project adhered to "U.S.

Geological Survey National Geospatial Program LiDAR Base Specification v1.0". Additionally, the project met National Enhanced Elevation Assessment (NEEA) Quality Level 2 (QL2) point density requirements of a minimum 2 ppsm and 0.7 m NPS. Deliverables included raw point cloud data, classified point cloud data, hydro flattened, bare earth DEM, supplemental and check point control data/report, intensity imagery, hydro break lines, metadata, and acquisition/project reports. **Services included: airborne LiDAR acquisition and processing, high resolution topographic product generation, survey and control, product generation, GIS services, acquisition of ancillary data, metadata creation, product validation, standard USGS raster and vector products, and emergency response, recovery, preparedness.**

South Platte River, Colorado Flood LiDAR

Quantum Spatial (as Photo Science) was tasked by USGS to acquire accurate, high resolution Light Detection and Ranging (LiDAR) data of the flood damaged areas of the South Platte watershed in Colorado covering approximately 4,616 mi^2over the highest priority damage areas. Quantum Spatial planned, mobilized and commenced acquisition on the same day that USGS issued a notice to proceed on October 24, 2013. A total of an additional 4 aircraft/crew/sensor teams were rapidly deployed in order to acquire the project area before snow fall. All but a very small section of the high mountain area was successfully collected in the fall of 2013 with that area being collected in the summer of 2014 after snow melt occurred. The LiDAR data was processed to produce a classified point cloud, bare earth elevation models and related products, necessary to support recovery efforts. FEMA as well as state and local agencies are utilizing the LiDAR data to support disaster response, recovery, long-term recovery, and other future disaster loss reduction efforts. Additionally, Quantum Spatial concurrently acquired and is processing LiDAR data and derivative terrain data products of the Denver Regional Council of Governments (DRCOG) area of interest, which totals approximately 3,600 mi^2, and added an additional 1,020 mi^2 of new area to the overall project. All LiDAR data and derivative products were produced in compliance with the USGS task order, which is based upon the "U.S. Geological Survey National Geospatial Program LiDAR Base Specification v1.0".

Specifically, Quantum Spatial planned, acquired, controlled, processed and delivered LiDAR derivative data collected at multiple nominal pulse spacing (NPS), point densities (PPSM) and NEEA quality levels (QL), and vertical accuracies (FVA) based on the priority collection areas identified by USGS and FEMA. These include:

- High Priority Mountain Reaches & Damage Areas (~205 mi^2): QL2, 0.7 m NPS, 4 ppsm, 18.5 cm FVA (1 ft contour equivalent)
- Eastern Plains Area (~3,150 mi^2): QL2, 0.7 m NPS, 2 ppsm, 18.5 cm FVA (1 ft contour equivalent)
- High Relief Mountain Region Area (~1,261 mi^2): QL3, 1-2 m NPS, 1-0.25 ppsm, 36.3 cm FVA (2 ft contour equivalent)

To support the response and recovery effort, Quantum Spatial expedited delivery of preliminary derivative terrain datasets that were used by damage assessment and mitigation teams. Services included: airborne LiDAR acquisition and processing, high resolution topographic product generation, survey and control services, product generation, GIS services, multi-temporal data, acquisition of ancillary data, metadata creation, product validation, standard USGS raster and vector products, and emergency response, recovery, preparedness. Final project deliverables include raw point cloud data, classified point cloud data, hydro flattened, bare earth DEM, supplemental and check point control data/report, intensity imagery, 1 ft and 2 ft topographic contour data, hydro break lines, metadata, and acquisition/project reports. All project deliverables will be referenced to UTM, Zone 13, NAD83, meters and NAVD88, GEOID12a, meters. The DRCOG area (~3,600 mi^2) deliverables will be based on in Colorado SPCS NAD83, feet and NAVD88, GEOID12a, feet.

Mount Rushmore, NM and Riley Pass, Custer NF LiDAR

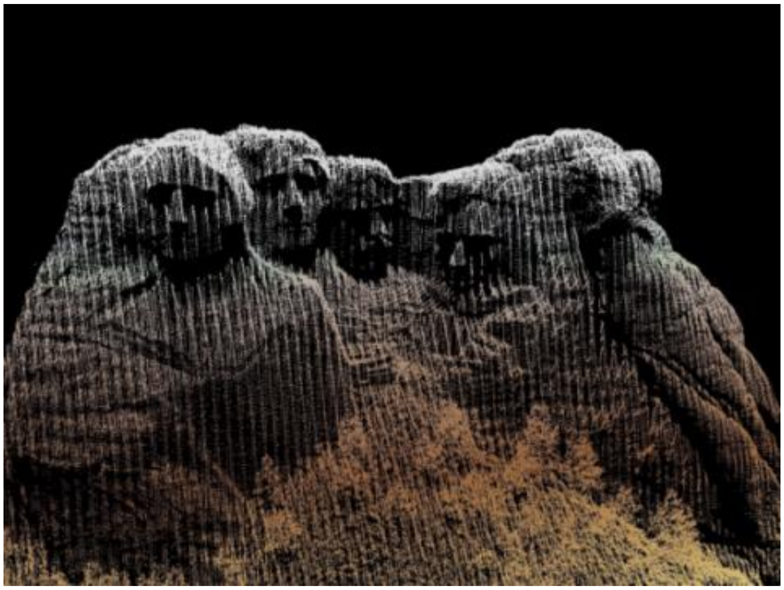


Figure 18: LiDAR point cloud of Mount Rushmore

Quantum Spatial was issued a Task Order by USGS to acquire and process a high-resolution data set of LiDAR covering approximately 32 mi^2 in South Dakota. The areas of interest included the Mount Rushmore National Monument and Riley Pass of the North Cave Hills Unit of Custer National Forest. The data was used to support analysis of disturbed lands for mining reclamation, develop hydrologic models, vegetation monitoring, and recreation planning. Using a Leica ALS70, the Riley Pass Center and Rushmore Park high density LiDAR was collected at 0.5 meter NPS (4 ppsm) while the Rushmore Monument was collected at 0.35 meter NPS (7.52 ppsm) per swath but with 70% planned side lap a final density of **15 ppsm** was achieved. Multiple spatial reference systems were established and used in the development process: Custer NF was based in Geographic Coordinate System, NAD83, NAVD88, GEIOD09, meters, Mount Rushmore NM/Park was based on UTM Zone 13 North, NAD83 NAVD88, GEIOD09, meters. **Services included airborne LiDAR acquisition and processing, high-resolution topographic product generation, survey and control services, GIS services.**

Glacier Peak WA QL1 LiDAR (8 ppsm [ANPD])

Figure 19: Photo taken by field crew at Glacier Peak, which highlights the elevation challenge that Quantum Spatial encountered to acquire LiDAR data.

USGS tasked Quantum Spatial to collect and process high-resolution LiDAR of a 475 square mile area encompassing Glacier Peak Volcano, part of the Cascade Mountains approximately 60 miles north east of Seattle, WA, at a point density of **8 ppsm** and a Nominal Post Spacing (NPS) of 0.35 meter. The high density LiDAR data being collected and processed by Quantum Spatial will help researchers examine past eruptions, prepare for future volcanic activity and determine the best locations for installing real-time monitoring systems. Base Stationing and supplemental and QA ground control is being established by Quantum Spatial. Services include **airborne LiDAR acquisition and processing, high-resolution topographic product generation, survey and control services, and GIS services.** Overall project deliverables will include raw point cloud data, classified point cloud data, hydro-flattened, bare earth DEM, supplemental and check point control data/report, intensity imagery, metadata, and acquisition/project reports.

State of Kentucky LiDAR & Digital Orthoimagery Program

Client
Kentucky Commonwealth Office of Technology

Client Contact
Thomas Rossman
(502) 564-6412
thomas.rossman@ky.gov

Project Size
15,390 mi^2 of LiDAR imagery plus 12,121 mi^2 of imagery

Dates of Service
2011-Present

Value
$4,218,065

DELIVERABLES:
- Delivered a raster DEM, classified LAS v1.2 point cloud and intensity imagery

As a Prime Contractor, Quantum Spatial (as Photo Science) has been tasked by the Kentucky Commonwealth Office of Technology to provide a common statewide digital orthophoto basemap, including current color leaf-off aerial photography and elevation data (LiDAR) for the entire state of Kentucky. The project includes higher resolution and base resolution sub area, supported by stakeholder funding. Program deliverables include, but are not limited to: leaf-off, 4-band digital orthophotos at 1 ft and 6 inch resolutions, along with LiDAR digital elevation products and planimetric mapping.

In 2012, Quantum Spatial collected a total of 3,784 mi^2 of LiDAR data utilizing both Optech and Leica sensors to deliver a raster DEM, classified LAS v1.2 point cloud, and intensity images. The dataset was acquired and delivered to meet USGS specifications, 1 point per square meter and 15 centimeters RMSEz. Additionally, a total of 5,785 mi^2 of 12 inch GSD imagery and 973 mi^2 6 inch GSD imagery were collected, processed, and delivered.

Tasking Highlights					
Year	LiDAR	3 inch Orthoimagery	6 inch Orthoimagery	12 inch Orthoimagery	Planimetrics
2012	3,784 mi^2		973 mi^2	5,785 mi^2	
2013	3,270 mi^2		323 mi^2	2,637 mi^2	323 mi^2
2014	6,691 mi^2		119 mi^2	1,951 mi^2	
2015	1,645 mi^2	1.82 mi^2	8.83 mi^2		

In 2013, Quantum Spatial collected 3,270 mi^2 of LiDAR; 2,637 mi^2 of 12 inch GSD orthoimagery; and 323 $mi^2$6 inch GSD orthoimagery. Additionally, Quantum Spatial performed 323 $mi^2$of planimetric mapping for Paducah/McCracken County KY, at 1″=100′ scale. This was an update of original mapping completed in 2007, but also contained areas of new mapping. In 2014, Quantum Spatial collected 6,691 mi^2 of LiDAR; 1,951 mi^2 of 12 inch GSD orthoimagery; and 119 mi^2 of 6 inch orthoimagery. In 2015, Quantum Spatial collected 1,645 mi^2 of LiDAR; 1.82 mi^2 of 3 inch orthoimgery, and 8.83 mi^2 of 6 inch orthoimagery. Processing is still underway for most of the 2015 products.

> **Client Performance Rating:** *"Photo Science has proven to be very professional and detailed oriented. Their cooperative approach, ability to meet deadlines and flexibility has made them easy to work with during all phases…Our experience of interacting with Photo Science has been extremely positive and their performance has been outstanding,"*
>
> **-Tom Rossman, Director**

All mapping products are delivered in Kentucky Single Zone State Plane coordinates NAD83 and NAVD88 vertical datum. Quantum Spatial is providing independent certification of the 12 inch and 6 inch GSD ortho imagery product accuracies to ASPRS Class 1 Accuracy Standards for 1″=100′ and 1″=200′ scale mapping, respective. Images are being submitted in uncompressed, untiled, ArcGIS readable, GeoTIFF file format. FGDC-compliant metadata is being provided in extensible markup language (xml) format for each orthorectified tile. A FGDC-compliant project-level metadata (SML format) is also being provided.

As part of this project, Quantum Spatial is also collecting ground control to be used to supplement the Airborne GPS positional adjustment and support the LiDAR calibration process and imagery orthorectification process. In addition to the ground control, Quantum Spatial is collecting 100 QA points in the five major land cover classes for every 500 mi^2 of data collected. LiDAR accuracies have varied between 8 centimeters and <15 centimeters RMSEz for all data sets.

Quantum Spatial's cloud-based ortho QA tool, VOICE, has been customized and deployed to support collaborative QA review of the ortho imagery across the state and local agencies. To date, a total of 11,000 ortho image tiles have been delivered to the State at a first time acceptance rate of 97%. Additionally, Quantum Spatial's FOCUS application is being utilized as a LiDAR quality "self-certification" tool.

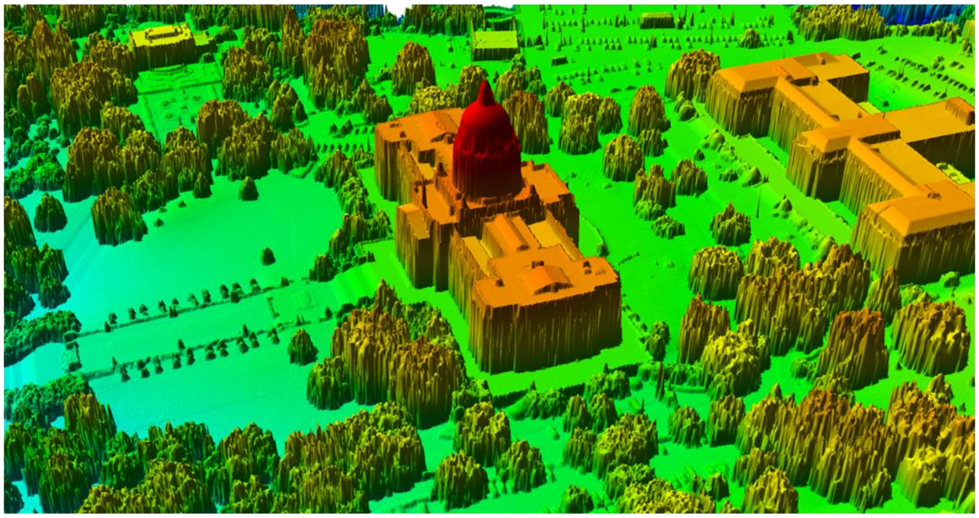


Figure 20: Shaded relief of the capitol of Kentucky in Frankfort.

Oregon LiDAR Consortium

Client
Oregon Department of Geology & Minerals Industry

Client Contact
Ian Madin
(971) 673-1555
ian.madin@dogami.state.or.us

Project Size
7,326.85 mi^2

Dates of Service
2010-Present

Value
$8,700,000

DELIVERABLES:

- Bare Earth and Highest Hit 1m (3ft) Digital Elevation Models tiled by USSG 7.5 minute Quad
- LiDAR Intensity 0.5 meter (1.5ft) GeoTiffs tiled by USSG 7.5 minute Quad
- Classified LiDAR point cloud in .las format (las version 1.2/1.4 available) tiled by USGS 1/100th quad
- shapefiles of las and product indices, flightlines, ground rtk, and survey monuments
- FGDC and/or USGS metadata
- Report with collection parameters, processing methods, and accuracy results

Quantum Spatial (as Watershed Sciences) has been the sole contractor to the Oregon Department of Geology and Mineral Industries (DOGAMI), the primary stakeholder of the Oregon LiDAR Consortium (OLC), since 2007, selected through a national competitive process. The OLC is a consortium of federal, state, and local government agencies who collaborate to fund large-area data collection at bulk rates. All projects contracted for OLC adhere to industry requirements and standard data products (e.g., classified point cloud and ground points (.LAS), bare-earth and first-return DEMs, intensity images, aircraft trajectories, pulse density maps, and reports & metadata), and all data is publicly available through USGS.

To date, Quantum Spatial has completed projects covering over eighteen million acres. In the past three years, Quantum Spatial received more than $8.7 million in task order awards, under the OLC contract. We have consistently met or exceeded client expectations and have never failed a final data inspection. Services provided on this project include data acquisition, calibration, ground modeling, processing, product creation, ground surveys and oversight, and data reporting.

Quantum Spatial was instrumental in developing the official technical acquisition and product specifications for the OLC, of which federal and state agencies now use extensively across the western U.S. – an industry standard. The U.S. Forest Service (USFS) and Bureau of Reclamation (USBR), for instance, have adopted these high-density (high-resolution) LiDAR specifications as standards across their respective agencies. Example high resolution LiDAR and orthophotography tasking under this project include:

- Washington, Multnomah, and Clackamas County, OR – approximately 100,000 acres
- Lincoln and Spokane Counties, OR – approximately 180,000 acres

The LiDAR was flown between 900 and 1500 meters above ground level (AGL) and captured at a scan angle of ±30 degrees from nadir. These settings were developed to yield points with an average native density of greater than 8 ppsm over terrestrial surfaces. We also collected 4-band

(RGB & NIR) orthoimagery with a native pixel size (ground sample distance) of 3 inches. 1,347 Ground Control Points were collected. The standard deliverables outlined above were provided to the OLC. Services provided included Airborne Acquisition (Topo LiDAR & Digital Multispectral Imagery), High-resolution Topographic Product Generation, Photogrammetric Mapping and Orthophotography Production, Survey & Control Services, and GIS Services.

Example high resolution LiDAR tasking under this project include:

- Clackamas and Marion Counties, OR (including the Clackamas River, Timothy Lake, and Silver Creek Reservoir) -- approximately 450,000 acres.
- Crook, Wheeler, and Jefferson Counties, OR (including Ochoco National Forest) -- approximately 300,000 acres
- Southwestern Oregon -- approximately 1.3 million acres

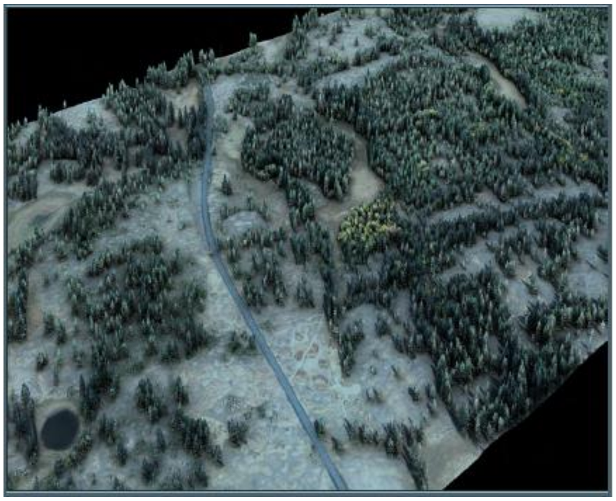


Figure 21: LiDAR point cloud of South Badger Road with RGB extraction

LiDAR was flown between 900 and 1500 meters above ground level (AGL), captured a scan angle of ±30 degrees from nadir yielding an average density of >8 ppsm. The study area was surveyed with opposing flight line sidelap of greater than 60% with at least 100% total overlap to reduce laser shadowing and increase surface laser painting. 6,708 Ground Control Points were collected for these projects. The standard deliverables outlined above were provided to the OLC. Services provided included Airborne Acquisition (Topo LiDAR), High-resolution Topographic Product Generation, Survey & Control Services, and GIS Services.

Overall tasking highlights are listed in the table below.

Task Order Name	Year	Fee
3DEP Umpqua LiDAR	2015	$1,004,049
Snake River LiDAR - FEMA	2015	$350,126
4 Rivers Eastside Restoration	2014	$396,720
Portland Metro LiDAR and Imagery	2014	$756,410
Lane County 1 & 2	2013	$984,473
Alaska LiDAR - FEMA	2013	$134,080
ClackaMol LiDAR	2013	$309,844
3DEP Umpqua LiDAR	2015	$1,004,049

State of North Carolina LiDAR Program

Client
State of North Carolina

Client Contact
Hope Morgan
State of North Carolina
(919) 715-5711
Hope.Morgan@ncdps.gov

Project Size
16,346 mi^2

Dates of Service
2014 - Present

Value
$3,206,355

DELIVERABLES:

- Raw Point Cloud
- Classified Point Cloud
- Hydro-Breaklines
- Bare Earth DEM
- Intensity Imagery
- FGDC Compliant Metadata
- Project Reports

In the spring of 2014 Quantum Spatial (as Photo Science) coordinated and collaborated with the State of North Carolina Emergency Management's (NCEM) Statewide Topographic Data Acquisition Program to collect and process 20 coastal North Carolina counties. This Phase 1 project was done in partnership and with funding from USGS. The LiDAR data was collected to assist in evaluation of storm damage and erosion of coastal systems from Hurricane Sandy.

As Phase I of the State of North Carolina collection Quantum Spatial acquired a total of 9,396 mi^2 of Quality Level 2 (QL2) LiDAR data. Data was collected at 0.69 m nominal post spacing (2.09 ppsm) and accurate to 9.25 cm RMSEz in open terrain. The project adhered to USGS LiDAR Base Specifications v1.0 and met National Enhanced Elevation Assessment (NEEA) QL2 requirements.

Figure 22: Phase 1 LiDAR collection

Quantum Spatial provided supplemental ground control for LiDAR calibration as well as QA/QC checkpoints to validate the FVA, CVA, and SVA data accuracies. LiDAR post processing and data classification included the integration of NOAA Hurricane Topographic/Bathymetric Airborne LiDAR data that was collected and processed by Quantum Spatial along the entire coastline of NC. Additionally, survey control data and calibrated LiDAR data falling along the USGS and NC Phase 2 project areas were exchanged and used to ensure a seamless transition between the data sets.

In 2015, Quantum Spatial was tasked to collect an additional 13 counties for the State. This was for Phase 3 of the statewide LiDAR which comprised of approximately 6,950 mi^2 of additional data collection. As with Phase 1, LiDAR data was collected at QL2 specifications. Data collection began in January 10, 2015 and continued through March 22, 2015.

For Phase 3 additional road and bridge classification work using breaklines is being completed and provided in the classified point cloud data. Additional deliverables include raw point clouds, intensity images, hydro-flattened breaklines, as well as ll standard reports and FGDC compliant metadata. Five incremental data deliveries were set up for the State, as of present 4 of the 5 deliveries have been provided. All products were delivered in North Carolina State Plane coordinates NAD83 and NAVD88 vertical datum.

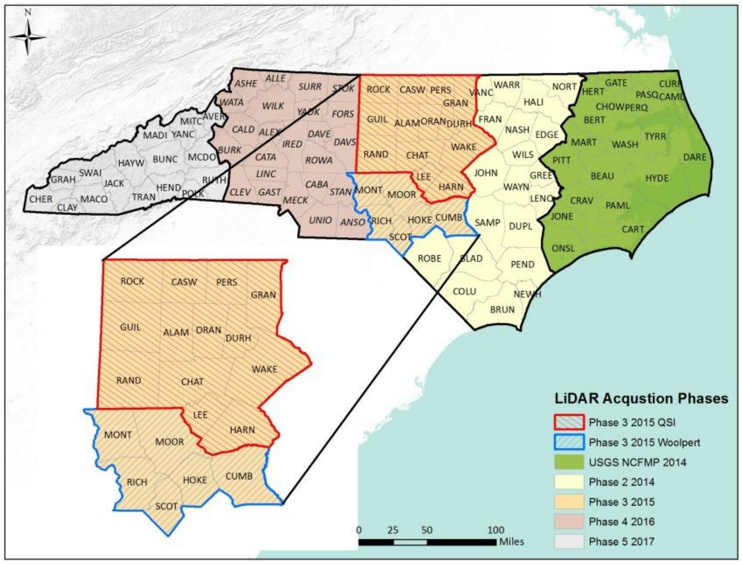


Figure 23: The Phase 3 collection area for 2015

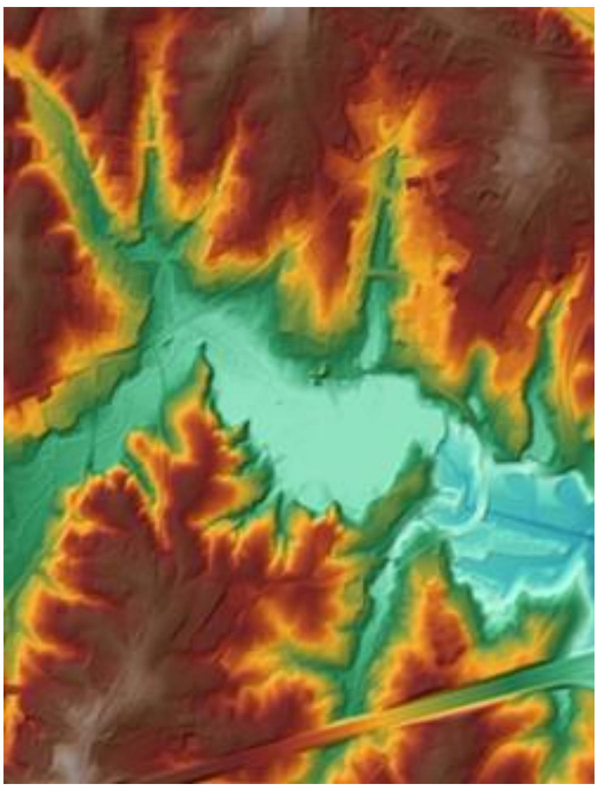


Figure 24: Hydro-flattened breakline

Client Performance Rating: *"North Carolina is in year 2 of a 4 year multi-phase statewide LiDAR collection. Quantum Spatial has been an integral part of this project either as a direct or coordinating partner. Quantum has been on time and on budget. More importantly, they have been willing to work with our state on direct needs, adjustments, and cooperation among many differing deliverable requirements. Their service, input and partnership is greatly appreciated."*

-Hope Morgan – GIS Manager

Wide Area Mapping Geiger Mode LiDAR Operations

Client
National Geospatial Intelligence Agency (NGA)

Client Contact
Cheryl Archibald
(314) 676-0343

Robert Thompson
(571) 557-8191

Project Size
Worldwide

Dates of Service
2010-Present

Value (Total Contract)
$132,000,000

DELIVERABLES:

- 1m and 30cm LiDAR datasets

Geiger Mode LiDAR technology is the future cost-saver for nationwide 3DEP implementation, and Harris is at the forefront of this technology. Since 2010, Harris has been integrating, managing, and performing all data processing, and collecting wide-area mapping 3D LiDAR with Geiger Mode technology, which enables high- area collection rates at high resolution.

Harris is a prime contractor and integrator for a Geiger Mode LiDAR wide area mapping collection and processing capability. http://www.govcomm.harris.com/geoint/images/LiDAR1.jpg. Recent innovations in LiDAR processing and sensors, including the processing of Geiger Mode LiDAR, have enabled collection of very large areas from high altitudes at low power. Harris delivered a large area of 1 m and 30 cm LiDAR datasets while jointly developing new standards for automated data quality and accuracy, which are required due to the high volume rate of data collected.

As the leader in fully integrating the life cycle of collection, automated forward-deployed processing of point targets and specialty products, factory processing of high-volume, large-area mapping data; and dissemination of the high-resolution reflective surface, bare earth, intensity image data and associated quality layer masks. Products derived from the LiDAR data, including point clouds, intensity images, and DEM's are then disseminated to various Harris and other community repositories and dissemination systems. Harris has processed a large area of 1 m and sub 1m LiDAR data in forward-deployed areas since 2010.

Figure 25: Harris collects, processes, and disseminates Geiger Mode LIDAR for wide area mapping for DOD. Harris can now also do wide-area Geiger Mode LiDAR collection and processing for nationwide implementation of the 3DEP.

Early on in the effort to support the SOUTHCOM Haiti earthquake response, named Operation UNIFIED RESPONSE (OUR), LiDAR data imagery was collected over Haiti to address many specific relief and recovery objectives. Within 24 hours of being tasked, the team set up a regional processing center in Miami and began collection operations. Forty-seven sorties were flown over a 25-day period.

Harris has developed a fully automated, high-volume Geiger Mode LiDAR production environment. This system runs on GRID-based cloud processing and takes the data from raw off-the-sensor through the entire processing flow including bare earth and automated QC – automatically supporting 1000s of km^2 of data in a matter of hours. Due to process improvements and consistent quality deliveries, the customer has transitioned from 100% data checks to periodic, spot checks, achieving a very high data acceptance rate.

Scope of Work Includes

- Setup and support of full operations
- Collection and mission planning
- Product format, accuracy, and quality standards definition
- Processing software integration, automation, and deployment
- Integration of a deployable, in-theater processing, exploitation, and dissemination environment
- In-theater production and exploitation operations
- US based operations for processing and wide area map production

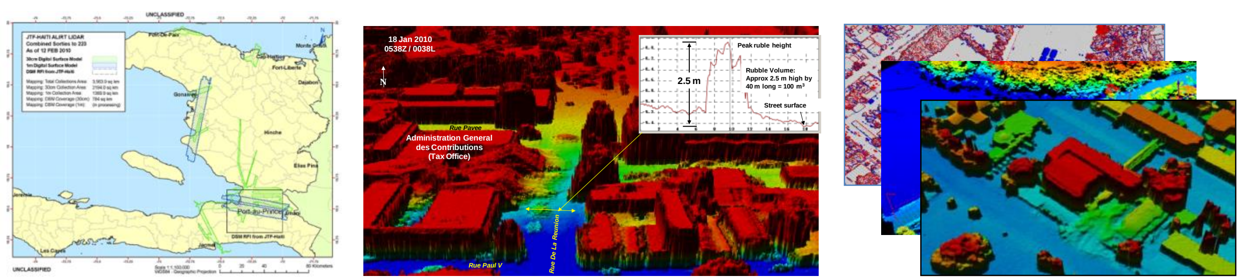


Figure 26: Harris collects, processes, and disseminates Geiger Mode LIDAR for DOD/DHS crisis situations.

LiDAR to Map Buildings for Sea-level Rise Scenarios

Client
Lincoln County Regional Planning Commission (LCRPC)

Client Contact
Robert Faunce
(207) 784-2617
rfaunce@megalink.net

Project Size
~10,000 acres

Dates of Service
2012-2013

DELIVERABLES:

- LiDAR derived building polygons

To study how public infrastructure may be affected by potential changes in rising sea levels during the next 100 years. By analyzing storm surge scenarios of 2 ft, 1 m, 6 ft, and 2 ft plus the February 1978 storm of record using state-acquired LiDAR topographic data to develop an accurately mapped highest annual tide (HAT), the LCRPC will study changes in the HAT based on the four sea-level rise scenarios. The analysis helps identify potential impacts on coastal wetlands; state, local and private roads; culverts; and coastal buildings and facilities, such as a sewage treatment plant.

KAPPA used its direct, immediate access to publicly available Northeast (NE) LiDAR data and produced criteria-based, building polygons mapped to locations in Lincoln County communities. KAPPA verified the data against the NAIP 2011 imagery, Google Earth imagery, and the NE LiDAR data itself. The LCRPC shared this accurate, relevant map data with scientists from the Maine Geological Survey, who developed the inundation studies.

Lincoln County's communities can develop sound strategies and adaptation planning to help mitigate the effects of rising sea levels on natural systems, public infrastructure and facilities in enclosed areas, as well as the open coast. The results of the study can help the LCRPC plan appropriately for existing and future development, including hazard planning for at-risk areas.

Figure 27: Building polygons

Multiple Mobile Mapping Projects in New York

Client
New York Department of Transportation

Client Contact
Lori Gallagher
(518) 457-5290
lori.gallagher@dot.ny.gov

Project Size
31 miles

Dates of Service
2013-2014

Value
$46,660

DELIVERABLES:

- Fully Classified LAS v1.2 Files
- DEM (DGN Format) 3FT Grid Spacing
- Calibrated Mobile Images along with Image Viewer
- Horizontal Control Report
- Vertical Control Report
- Survey Report

Quantum Spatial under two separate contracts for the New York State Department of Transportation was contracted to provide mobile mapping services for two separate projects in Steuben County, New York totaling approximately 31 miles.

The first contract was to provide Mobile Mapping acquisition and processing along approximate 11.4 miles of Route I-86/17 and a portion of Route I-390, in the Kanona. Additionally Quantum Spatial was to complete mobile mapping on 9.1 miles of Route I-390 in Cohocton, Steuben County, New York.

The second contract was issued to complete Mobile LiDAR collection and processing along approximately 10 miles of Route 86 in the City of Corning, Steuben County. Quantum Spatial was instructed to complete the collection with a need to minimize obstruction to traffic and collection had to be performed at highway speeds.

A plan was developed to complete the LiDAR acquisition when the GNSS had a PDOP of 5 or less using a minimum of 5 satellites during data collection.

All control was picked by Quantum Spatial, but the State of New York provided the field survey control and QC checks. Additional control points were established to allow Quantum Spatial to maintain a ground based GPS receiver during the actual collection mission.

Figure 28: LiDAR Point cloud

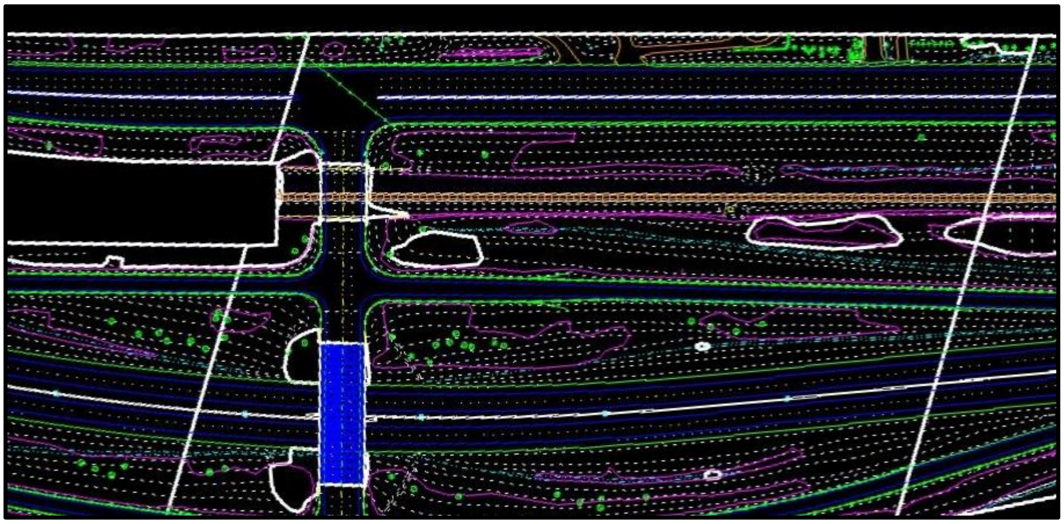


Figure 29: Planimetrics developed for the project.

At the completion of the project the New York State Department of Transportation completed a quality control check of all data submitted. On hard surfaces the data was tested to meeting a vertical accuracy of 0.065-feet at 95% confidence level and 0.089-feet horizontal at 95% confidence level. The average point density was 175 points per square foot. These results were the result of checking a total of 139 ground surface points.

All bridge structures were collected (over and under) to account for bridge clearances. All LAS files to be delivered were in version 1.2 and all geo-referenced images were delivered along with a proprietary image viewer software

Prior to beginning this mobile mapping effort, the Quantum Spatial staff completed a mission planning phase internally. A detailed project scope, including deliverables and project intent was reviewed by both the in-house processing staff as well as the acquisition crew. It was imperative that a clear and concise understanding of the scope and deliverables was paramount to meeting the client’s expectations.

Multiple Mobile Mapping Projects in Pennsylvania

Client
Pennsylvania Department of Transportation

Client Contact
Michael Loose, CP
(717) 783-9693
mloose@pa.gov

Project Size
63 miles

Dates of Service
2013-2014

Value
$183,244

DELIVERABLES:
- Fully Classified LAS v1.2 Files
- DEM (DGN Format) 3FT Grid Spacing
- Calibrated Mobile Images along with Image Viewer
- Horizontal Control Report
- Vertical Control Report
- Survey Report

Quantum Spatial is currently under an on-call contract for the Pennsylvania Department of Transportation has been contracted to provide mobile mapping services for five separate projects totaling approximately 63 miles.

Projects included two separate projects of 7 mile sections of Interstate 84; a five mile section of Interstate 99 and an 18 mile segment of Interstate 90. These three projects consisted of acquiring mobile LiDAR datasets that when post processed, met the specification of 0.07-foot vertical and 0.20-feet horizontally. At the completion of the post processing, DTM was developed and a contour file was prepared with 1-foot contours.

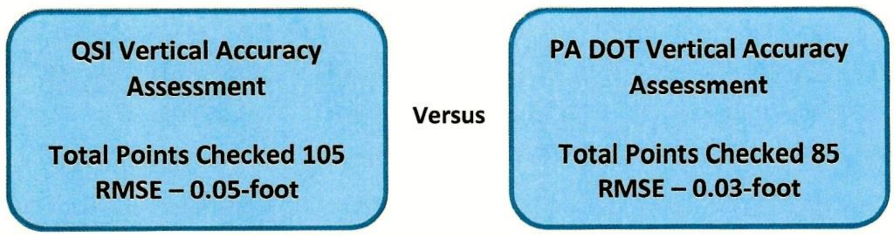
A fifth project was complete along a 27 mile segment of Interstate Route 80. This project was for planning purposes only and was not to be utilized for design. Due to this, a very limited amount of control was established (37 points). The specification stated a vertical accuracy of 0.25 ft was required.

These projects were all 4-lane roadways, and located in both rural and urban settings. In most cases, the cross streets were to be included in the collection and processing and bridge clearances for all overpasses were required.

For these projects, Quantum Spatial made the determination that a minimum of six satellites in view for the GNSS control stations as well as the GNSS unit in the mobile mapping vehicle and the PDOP value during acquisition should not exceed 4.0. A final SBET (Smoothed Best Estimate of Trajectory) was developed utilizing Optech DASHmap software.

Figure 30: Pavement analysis pot holes joint failure

The raw data (Range) were processed into LAS files for both the bore sight and mission using TerraScan, TerraModeler software, and proprietary Quantum Spatial filtering routines. The TerraScan software reads raw laser points as X, Y, Z text files or binary files, and provides automated and semi-automated tools used to calibrate, check, and correct the data for systematic errors.



Note: PA DOT Check Points Independent of QSI Points

All data was manually reviewed and the remaining artifacts were removed. QT Modeler was used as a final check of the bare earth dataset. The final step was to create the deliverable LAS files for the point cloud data, finalize the bare earth model, DEM files, DTM and contour files and create NSSDA accuracy assessment and reports.

The Pennsylvania Department of Transportation did an independent check of the deliverable DEM and contour files. The results shown above are a comparison of our quality control checks versus the state's totally independent check.

Tree Farms Inventory Project

Client
Port Blakely

Client Contact
Chris Lacy
(360) 596-9443
clacy@portblakely.com

Project Size
121 acres

Dates of Service
2013-2014

DELIVERABLES:

- Updated Esri geodatabase containing
- Attributed treetop points with original metrics and estimated values
- Attributed tree polygons with original metrics and estimated values
- Plot locations with field summary and estimated values

Quantum Spatial conducted a LiDAR and imagery collection for Port Blakely Tree Farms in July 2013, located in Washington State. The project classified ground-level features, created the ground model, then classified vegetation points above eight feet using the LiDAR data.

Using automated techniques individual units of vegetation were delineated. These automated techniques utilized unique point geometry of vegetation to segment the individual units of vegetation and create crown polygons representing them.

Tree height metrics were summarized for treetop points using automated measuring procedures based on an 11.35 meter search radius. The trees were then stratified based upon metrics of interest. Stratification typically involved general grouping using a specified tree height metric which was further refined through additional metrics such as canopy cover or relative height ratio.

The best fit relationships between the field inventory and LiDAR data sets was found utilizing R. Regression models were generated for forest structure attributes and are shown below with their respective r^2:

- Total Height (r2 = 0.89)
- Gross Board Feet Acre (r2 = 0.91)
- Basal Area Acre (r2 = 0.78)
- Trees Acre (r2 = 0.70)
- Quadratic Mean Diameter (r2 = 0.84)
- Height to Live Crown. (r2 = 0.90)
- Modeling Parameter R2 Mean

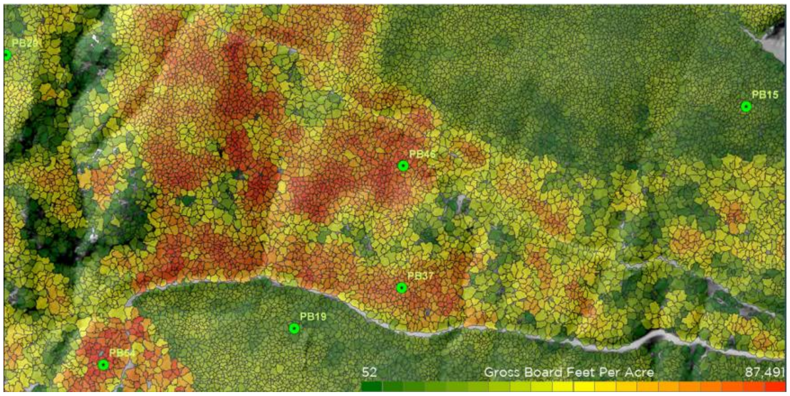


Figure 31: Segmented trees with estimated board feet per acre attributes

Osborne Preserve LiDAR Survey

Client
Sonoma State University

Client Contact
Dr. Claudia Luke
(707) 664-3416
lukec@sonoma.edu

Project Size
403.5 mi^2

Dates of Service
2013-2014

Value
$34,744

DELIVERABLES:

- 1 foot contours
- Geomorphic landform shapes
- Updated vegetation polygons
- Updated tree top points
- Field plot data
- 0.25 meter bare earth DEMs
- 0.25 meter resolution vegetation height DEMs
- 3 inch orthoimagery
- 3 meter point grid attributed with LiDAR derived metrics
- All biomass raster
- Living biomass raster
- Dead biomass raster

Quantum Spatial completed collection of LiDAR data for the SSU Osborn Preserve study area in April, 2013. The data were processed into 0.25 m rasters (bare earth and vegetation height DEMs), one-foot contours, vegetation polygons and tree top points, geomorphic landform shapes, and 3 inches orthoimagery was also collected.

Datasets of individual tree locations were created by analyzing point cloud geometry and spatial distribution patterns. Forest metrics relating to tree height, canopy height, canopy cover, stem density, and crown area were generated directly from the LiDAR point cloud and derived tree top locations, resulting in precise calculations of horizontal and vertical point distributions.

The general workflow for vegetation segmentation was as follows:

- Classify ground-level features and create the ground model.
- Classify vegetation points above five feet.
- Identify individual units of vegetation using automated techniques. These automated techniques utilize the unique geometry of classified point cloud data to segment and identify the location and heights of individual tree tops.
- Calculate LiDAR and tree height metrics for each point in the 3 meter by 3 meter grid based on a 11.35 meter search radius.

R Studio was used to generate predictive models based on the field data provided by the client. Scatter plots were explored to determine the correlation between each observed and predictor variable. Ten-fold cross validation was performed to reveal relationships which produced the smallest residual standard error. These models were subjected to backward and forward stepwise elimination, yielding a second set of significant predictor variables for each model.

Models predicted living, dead and total biomass with living and total biomass predictions being better correlated than dead biomass.

Figure 32: Map of tree top points (left) and vegetation and tree top polygons (right) overlying 3 inch orthophotos within the SSU Osborn Preserve Study Area.

Stevens Islands Digital Orthophotography & Cover Typing Services

Client
Seven Islands Land Company

Client Contact
Ian Prior
(207)947-0541
iprior@sevenislands.com

Project Size
840,000 acres

Dates of Service
2011-2012

DELIVERABLES:

- 4-band digital imagery in GeoTIFF and MrSID formats.

Aerial

Seven Islands Land Company requested 4-Band aerial image acquisition of approximately 840,000 acres of forest land in the state of Maine. Image capture was requested to occur during full leaf conditions in the early summer of 2012. All lands were flown at 28 cm GSD to achieve the final product of 0.3 meter pixel resolution digital orthomosaics.

Ortho-Mosaic

Orthoimagery was processed using a 10 meter elevation model acquired from USGS. All imagery was visually inspected and any flaws outside the scope of the contract were corrected. Sewall delivered 4-Band GeoTIFF tiles and 3 Band RGB and IR imagery in MG3 MrSid format.

Cover-Typing

Forest cover types were interpreted as to compositions, size, and density using the cover-typing conventions provided by Seven Islands Land Company. To assist with this process, Sewall employed its proprietary CanopyData™ product, an analysis process designed to progressively summarize complex "point cloud" datasets into raster images and vector attribute data that can be used for forest management. "Point Cloud" data provides height information; thus, the derivative products focus on the height of the forest and the spatial variation of those heights. Deliverables were easily integrated with existing base and covertype mapping, inventory systems, and GIS.

The solution improved stratification and added biologically meaningful data to stand mapping and stratification, improving inventory control and forecasting. It also provided within-stand height/closure data for sub-stand prescriptions and harvest allocations.

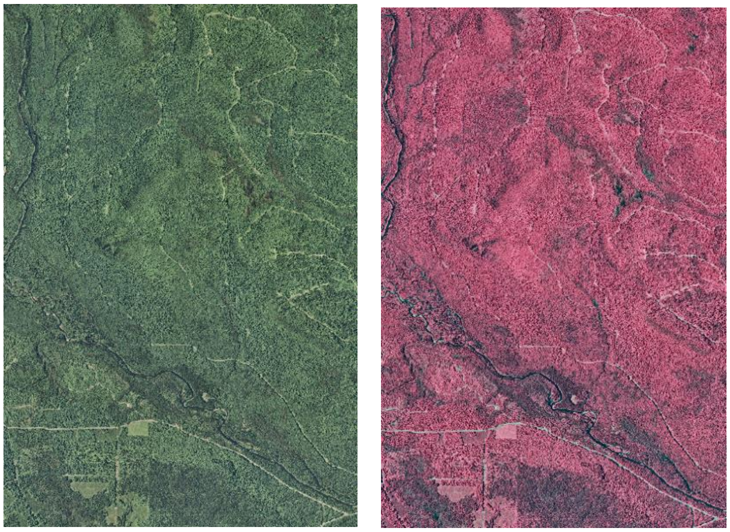


Figure 33: 4-band imagery

2. PROPOSED SERVICES

2.1. Services to be Provided

Overview

The Quantum Spatial Team offers the following proposed solution for the 2016 State of Maine Western LiDAR Project. Our solution includes an integrated technological, management, production, and quality assurance approach built upon our extensive USGS and statewide LiDAR program experience. Key elements of our solution include:

- State of the art technology options to provide the state with options for high density wide area collection at rapid data acquisition rates and cost efficiencies.
- Local survey team members who bring knowledge and experience of working in the State of Maine.
- Project managers who are highly experienced and ASPRS Certified Photogrammetrists employing innovative and cost effect methodologies
- Utilization of a LiDAR workflow methodology that is reliable, efficient, and integrated with advanced airborne and ground-based positioning technology.
- Methodology and solution planning to ensure all stakeholders have necessary information needed for informed technology selections.
- Access to an industry-leading data processing and data storage capacity facility
- Streamlined quality assurance inspection and testing regimen anchored by a robust reporting tool FOCUS and our web-enabled application, VOICE, to facilitate and manage the stakeholder review process
- Buy up options for higher LiDAR density (QL1 and 20 ppsm)
- Methodology and buy up options for forestry analytics and mobile mapping offerings

All of these elements will be managed and executed by our highly experienced, and accredited, project team.

Team Methods and Resources

Quantum Spatial is constantly exploring and working with emerging LiDAR technologies and evaluating how to incorporate these into our innovation toolkit. We stay current with industry developments and are active collaborators within the LiDAR research community, allowing us to review how we can best contribute to technological solutions for tomorrow’s public data needs. Quantum Spatial is presenting a work plan to the State of Maine utilizing two different state of the art technologies; Emerging Geiger-mode LiDAR and Linear-mode LiDAR. We are excited about the opportunity to discuss both technologies with the State and work in collaboration to select the solution(s) that best meet its needs. Both technologies are summarized below and discussed in detail throughout Section 2.1.

Our team provides the most up-to-date LiDAR technology using the Harris Geiger-mode LiDAR sensor. This sensor collects extremely large areas of LiDAR at incredibly fast collection rates. Standard collection is approximately 10 times faster than traditional linear LiDAR sensors. This sensor acquires data from 2 to greater than 20 ppsm at collection rates greater than 1000 km^2 hour. Other benefits of the Geiger system include penetrating foliage to map the underlying ground and structures, as well as detecting utility wires and other fine features of critical importance for city / infrastructure planning, utility management, forestry analytics, disaster management, transportation, water resource management, and many more. Geiger-mode LiDAR has been in use within the U.S. Government for the past 15 years and has just transitioned to the public sector. The Quantum Team is excited to bring this technology option to the State of Maine. The Geiger system provides a scalable product and can provide very dense data, which proves valuable for dense forestry applications.

Quantum Spatial is also offering traditional Linear – mode LiDAR technology to the State of Maine. The Leica ALS70 and 80 are top of the line linear sensors that are proven for wide area collections and approved for use by USGS. Leica sensors have been in use in the public market for over 15 years and have become more powerful and efficient in most recent years. The Leica ALS80 sensors are the newest linear mode LiDAR sensors out in the market. Currently there are four ALS80 systems in the United States and Quantum owns and operates three of these sensors. These sensors provide increased data collection by flying at higher altitudes and providing greater point densities at the surface. This helps increase capture rates while providing cost efficiencies to the State.

In conjunction with data collection our survey team which includes local teammates, Sewall and SSG, will collect ground control in the Western project area for LiDAR calibration and USGS checkpoints for data verification. LiDAR data will be collected with the Geiger-mode LiDAR sensor or optional traditional Linear – mode ALS-70/80 LiDAR sensors. Once the data has been acquired and pre-processed through calibration the data will move into our streamlined production workflow. This is where the LiDAR data is classified, hydro-breaklines are generated, and data products and reports are generated. QA/QC is inherent in all steps of the process. We utilize our FOCUS (Final Observed and Calculated User Statistics) reporting tool that reports on USGS specific requirements and LAS header and point information.

All LiDAR acquired and processed by the Quantum Spatial Team will be done in full compliance with U.S. Geological Survey National Geospatial Program Base LiDAR Specification, Version 1.2 and would involve a minimal collection area of 1000 mi^2 per year for up to 5 years. As a USGS GPSC contractor, Quantum Spatial fully understands and routinely delivers USGS compliant LiDAR datasets with QL2 specifications.

The table below provides information on each of our team members and their specific role in the State of Maine’s LiDAR project. Each team member was specifically chosen due to their knowledge and experience working in Maine as well as experience collecting and processing LiDAR data. Quantum has familiarity working with each team member on many projects in the past and a proven track record of successful projects. Together we have over 60 years LiDAR experience and look forward to sharing our experience with the State of Maine.

Team Member	Contract Management	QA/QC	LiDAR Acquisition (Linear & Geiger)	LiDAR Processing (Linear & Geiger)	Bare Earth Editing and Hydro Breklines	Mobile Mapping	Forestry Analytics	Ground Control
Quantum Spatial - Prime	✓	✓	✓	✓	✓	✓	✓	✓
James W. Sewall		✓		✓	✓	✓	✓	✓
Kappa Mapping		✓			✓	✓		
Shyka, Sheppard & Garster (SSG)		✓						✓
Precision Aerial Reconnaissance (PAR)		✓	✓					
Harris Corporation		✓	✓	✓				
University of Maine Cooperative Forestry Research Unit (CFRU)		✓					✓	
Mira Solutions, Inc.		✓			✓			

Figure 34: Quantum Spatial Team roles and responsibilities

Uniform Collection

Utilizing the two leading data capture technologies, Quantum Spatial's approach has the State and their stakeholder's best interest taken into account. Both options will provide the leading LiDAR technology to provide quick capture for uniform vegetation conditions.

Geiger mode LiDAR provides cost-effective, high-density data collection. For QL2 data the sensor acquires approximately 850 mi^2/hour at an altitude of 27,000 ft AGL. By utilizing this sensor, the State of Maine can have the 7,647 mi^2 Western project area collected in approximately 15 days, taking weather into consideration for down days. The Quantum Team will provide one Geiger sensor for this approach. Harris will have a second sensor available in reserve should it be needed by spring 2016 acquisition. As you can see in Figure 35 provided below, the sensor can also acquire QL1 data for the AOI in approximately 15 days providing a much denser data product that has value for forestry applications. If greater density is still required, the one Geiger sensor can collect a density of 20 ppsm and acquire the 7,647 mi^2 at a highly accelerated speed in approximately 20 days. More information about the specific flight plan and flight logistics is provided in Section 2.2 below.

	Harris' IntelliEarth™ Geiger-mode LiDAR	
Density (points/m^2)	2 ppsm / 8 ppsm (QL2 / QL1)	20 ppsm
Instantaneous Coverage Rate (mi^2/hr)	**850**	**580**
RMSEz (cm)	9.25	9.25
Altitude (AGL ft)	27,000	18,000
Swath Width (ft)	16,000	13,000
Ground Speed (kts)	290	290
Number of Systems	1	
Total Collection Days For Western AOI	15	20

Figure 35: Geiger-mode LiDAR sensor specifications

The linear LiDAR QL2 approach would involve an all Leica system collection. By utilizing team resources we have three Leica ALS70 and three ALS80 LiDAR systems. Quantum plans to allocate 2-3 platforms for the State of Maine project. Our flight team has projected approximately 165 hours of flight time. By utilizing 2-3 ALS70 sensors this would take approximately 10-16 days to collect the 7,647 mi^2 project area, taking into consideration down days for weather.

	ALS70/80 Linear LiDAR	
Density (points/m^2)	2 ppsm (QL2)	8 ppsm (QL1)
RMSEz (cm)	9.25	9.25
Altitude (AGL ft)	7545	6900
Swath Width (ft)	4,612	3,435
Ground Speed (kts)	150	150
Grayscale Reflectance Image	Yes	
Operations	Day or Night	
Number of Systems	2	3
Total Collection Days for Western AOI	16	32

Figure 36: Linear-mode LiDAR sensor specifications

2.2. Implementation

The project implementation consists of planning and pre-production activities that provide the opportunity for the contract to be reviewed by our production team to ensure all terms and conditions are understood, acceptable and able to be met during the course of the project. This review will also focus on identification of State supplied resources and materials, deliverables, standards to be followed, and accuracy requirements. These items are discussed thoroughly with the Project Team during the course of the kick off meeting. In this way, the entire Team will be committed to the State's requirements at the project's inception.

A project work plan is created and tailored to meet the requirements in the contract. This plan outlines responsibilities, accountability, and reporting requirements, as well as the quality plan for the project. As shown in Figure 37 in our work plan discussion, a workflow process is generated while detailed procedures, work instructions, QC checklists, transmittals, document control, reporting, schedule and in-process audit procedures are created and integrated into the project plan. The work plan is then verified and validated by the project team and the State of Maine.

For the State of Maine's project The Quantum Spatial Team is excited to provide the most advanced technology combined with local team member contributions, proven processing procedures, and excellent USGS and Statewide past performance. Our teams' extensive experience in data acquisition, data processing, as well as forestry analytics, allows us to create scalable buy up options specific to the stakeholders needs.

2.2.1. Aerial LiDAR Acquisition Work Plan

The Quantum Spatial Team has developed a detailed USGS LiDAR Base Specification LiDAR workflow methodology that is founded on professional expertise, understanding of the technology, and well-documented record-of-performance. As shown in Figure 37, our methodology is generally divided into four phases of operation that include flight planning, data acquisition and field survey, dataset post-processing and final product development and QA/QC.

Quantum Spatial's work plan for the State of Maine will involve the following steps:

1. **Phase I – Project Initiation:** project planning, project management plan, flight and sensor parameter plan, and geodetic control plan.
2. **Phase II – Data Acquisition:** flight, data verification, and QA/QC checkpoint survey.
3. **Phase III – Data Processing:** data calibration, point classification, intensity image production, hydro-flattening of breaklines.
4. **Phase IV – Final Product Development:** final deliverables such as; bare-earth DEM, tile and metadata are generated and QA/QC review.

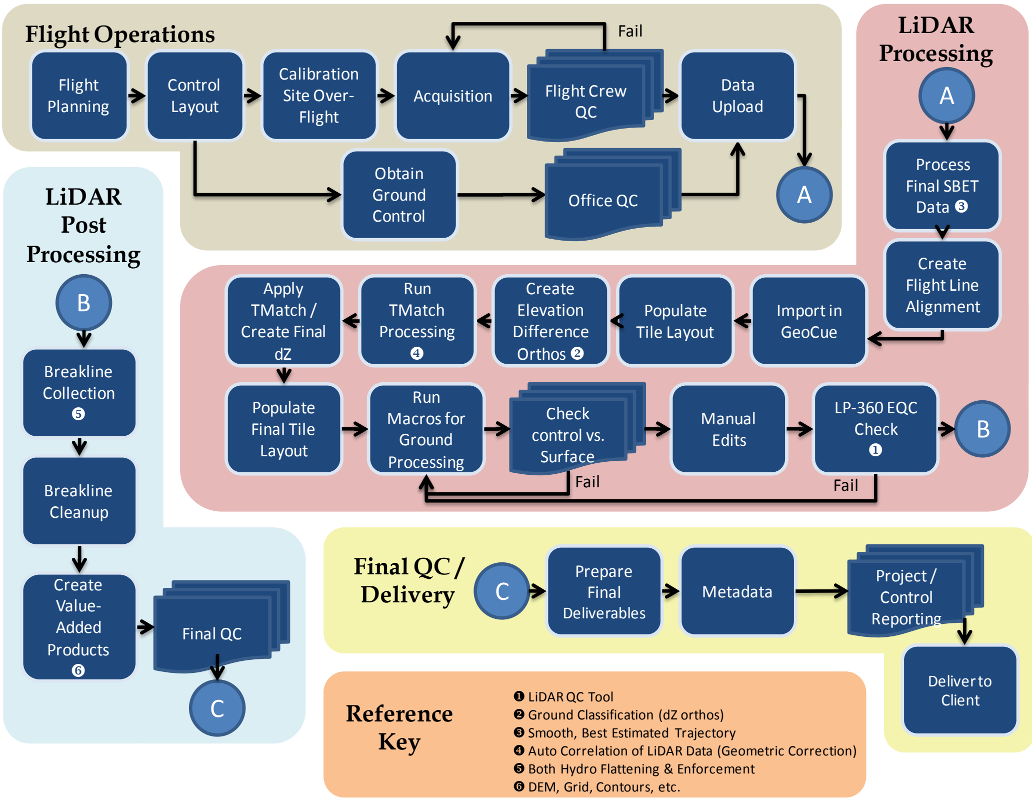


Figure 37: State of Maine LiDAR methodology workflow

PHASE I – PROJECT INITIATION

As stated above our project initiation plan includes all the coordination and planning for the State of Maine's project. Our project team generates the survey plans and crew logistics, flight plans and flight logistics, and project management approach.

Project Management Plan

Quantum Spatial will provide overall project management activities associated with each phase/task included and identified throughout the project (see Figure 37). Quantum Spatial's proposed Contract Principal is Michael Shillenn, CP. Mike has 28 years of professional experience including 24 years of experience managing multi-year, multi-million dollar geospatial contracts in support of Statewide mapping programs and Federal agencies such as USGS and USACE. Jen Whitacre, GISP is the proposed Contract Administrator and will report directly to Mike. Jen is empowered by Mike to act on behalf of the corporation and to commit the financial and human resources necessary to ensure that Quantum Spatial is meeting its contractual and tasking requirements. As Principal, Mike will have ultimate responsibility and authority for the management, direction, utilization, and performance of this contract. He will be responsible for 100% client satisfaction concerning all contractual and performance requirements.

1) Methodologies

Quantum Spatial's approach to project management embraces many of the methodologies promulgated by the Project Management Institute (PMI) and dictates a standard project management methodology for all projects. Quality management takes place in all process groups including: initiation, planning, execution, monitoring and controlling, and closing (see Figure 38). This methodology defines standard processes that enable the Quantum Spatial Team to consistently deliver successful projects.

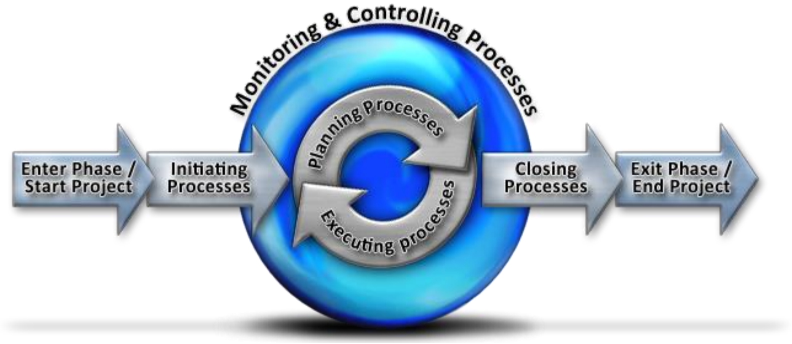


Figure 38: Quantum Spatial's Monitoring and Control Process

The project management function will manage and coordinate the planning efforts for data and control acquisition. Our assigned project manager, Mr. Joel Burroughs, supported by Jen Whitacre, will also oversee and verify the production processes and quality controls used by Quantum Spatial production teams, as well as, all of our team members associated with data collection, processing, and survey collection. This comprehensive oversight and control of the project from initiation through closeout will result in delivery of high-quality products within the schedule/budget and meeting the specifications.

2) Project Communications

Joel will establish a communications plan to identify the key stakeholders and the required communications throughout the lifecycle of the project. In addition to the methods of communication, the plan will establish protocols for documenting project communications, the frequency of communications, and the processes for reporting project status. Quantum Spatial believes in frequent, effective communications. Joel will respond to the State of Maine's emails and phone calls within one business day. The communication plan will include the names and contact information for all key stakeholders and State of Maine representatives as well as the Quantum Spatial Team. This document will be published to a web based collaboration portal for reference throughout the project.

3) Project Status Reporting

Joel in conjunction with all team members, will compile and issue a weekly status report to State of Maine representatives. The status report will include a status map (PDF) that graphically illustrates the production progress throughout the study area. In addition to the status map, the status report will include details about project activities, planned activities, issues, milestones, and the schedule. Status reports will be published to the project SharePoint site and a notification will be sent out to all State of Maine stakeholders. During scheduled conference calls, the project status report will be reviewed and discussed by the project Team.

4) Project Management Plan

Joel will build a comprehensive project management plan, which will include the following PMI recommended documents:

- Project scope definition
- Communications plan
- Work breakdown structure (WBS)
- Schedule management plan (Microsoft Project schedule)
- Risk management plan
- Quality management plan

Joel will draft the project management plan documentation and will distribute to the entire project Team. This documentation will serve as the project manager's overall plan for conducting and completing the project. During the pre-flight initiation meeting, the project management plan will be reviewed and discussed with the State of Maine representatives. This plan will include a detailed project schedule, which will be updated on a weekly basis for tracking progress (percent complete) and due dates for milestones and tasks. All documentation included in the project management plan will be "living" documents that will be actively maintained and updated throughout the lifecycle of the project and will be delivered to the State of Maine as final project documentation.

Risk Management

A risk management plan will identify potential risks that could impact the implementation of the project. Each risk will be captured and documented with a unique risk identifier as well as a risk description, trigger, and probability. Through communication with the State, Joel will develop the initial risk management plan to establish strategies to manage the risks, including mitigation, acceptance, transference, or avoidance. He will only attempt to develop mitigation strategies for risks that have a high probability of occurrence and a significant impact. The risk management plan will be updated continuously throughout the lifecycle of the project as new risks are identified or risk events occur. The intent of utilizing a risk management plan is to be aware of the potential risks and address risks, where necessary, to help ensure a successful implementation. This proactive strategy to identifying potential issues will minimize the impact and effect of risk events on the schedule and/or quality.

Quality Management

Quantum Spatial Team utilizes a mature quality management plan including both a series quality assurance plan and quality control procedures. Our quality assurance plan is compatible with ISO 9001:2008 standards. Our assigned QA/QC Manager, Mark Meade, PE, PLS, CP will be responsible for ensuring all quality procedures are followed by all Team members as well as the verification of deliverables for completeness, accuracy, and compliance to the specifications as a result of the independent quality assurance and quality control verifications.

Quantum Spatial's quality management plan will establish the methods for ensuring a high-quality product that conforms to the USGS QL2 specifications and is fit for use by the State meeting their expectations. The quality management plan will capture the associated workflows, tools, techniques, and methods for reviewing and identifying defects in all deliverables as well as tracking those defects through to resolution. Joel in collaboration with Mark will direct the development of the quality management plan and will ensure that all methods employed directly assess the quality of the products as compared to the acceptance criteria.

Schedule Management

A detailed schedule was developed for the State of Maine (Figure 39). The project schedule includes all task definitions, along with the estimated month it will be carried out, as well as the name of each person/team member responsible for each task. After the project kick off meeting a new schedule will be generated updating start and finish times for the project tasks. The schedule will identify predecessors for tasks and will clearly delineate task responsibilities between all project Team members. The schedule will be actively managed throughout the lifecycle of the project with percent complete and start and completion dates. The Gantt chart will illustrate the duration of the activities as well as the relationships between tasks to help the Team members and the State of Maine representatives clearly identify how the project activities will be conducted. Through actively managing the schedule, the project manager will be aware of any delay in progress and can work with the project Team to identify corrective action to resolve the issue.

Task Name	Assigned To
Contract Award / Notice to Proceed	State Of Maine
Kick off Meeting	Mike Shillen, Jennifer Whitacre, and Joel Burroughs QSI
Project Implementation Plan	Joel Burroughs QSI
Deliverable:Flight & Control Plan	Joel Burroughs QSI
3rd Party QA Review Feedback	3rd Party Contract
Ground Control	
Calibration Survey	John Allen- Sewall, Byron Freeman - QSI
QA/QC Survey	John Allen- Sewall, Byron Freeman - QSI
Deliverable - Survey Report	Joel Burroughs QSI
Data Acquisition	
Mobilization	Brett Baker, Acq. Manager QSI
Acquisition	Brett Baker, Acq. Manager QSI
DeMobilization	Brett Baker, Acq. Manager QSI
Deliverable - Flight trajectory maps	Joel Burroughs QSI
LiDAR Post Processing	
Calibration	Steve Blask-Harris, Adam Pike - QSI
Pilot Development	Adam Pike, QSI
Deliverable - Pilot Data and Accuracy Review	Joel Burroughs QSI
Initial Classification	Adam Pike, QSI
3rd Party QA Review Feedback	3rd Party Contract
LiDAR Production	
Bare Earth Clean Up	Adam Pike-QSI, Nicole Cyr- Sewall, Claire Kiedrowski- Kappa
Hydro-Breakline Generation	Adam Pike-QSI, Nicole Cyr- Sewall, Claire Kiedrowski- Kappa
Deliverable Generation	
Delivery Lot 1	Adam Pike, QSI
QA/QC Review	Mark Meade, QSI
NVA and VVA Accuracy Assessment	Mark Meade, QSI
Delivery Lot 2	Adam Pike, QSI
QA/QC Review	Mark Meade, QSI
NVA and VVA Accuracy Assessment	Mark Meade, QSI
Delivery Lot 3	Adam Pike, QSI
QA/QC Review	Mark Meade, QSI
NVA and VVA Accuracy Assessment	Mark Meade, QSI
Final Project Reports	Joel Burroughs QSI
3rd Party QA Review Feedback	

Figure 39: State of Maine schedule

5) Flight and Sensor Plans

As previously discussed The Quantum Spatial Team is proud to present two uniquely different state-of-the-art sensor technologies to the State of Maine for consideration. In this section, we will discuss the Harris Geiger-mode LiDAR sensor and follow up with the Leica Linear-mode LiDAR system option.

Geiger-mode Sensor Acquisition Approach

Over the past 15 years, Harris has built and operated automated, scalable, large-volume Geiger-mode LiDAR data processing systems that have efficiently delivered hundreds of thousands of square miles of high-quality LiDAR products to the defense and intelligence communities.

Figure 40: Geiger-mode LiDAR sensor

The operation of a GmAPD LiDAR is conceptually very simple. A laser pulse is used to illuminate a scene. By precisely measuring the time of flight of the photons reflected off the scene, the three dimensional coordinates of features within the scene can be determined. The array enables measuring 4,096 locations in a single laser flash, combined with operating the laser at 50 kHz, providing >200 million ground measurements per second.

The focus of Harris' IntelliEarth™ Geiger-mode LiDAR design was to maximize the data collection rate, enabling USGS Quality Level One (QL1) collection at an area coverage rate exceeding 1,000 km^2/hour, with 50 percent swath-to-swath overlap. The system uses a coaxial transmit to receive 270mm clear aperture with a Palmer scanner that scans the beam at a 15-degree half angle. Given the operating flight altitudes and scan rates of the system, it is critical that the pointing offset between the transmit and receive channels be adjustable in order to maintain optimal overlap between the transmitted beam and the receiver field of view (FOV). To this end, the system incorporates a subsystem to adjust the transmitter FOV relative to the receiver FOV in real time (US Patent Pending, application 14/703035, filed 05/04/2015). The sensor also has automated gate control and multiple pulse in the air tracking and compensation.

When flown with >50 percent swath overlap, the scan pattern provides four looks from four different directions. This ensures that the sides as well as roofs of structures are sampled, mitigating voids near their base and significantly increasing the interpretability of the point cloud data (Figure 42).

Figure 41: Example of a surface model colored by elevation

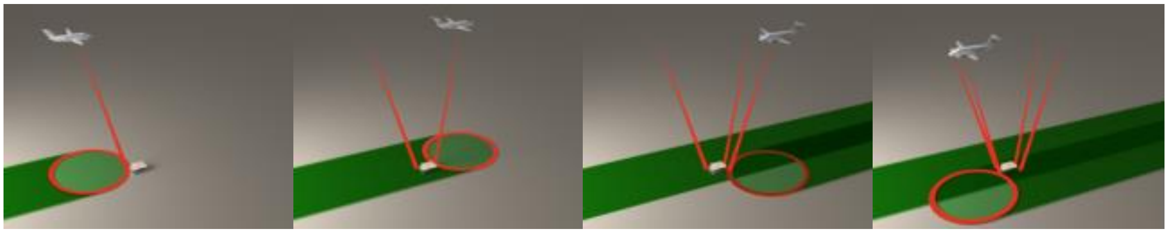


Figure 42: Palmer scan pattern with 50-percent overlap provides four independent views of the scene

Project Planning and Logistics

The Harris Geiger-mode LiDAR Mission Planner software tool will be used to develop and plan the entire aerial survey activities for the Western Maine AOI. To achieve ≥2 points per m^2, the aircraft will be flown at an altitude of approximately 27,000 ft above ground level (AGL) at a speed of 240 knots. The sensor will be flown in a Beechcraft King Air 200 aircraft. It is estimated that the Western Maine project AOI can be collected in approximately 59 total flight hours which relates to approximately 15 collection days taking into consideration down days for weather.

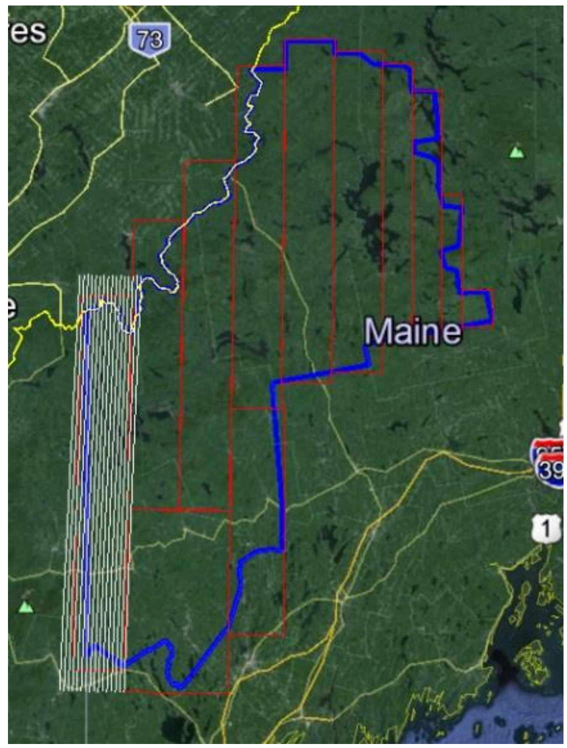


Figure 43: Geiger flight plan. Collection bricks in red and sample flight lines (white) within each brick.

The individual flight missions are planned as collection bricks with multiple flight lines per brick. Figure 43 provides the Geiger flight plan for the Western Maine AOI and an example of the individual collection bricks. Each flight covers a swath width of approximately 3.3 km and a swath length range of 86,000 km to 154,500 km. This is planned with 55 percent overlap between swaths. On average 2000 km^2 of "effective" area can be covered, assuming a conservative 5 hour collection each day.

Figure 44 provides the planned flight and Geiger sensor specifications for the State of Maine Western project area.

LiDAR Preliminary Flight Parameters Geiger-mode QL2	
Area of Coverage (sq. mi)	7647
Flight Altitude (AGL)	27,000 ft
Airspeed (kts)	240
Vertical Accuracy	10 cm RMSEz
Aggregate Nominal Pulse Spacing (ANPS)	≤ 0.71 m
Aggregate Nominal Pulse Density (ANPD)	2.0 m
Swath Width	10,826 ft.
Overlap	55 %
Laser Repetition Rate (PRF)	50 kHz
Total Flight Hours	59

Figure 44: Geiger-mode LiDAR flight parameters

Control and Accuracy

Global Positioning System (GPS) base stations are required to provide positional accuracy for the system and ensure USGS LBS horizontal and vertical accuracies are met. Harris will utilize a minimum of 4-5 existing CORS stations that provide the required coverage over Western Maine AOI. Harris estimates at least one additional temporary CORS station will be required to cover the gap in the northern section of the AOI. The temporary CORS station will be established in accordance with the U.S. National Geodetic Survey (NGS) guidelines for CORS establishment and Real Time GNSS Networks v2.0, published in January 2013 and March 2011, respectively. Additionally, Harris also plans to utilize the Trimble's CenterPoint RTX Correction service to augment the CORS and meet the required 10 cm RMSEz data accuracy.

Data Processing and Workflow

Harris will perform all initial post processing of all Geiger mode LiDAR data in their grid computing facility located in Melbourne, Florida. This is a state-of-the-art geospatial production center dedicated for end-to-end processing supporting government and commercial programs.

Harris will process the Western Maine LiDAR data using the Processing, Exploitation, and Dissemination (PED) infrastructure at this production center. This is a fully automated workflow. The PED will support:

- Mission and daily collection planning
- Flight data ingest and storage
- Point cloud processing and product creation
- Data management

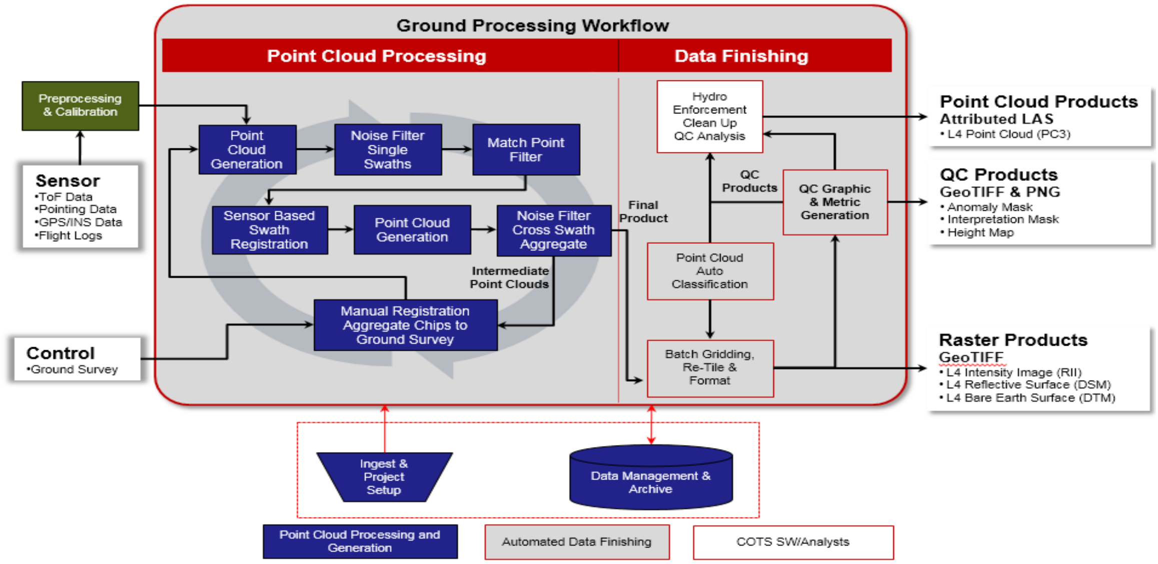


Figure 45: Geiger-mode LiDAR workflow

Harris developed the workflow shown in Figure 45 to minimize the amount of analyst labor required to support large-scale collection and production without sacrificing data quality. In the pre-processing phase, a blend of automatic and manual tools performs sensor calibration and non-causal adjustment of the platform GPS trajectory to improve accuracy. The improved trajectory and sensor calibration data are then sent, along with the raw time of flight (TOF) sensor data, to the first stage of automated processing. Here the TOF data is converted from sensor angle-angle-range space to 3D geodetic coordinates on a swath-by-swath basis. Next, fast noise filtering is performed on each swath. Potential match points are then found between swaths and used to align the swaths via a sensor model based bundle adjustment that improves knowledge of the platform trajectory. The raw data is then re-projected from sensor space to 3D ground coordinates using the adjusted trajectory, and multi-swath aggregate point clouds are formed. These aggregate point clouds then undergo noise filtering to produce the final 3D point cloud products.

Accuracy Improvements

While the system incorporates a highly accurate INS/GPS system, the production of precise geodetic data also requires 3D registration of individual swaths. Over several decades, Harris has developed an autonomous process that allows true sensor model bundle adjustment using photogrammetric registration techniques that are driven by aligning automatically selected tie points between swaths. Figure 46 provides an overview of the bundle adjustment.

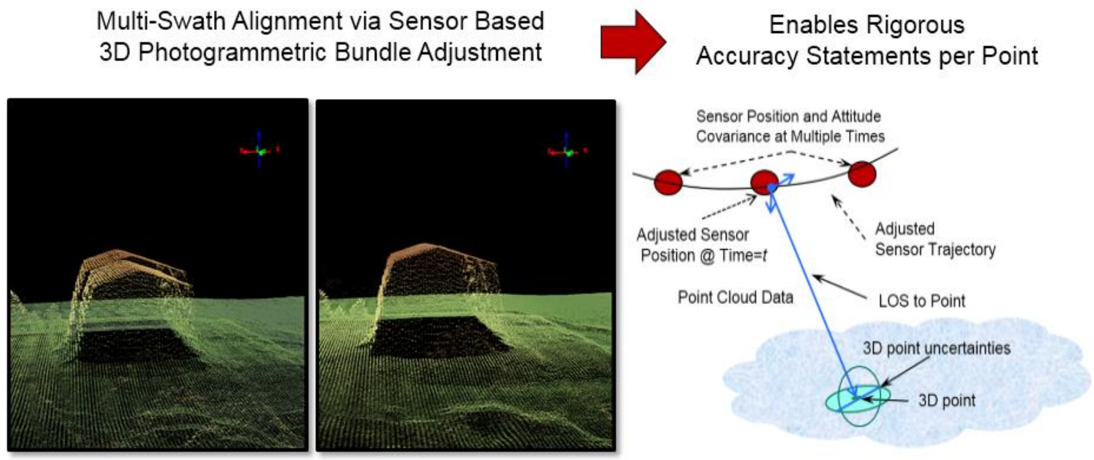


Figure 46: Sensor-based bundle adjustment of LiDAR provides superior relative and absolute accuracy similar to traditional imagery aerial triangulation.

This technique also allows the integration of ground control points into the best and final production process for a given customer or collection area by manually locating ground survey points in the data and using them as locked points in a final bundle adjustment. Not only does this process produce more accurate data than current techniques in use for LiDAR today, it also provides customers with accuracy statements for the LiDAR data on a per point basis—a unique value proposition in the commercial market. It also enables production of accurate products in areas with minimal GPS base station coverage. All data will be produced in accordance with USGS LiDAR Base Specifications v1.2.

6) Linear LiDAR Sensor Approach

Make and Model	IMU Unit	Mount	Quantity
Leica ALS70	Yes	Yes	3
Leica ALS80	Yes	Yes	3

Figure 47: Quantum Spatial Team Leica LiDAR Sensor Resources

LiDAR data will be acquired using the latest generation of high pulse rate LiDAR systems. (Leica ALS70 or 80) These sensors are comprised of a roll-compensated sensor with GPS (≥2 Hz sampling frequency)/IMU, and capable of multi-pulse in air (MPIA). Calibration test flights are performed frequently to verify computation of lever arms and ultimately the relative and absolute accuracy of the system. The Quantum Spatial flight methodology includes flying opposing lines with ≥30 percent swath overlap to ensure the laser penetrates to the ground in variable terrain and at multiple angles. In addition, Quantum Spatial will plan flight lines in a manner which will protect against single line coverage and minimize pulse density non-uniformity due to aircraft pitch variation in steep terrain.

Our LiDAR collection protocols are rigorous and deliberate. Operational procedures include detailed flight planning and parameter settings to guarantee executing the nominal pulse density with 100% coverage. These include careful determination of scan angle and flight altitude configurations to meet pulse density specifications; >30 percent overlap of flight lines to ensure multi-angle laser penetration and characterization of features; terrain following; coordination of flight headings with terrain contours; and GPS/IMU/boresighting coordination to result in indiscernible line-to-line differences in point locations. Thorough survey and ground control procedures are also critical to enabling corrections for aircraft position, calibrating flight lines, and verification of accuracies.

Flight Planning

To collect LiDAR data at the specified quality level (QL2) requires close attention to a number of factors in the flight planning phase, and our experienced and talented acquisition team is instrumental in drafting an execution plan for the data collection. Status maps illustrating progress are provided throughout the collection phase by the Quantum Spatial project manager, Joel Burroughs.

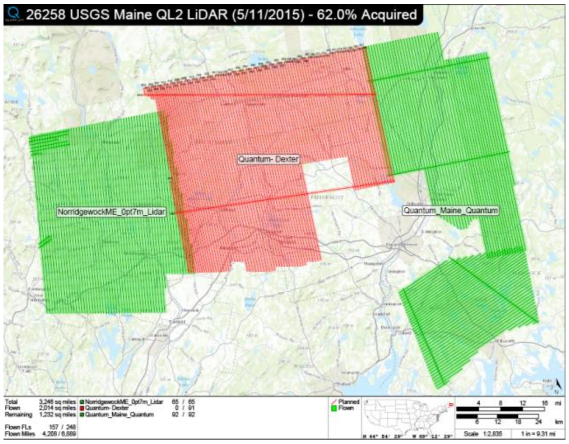


Figure 48: Example of a Flight Status report

Factors determined and established for each project include:

- Specific sensor settings (field of view, pulse rate, etc.);
- Flight parameters (altitude, speed);
- Timing of collection in relation to ground conditions (leaf off, snow free);
- Probable weather patterns and related contingency planning;
- Base of operations logistics (logical and economical);
- Prioritization and order of collection plan given client needs and collection constraints (impending snow, weather windows, tidal changes, changing vegetation conditions);
- And comprehensive ground survey control and verification planning (logistics and standards for collection of static control, calibration checkpoints, and validation checkpoints for NVA and VVA).

Flight Planning Overview

Our flight operations will be planned, managed, and controlled through our flight operations center in Lexington, Kentucky by Brett Baker, Quantum Spatial's Acquisition Manager. Quantum Spatial relies on a computerized flight-management system to maximize mission execution accuracy. Finalized digitized flight data is fed into an independent flight-management system in each aircraft. The start and stop points of each flight line are processed by the aircraft's onboard navigation system. Beyond the project specific technical specifications that are factored into planning process, several other key variables are taken into consideration in this phase. These include, but are not limited to:

- Safety of operations
- Flight line orientation that factors major terrain conditions and/or airspace restrictions

- Sustainment of point densities and flight line sidelap associated with terrain variation (steeper slopes generally require tighter line spacing between adjacent parallel lines)
- Design of base station proximity for use in all flight line control
- Checks for along and cross-track point spacing as the terrain varies along the flight lines
- Checks for side overlap to eliminate gaps or slivers, and to ensure the specifications for overlap are met

Flight Logistics

Sidekick is a custom application developed by Quantum Spatial that provides critical support in the development of detailed flight plans and cost estimates, and is incredibly helpful in our peer review process for the planning and estimating phases. Sidekick automates the development of project specific information and typically replaces days of data gathering and analysis into a task of a few seconds. The data gathering and analysis is completed after a simple definition of the project area of interest (AOI – typically in a shapefile format), maximum radii for ground control base stations, and overlap requirements. Specific information gathered and reported by Sidekick are detailed below.

Figure 49: Western Maine project area.

A shaded relief map of the project area is included so that we immediately understand how terrain change will affect flight line layout and aerial acquisition. Additionally, thirty Year historical weather information from NOAA – including rain, snow, wind, and clear days -which allows us to better understand weather patterns during the acquisition window, develop realistic estimates for the acquisition opportunities (e.g. flight days per week or month while on site). This allows us to develop an accurate understanding of the number of aircraft and sensors needed to accomplish the project during the acquisition window.

Quantum Spatial relies on a combination of Leica sensor software tools, in combination with programs such as, sidekick, XMAP and Topoflight for flight operations planning. Once our flight plan is generated for the project area, it is reviewed to ensure complete coverage, correct sensor specifications and flight parameters. Figure 50 presents our preliminary flight plan for the Western Maine project area as well as our flight and sensor parameters. These parameters will ensure we capture Quality Level 2 data per USGS LiDAR Base Specifications v1.2.

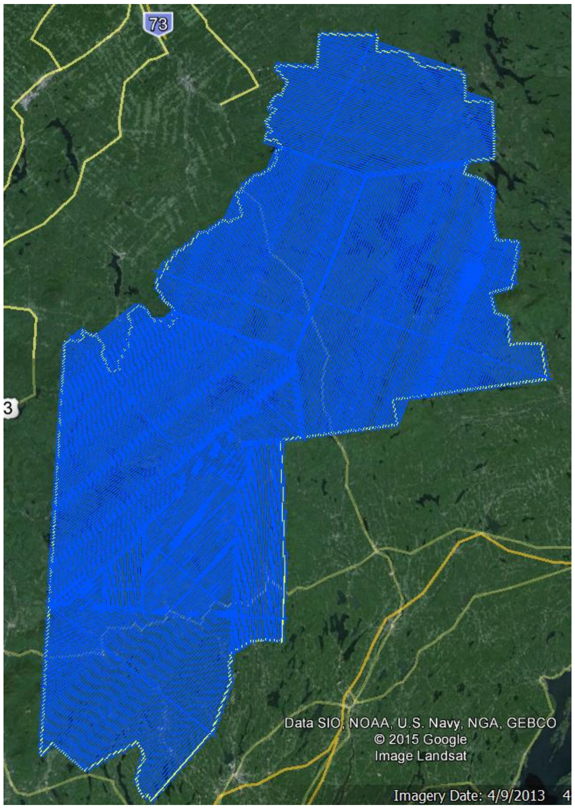


Figure 50: Western Maine flight plan

	LiDAR Preliminary Flight Parameters ALS70 QL2
Area of Coverage (sq. mi)	7647
Flight Altitude (AGL)	7545 ft.
Airspeed (kts)	150
Vertical Accuracy	10 cm RMSEz
Aggregate Nominal Pulse Spacing (ANPS)	≤ 0.71 m
Aggregate Nominal Pulse Density (ANPD)	≥ 2.0 m
Scan Angle	34 °
Scan Frequency (Hz)	41.2
Swath Width	4613 ft.
Overlap	30%
Laser Repetition Rate (PRF)	51.6 kHz
Flight Lines	627
Total Flight Time (hours)	165
Laser Time (hours)	106
Turn Time (hours)	31.4
Ascend/Descend Time (hours)	27.7

Figure 51: Flight and Sensor Parameters

Our acquisition plan for the State of Maine includes deploying a minimum of 2-3 Leica ALS70/80 Sensors. These sensors are configured in our twin-engine Navajo aircraft. With this configuration, Quantum Spatial is able to provide maximum cost benefit, given the state-of-the-art capabilities of our Leica sensors, and the aircraft speed of the Navajo. In addition to resource redundancy, the use of similar platforms and sensor configurations maintains consistency throughout the data collection as well as the workflow process. If it is noted by our pilots or field crew that we see a rapid growth of vegetation an additional sensor will be deployed to help finish the data collection. Last year, Quantum Spatial was awarded a BAA 3DEP LiDAR collection for Maine through USGS. Due to a very abnormal winter, snow conditions lasted late into the spring and we had a very short window for data acquisition prior to leaf out conditions. Due to lessons learned on this project we plan deploy a minimum of two aircraft/sensors, as well as double flight crews (two crews per aircraft) to allow for up to three flights per day. This will allow for quicker seasonal collections when we have a limited time for leaf off and no snow conditions on the ground.

Figure 52: One of Quantum Spatial twin-aircraft and a Leica ALS sensor.

It is anticipated it will take approximately 16 days for QL2 data collection utilizing 2 sensors and 10 days utilizing three sensors, with a conservative 2 lifts per day. Also figured into this timeframe is downtime for clouds and weather.

Timing of Collection

Whenever possible, LiDAR acquisitions will be acquired during USGS recommended collection conditions. Atmosphere will be free of clouds, snow, haze, dust, and fog between ground and aircraft, as well as no high winds and turbulence as this can cause noise in the data set. The ground will be free of flooding or inundation. As indicated in the RFP, the State of Maine expects collection starting spring 2016. If weather conditions allow Quantum recommends starting data acquisition in early to mid-April. NOAA weather averages for the State of Maine show slightly better chances of less cloud cover.

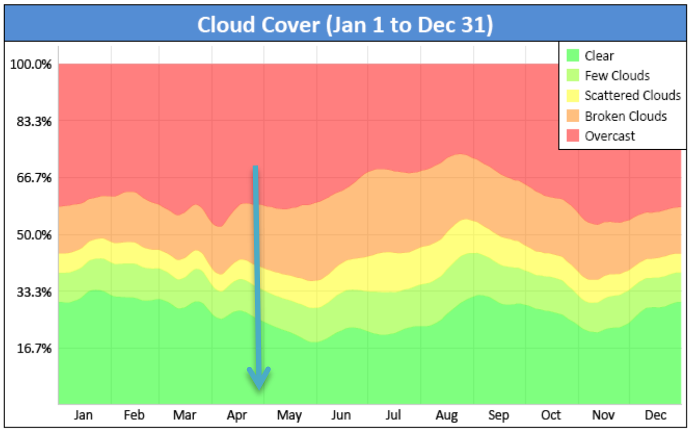


Figure 53: According to cloud cover averages, early to mid-April should see better collection windows assuming good ground conditions.

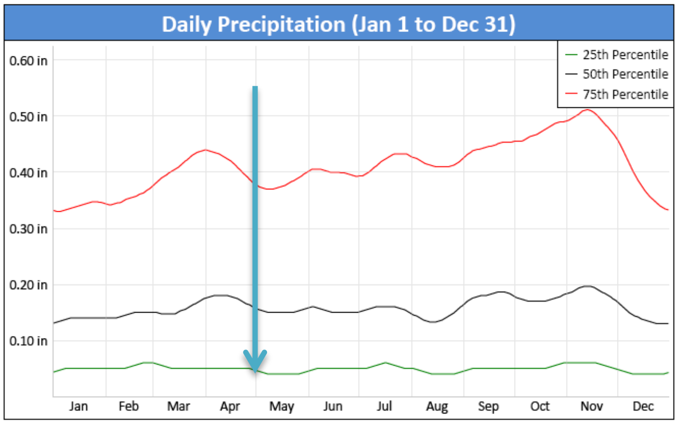


Figure 54: The average daily precipitation for the mid-April timeframe.

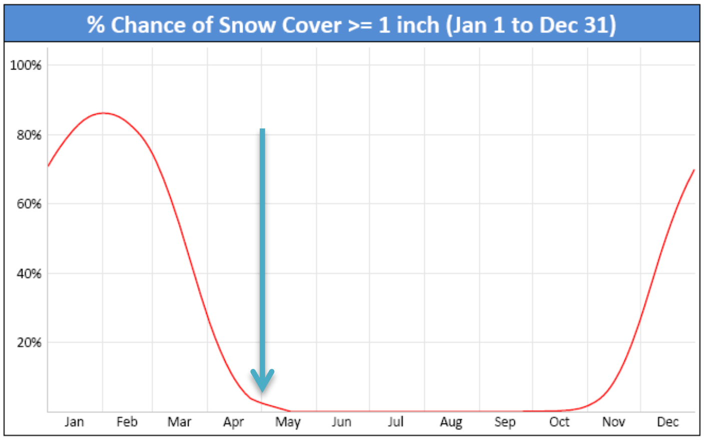


Figure 55: This graph depicts the chance of greater than 1 inch of snow cover is on the ground. According to averages my mid-April there is less than a 20% chance of an inch or more of snow will be on the ground.

Base of Operations

Quantum Spatial plans to use multiple airfields while acquiring the data in the Western project area. These sites are picked based on fuel availability, runway length and services provided. Airports are used for mission refueling, potential maintenance, and base stationing for the flight control.

ID	Airport	Runway
KLEW	Auburn/Lewiston Municipal Airport	5,001 ft
KAUG	Augusta State Airport	5,001 ft
KBML	Berlin Regional Airport	5,200 ft
KOWK	Central Maine Airport of Norridg...	4,000 ft
KIZG	Eastern Slopes Regional Airport	4,200 ft
3B5	Twitchell Airport	10,000 ft
KWVL	Waterville Robert LaFleur Airport	5,500 ft

Figure 56: Airfields located within the Western project area.

Quantum Spatial owns and operates 23 aircraft and five Leica ALS70/80 sensors. This resource capacity allows us redundancy in the event of sensor malfunction or unexpected aircraft maintenance to avoid any project delays. Our team member PAR has additional surge capacity that includes an additional Leica ALS70 with plans to acquire a second ALS70 prior to the spring 2016 flight season. PAR's back up resources help mitigate unexpected aircraft or sensor malfunctions of Quantum Spatial's assets while on site. Our deep resources enable us to quickly respond and recover from unanticipated events without collection disruption.

Prioritization of Collection Areas

Quantum Spatial will coordinate with the State of Maine to set areas of priority for data collection during the kick off meeting. If there are priority areas our Team will provide best effort to acquire these locations first, assuming weather is good. Similar to our contingency planning our acquisition department will be following the weather using various different types of weather information such as current radar and cloud information, National Weather Service, Automated Surface Observing Systems (ASOS), and various online tools. If clouds or precipitation starts to move into one collection area, our Team will check the remaining flight areas within the AOI and mobilize to continue collection capabilities.

7) Control Planning

GPS Surveys

Ground control planning is critical for base station placement, data calibration points, and QA/QC checkpoint locations. Maine presents unique ground control challenges. The Western Maine AOI focuses on rural and forested portions of the state. Much of this area is remote making access extremely difficult.

Calibration points are used to calibrate the LiDAR data set to achieve the required 10 RMSEz cm bare earth vertical accuracy. Once the flight plans are generated they are reviewed by our survey department. Calibration point locations are selected by reviewing flight line placement as well as the surface locations. These points need to be located in relatively flat and even terrain at least 5 meters from any break in terrain or other vertical features. They also should not be placed on any highly reflective surface or near significant changes in reflectivity. Ideal areas to place these points are in dirt, gravel, or very low grass such as on a golf course. These points need to be at least 3x more accurate than the required 10 cm surface accuracy. Please see Figure 57, which shows the 130 calibration points that will be needed for the 7,647 mi^2 project area for both the Geiger-mode and Linear-mode approach.

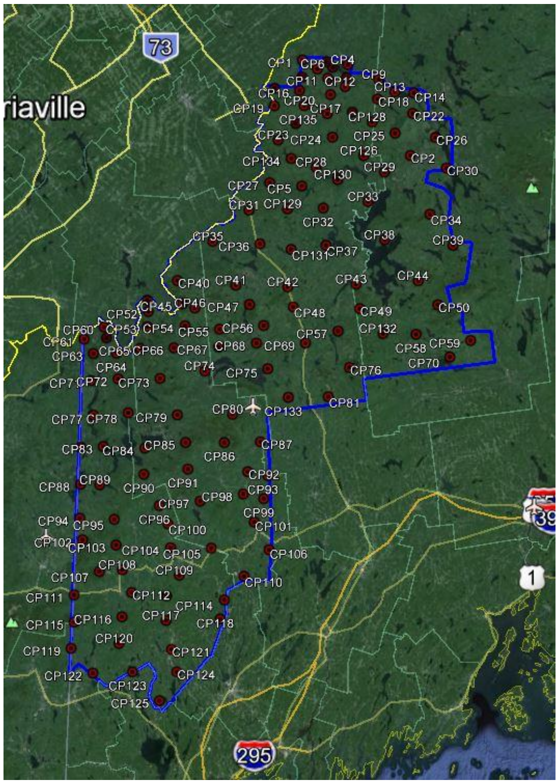


Figure 57: Calibration points needed for the 7,647 mi^2 project area for both Geiger- and Linear-mode LiDAR approaches.

QA/QC checkpoint planning follows the American Society for Photogrammetry and Remote Sensing (ASPRS), Positional Accuracy Standards for Digital Geospatial Data (2014). Check points are used to validate the horizontal and vertical accuracy of the LiDAR data. ASPRS recommends a certain number of check points relative to the size of the AOI. Figure 58 was used to determine the total number of check points. For projects greater than 2500 km^2, an additional 5 points should be added for every additional 500 sq. km. For the additional 5 points, 3 should be NVA and 2 should be VVA. Therefore, for the Western Maine AOI totaling 7,647 mi^2 a total of 160 NVA check points and 115 VVA check points are required to meet USGS specifications based on ASPRS guidelines.

Project Area (Square Kilometers)	Horizontal Accuracy Testing of Orthoimagery and Planimetrics	Vertical and Horizontal Accuracy Testing of Elevation Data sets		
	Total Number of Static 2D/3D Checkpoints (clearly-defined points)	Number of Static 3D Checkpoints in NVA[9]	Number of Static 3D Checkpoints in VVA	Total Number of Static 3D Checkpoints
≤500	20	20	5	25
501-750	25	20	10	30
751-1000	30	25	15	40
1001-1250	35	30	20	50
1251-1500	40	35	25	60
1501-1750	45	40	30	70
1751-2000	50	45	35	80
2001-2250	55	50	40	90
2251-2500	60	55	45	100

[9]Although vertical check points are normally not well defined, where feasible, the horizontal accuracy of lidar data sets should be tested by surveying approximately half of all NVA check points at the ends of paint stripes or other point features that are visible and can be measured on lidar intensity returns.

Figure 58: Recommended number of checkpoints based on area

Non-vegetated Vertical Accuracy (NVA)

NVA Points are planned to be proportionate to the land cover classes within the Western Maine project area. As with all vertical assessment points, they should be placed on relatively flat terrain at least 5 meters from breaks in terrain. These include bare earth and urban areas.

Vegetated Vertical Accuracy (VVA)

VVA Points also planned to be proportionate to the land cover classes and should be placed on relatively flat terrain at least 5 meters from breaks in terrain. The land cover types for the Western Maine AOI are tall grass, forested and wetlands.

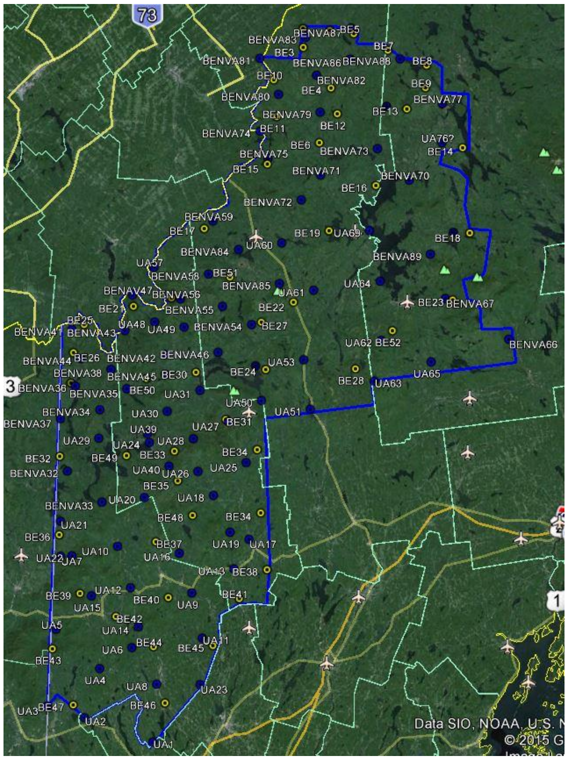


Figure 59: NVA point locations for Bare Earth and Urban locations.

Total of 160 points

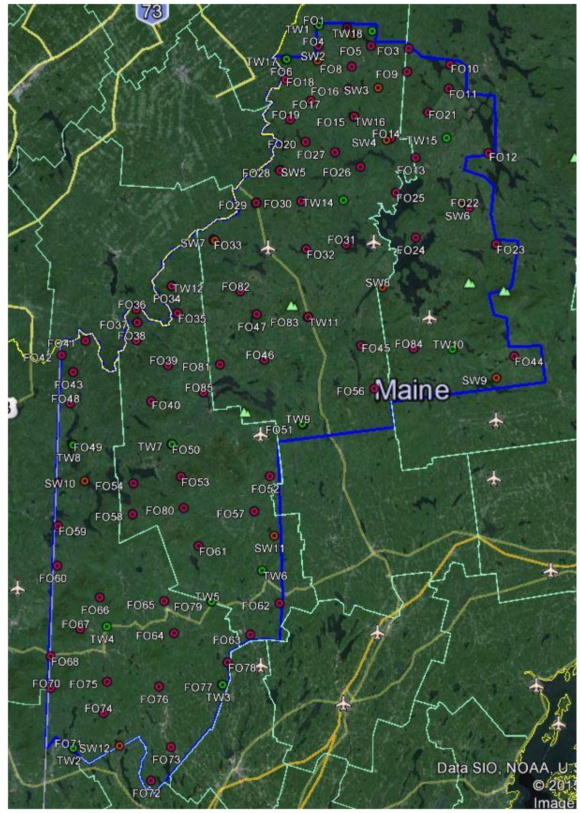


Figure 60: VVA point locations for forested, tall weeds, and swamp locations.

Total of 115 points

PHASE II – DATA ACQUISITION

The digital flight plan created during Phase I is used to carry out all LiDAR acquisition missions. The digital flight plan includes flight overlap to exceed USGS's minimum requirement of 10%; this is to improve the angle of incidences to improve the probability to reach the ground though tree canopy even during leaf off conditions. Our planned swath overlap will be 30%. This eliminates the possibility of gaps (flight line holidays) between flight lines in steep terrain and improves the representation of features in areas of vegetation. By overlapping the lines with >30% sidelap and flying opposing flight lines, the pulses hit remaining vegetation at different angles to essentially get more returns under the canopy. Additionally, this improves the relative accuracy and flight line to flight line accuracy within the data set by providing more data for use in the calibration process.

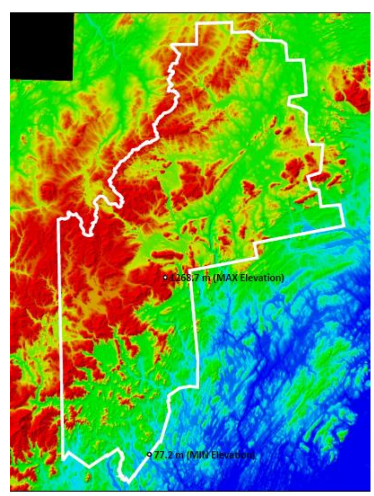
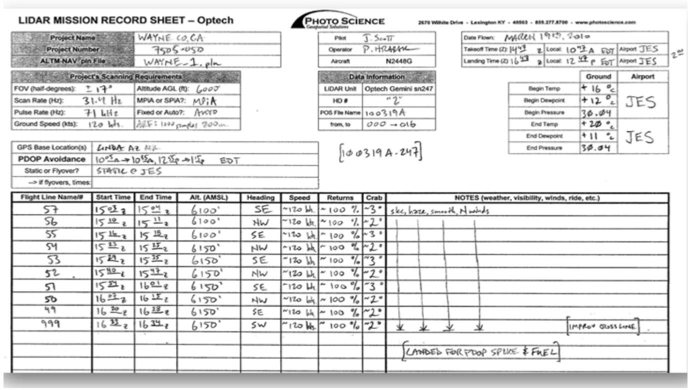


Figure 61: Elevations of the Western Maine AOI


LIDAR MISSION RECORD SHEET – Optech

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Project Name	WAYNE CO, GA
Project Number	7505-050
ALTM-NAV .pln File	WAYNE_1.pln
Pilot	J. Scott
Operator	P. Hrabak
Aircraft	N2448G
Date Flown:	MARCH 19th, 2010
Takeoff Time (Z): 1447 z	Local: 1047 A EDT — Airport JES
Landing Time (Z): 1647 z	Local: 1247 P EDT — Airport JES

Project's Scanning Requirements			
FOV (half-degrees):	± 17°	Altitude AGL (ft):	6000'
Scan Rate (Hz):	31.4 Hz	MPiA or SPiA?:	MPiA
Pulse Rate (Hz):	71 kHz	Fixed or Auto?:	AUTO
Ground Speed (kts):	120 kts.	ARF: 1000 samples 200 m	

Data Information	
LiDAR Unit	Optech Gemini sn247
HD #	"2"
POS File Name	100319A
from, to	000 → 016

	Ground	Airport
Begin Temp	+16 °c	JES
Begin Dewpoint	+12 °c	
Begin Pressure	30.04	
End Temp	+20 °c	JES
End Dewpoint	+11 °c	
End Pressure	30.04	

GPS Base Location(s)	LINDA AZ MK
PDOP Avoidance	1005A → 1035A, 1255p → 115p EDT
Static or Flyover?	STATIC @ JES
--> if flyovers, times:	

[100319A-247]

Flight Line Name/#	Start Time	End Time	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES (weather, visibility, winds, ride, etc.)
57	1503z	1504z	6100'	SE	~120 kts	~100 %	~3°	skc, haze, smooth, N winds
56	1510z	1511z	6100'	NW	~120 kts	~100 %	~2°	
55	1516z	1518z	6100'	SE	~120 kts	~100 %	~3°	
54	1523z	1525z	6150'	NW	~120 kts	~100 %	~2°	
53	1529z	1535z	6150'	SE	~120 kts	~100 %	~3°	
52	1540z	1547z	6150'	NW	~120 kts	~100 %	~2°	
51	1554z	1601z	6150'	SE	~120 kts	~100 %	~3°	
50	1607z	1615z	6150'	NW	~120 kts	~100 %	~2°	
49	1620z	1628z	6150'	SE	~120 kts	~100 %	~2°	
999	1633z	1634z	6150'	SW	~120 kts	~100 %	~2°	[IMPROV CROSS LINE]
								[LANDED FOR PDOP SPIKE & FUEL]

Figure 62: Example of a project flight log

The flight altitudes are held within 5% above or below the average altitude necessary to maintain a minimum ranging distance required for the project area. The elevations in the Western Maine project area range from 253.3 ft in the southeast portion to 4,162.4 ft located in the east central area. The elevations are monitored during flight operations by the sensor operator. The operator provides important support during LiDAR acquisition by monitoring the performance of the ABGPS and IMU during data acquisition as well as documenting important information about the flight mission on flight logs. Notable information included in the flight logs consists of the aircraft and sensors utilized, atmospheric and ground conditions, as well as the LiDAR sensor parameters.

Prior to every mission, the GPS satellite constellation and PDOP values will be computed for the project area and used to plan flight times. Our LiDAR systems are GPS/GNSS capable and include "tightly coupled" GNSS-IMU technology. This allows for greater flight efficiencies by having a greater range of available satellites and no longer requiring maintaining satellite lock during turns. PDOP values will not exceed 3.0 based upon a satellite constellation of 6 or more.

Base Stations

Figure 63: Base station

Simultaneous to the LiDAR data collection missions, Quantum Spatial will conduct a static (1 Hz recording frequency) survey of the horizontal and vertical positions of a network of survey control dual-frequency DGPS base stations established at monuments with known coordinates. Maximum baseline lengths between control points and the aircraft GPS do not exceed 24 km (13 nautical miles). When feasible, QSI will use First Order NGS published monument with NAD83. Seven potential monument locations fitting this description have been identified for the Western Maine project area. In areas where existing control monuments do not meet the minimum criteria of currency, reasonable access, and proximity to the mission area, new control will be established in a suitable location. Newly established vertical control shall be tied to First Order NGS published monuments with horizontal coordinates tied to available highest order or better NGS published monuments with NAD83 and NGS Continuously Operating Reference Stations (CORS). After the static GPS data have been collected, the files will be processed using the Online Positioning User Service (OPUS). Multiple sessions will be processed over the same monument to confirm antenna height measurements and reported OPUS position accuracy.

Flight Safety

Operational safety during airborne missions is of utmost importance to us. All missions will be accomplished using our fleet of fixed-wing aircraft which are maintained, operated, and insured in accordance with FAA regulations. Our on-staff pilots have high flight time experience, and all field staff undergo regular safety briefings. We follow all FAA communication and flight regulations specific to the project area. Our pilots have proper FAA pilot certificates with appropriate aircraft/instrument ratings.

Flight Ground Test

Quantum Spatial aircrews calibrate the sensor before each mission. The ground test involves booting the sensor control system, recording GNSS/IMU data, initializing the gyro-stabilized mount, and recording image data from the sensor head. These ground tests ensure proper cabling and function of the control, navigation, laser, and data storage subsystems. Once ground tests are completed, crews launch the acquisition mission. The pilot performs an in-air initialization of the navigation system, by flying a figure eight pattern, before beginning collection of the first line. After each line is acquired, the pilot makes the turn onto the next line in a tear-drop pattern. These flight patterns ensure both left and right turns are made between flight lines, which is critical for collection of the accurate IMU data required for the sensor.

Calibration Flight

A local airport will be base of operations and where we will set a calibration site. Data are collected from three different headings to identify any potential issues in the system calibration. This is in addition to the factory and primary calibration flights that are done on a regular basis. An ABGPS error of less than 5 cm to the vertical error budget will be achieved. High quality, dual frequency GPS geodetic receivers and antennae are used in both the airborne and ground base stations for recording data at a 2.0-second epochs. A system calibration file is generated with each data acquisition flight mission and is used in the processing of all LiDAR data.

Cross Flights

Cross flight lines are run perpendicular to the overall flight lines for the project area. Careful analysis takes place from the crossing flight lines to ensure that accurate modeling of the ground surface is attained from the use of the LiDAR sensor. This provides further information for data calibration and tying flight lines.

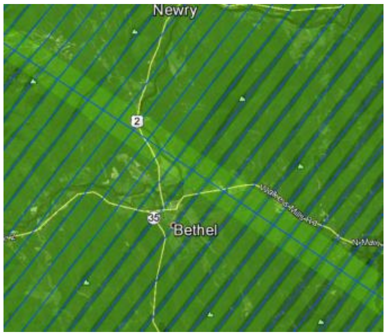


Figure 64: Example of a cross flight

Data Validation

For field quality control purposes, after each flight, the LiDAR datasets are field checked for data acquisition swath coverage and as a preliminary GPS review. Both horizontal and vertical aircraft position and orientation are verified and reviewed using the flight plan to ensure proper coverage of LiDAR data. The in-office processing steps are similar to the field processing with the addition of GPS data quality reports generation. IMU data is processed and checked for gyro bias, systematic errors, as well as positional error. The GPS trajectory of the survey aircraft is post-processed and the smoothed best estimated trajectory (SBET) is calculated combining the post-processed GPS solution with IMU and lever arm measurements. Relative accuracy of overlap consistency (interswath) will be less than or equal to 8 cm RMSEz, and smooth surface repeatability (intraswath) will be less than or equal to 6 cm RMSEz per USGS LBS v1.2.

Data Voids

Data voids for this project are defined as areas greater than four times the post-spacing of data. For the QL2 data this would be 8 m (0.71 m NPS x4)². he data sets will be reviewed to ensure data voids do not exist as part of the initial calibration and data acquisition quality control process.
Data voids that occur as a result of system malfunction or errors in collection will be scheduled for re-flight. Consistent with the USGS v1.2, data voids (areas =>(4*NPS) ², measured using 1st-returns only) within a single swath are not acceptable except:

- Where caused by water bodies.
- Where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing.
- Where appropriately filled-in by another swath.

In the unlikely event that data review determines an issue in the data during post flight processing a re-flight would be completed at the earliest convenience with no additional cost to the State of Maine.

Calibration and QA/QC Surveys

Concurrent with LiDAR acquisition, the Sewall and SSG will establish accurate control to support the LiDAR calibration and QA/QC process. The control surveys will begin with the establishment of a primary control network located throughout the Western Maine area of interest. Our local crews will deploy a combination of static and rapid-static GPS observations to develop closed polygons for this primary control network. Each of the closed loops will be carefully analyzed for closure, and after initial refinement will be combined into a least squares adjustment in order to develop the final coordinate positions for all control stations. It is anticipated that these stations will also double as either calibration points for the LiDAR surface, or as blind QA points for the bare earth land cover classification.

Once these primary control points are established, they will be used as the basis for the development of all other calibration and QA/QC check points. As discussed in Phase I, approximately 130 calibration points will be established in open areas, on generally flat terrain, and located away from significant breaks in the elevation surface for Geiger-mode and Linear-mode post-processing. Some of the points will be located on photo identifiable features (in the intensity surface) to facilitate calibration of the horizontal position of the LiDAR surface. These points will be selected along breaks in long, linear features that will be readily apparent in this intensity surface at our planned 0.71 m nominal point spacing. This might include significant transitions from concrete to asphalt surfaces, the intersection of stop bars with curb lines, or corners of tennis courts. The latter can serve as an excellent horizontal calibration location. These points will be established with dual occupation RTK surveys with reasonable baseline lengths from the primary control points. These dual observations will be conducted under differing satellite conditions to ensure independent observations. Oftentimes our crews will conduct the first observation on a point in the morning and follow up with the second observation in the afternoon, with approximately five hours of time passing between the two observations. This ensures a very different satellite configuration for the two observations. The results of these independent observations are carefully checked to ensure an accurate position of the control point.

Finally, a minimum of 275 USGS compliant NVA and VVA checkpoints will be established to verify the accuracy of the final elevation product. These points will be well distributed throughout the project area, and further will be located in the predominant land cover classifications in the project area. The land cover classifications for the Western Maine project area include bare earth; urban; forested; tall weeds; and wetland locations.

Figure 65 states the number of control Quantum Spatial requires for the Western Maine AOI based on ASPRS Positional Accuracy Standards (table located in Phase I Control Planning). This is for Geiger-mode, and Linear-mode QA/QC review.

Location	Total Area mi^2	# NVA Points	# VVA Points	Calibration Points	Total number of Points
W. Maine	7,647	160	115	130	405
		53 Bare Earth	85 Forested		
		107 Urban	18 Tall Weeds		
			12 Marsh		

Figure 65: Number of control points required for the Western Maine AOI.

The state will receive a final Control survey report per ASPRS Positional Accuracy Standards as qualified in USGS LBS v1.2 and reported as RMSE. In addition, the report will provide detailed documentation on each control point surveyed. When the ground control survey has been completed, all survey and documentation information will be examined for compliance with the project specifications and be provided to the State of Maine.

PHASE III – DATA PROCESSING

Linear-mode LiDAR Post Processing

Once collected, LiDAR datasets are provided to an accomplished and experienced processing team with almost two decades of technical expertise in LiDAR data handling—a great many with familiarity specific to USGS product deliverables. Post-processing is centered on the point cloud. Point data go through multiple inspections throughout the workflow to ensure the most representative models of the project area terrain and above ground features are ultimately delivered.

The workflow includes accurate calculations of laser point position using precise survey control and airborne GPS/IMU data, relative accuracy testing and tight line-to-line calibration, a combination of rigorous automated and manual point filtering procedures, and classification of the point cloud using in-house proprietary processing algorithms tailored for the particular study area/landscape.

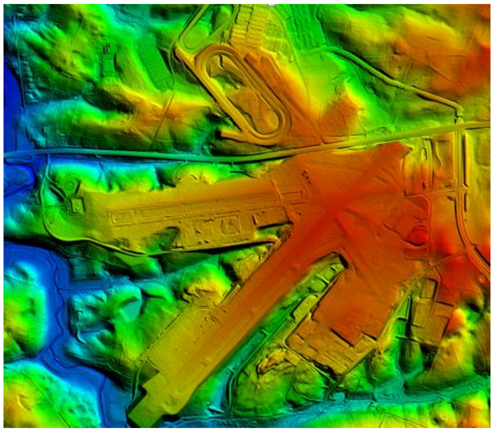


Figure 66: Example of a bare earth DEM

Quantum Spatial has been uniquely adamant in its position that calibration procedures and density evaluations are of utmost importance in achieving accurate topographic modeling. In fact, we are known within the industry for providing datasets with tight line-to-line calibrations and exceptionally high relative accuracy (<10 cm, very often <5 cm). We follow a stringent protocol for field validation methods (collection of calibration check points) and in-house calibration of flight lines, both to ensure high relative and absolute accuracy, and to facilitate data consistency among missions. In addition, native (first return density) and ground classified densities are initially calculated in calibration to check that acquisition of the AOI was completed to the nominal pulse density specified in the contract.

We also take care to match acquisitions collected over the same area at different times. For example, different projects adjacent to one another, by collecting data in an overlap area, using comparisons of ground check points collected with each acquisition area, and direct comparison of the LiDAR point clouds. When possible, the same established GPS monuments are used for each acquisition.

Processing Tasks

Processing tasks include GPS control computations, kinematic corrections, calculation of laser point position, calibration for optimal relative and absolute accuracy, classification of ground and non-ground points, and creation of ground/DSM models.

Bare earth classification is accomplished using an automated ground modeling process with visual QA/QC inspection to identify any misclassifications. We will employ LiDAR ground model parameters appropriate for the project land cover and terrain based on our past project experience. Key software includes Waypoint GPS, Trimble Business Center, IPAS TC, ALS Post Processing, ERDAS, TerraScan/TerraMatch/ TerraModeler of the TerraSolid software suite v.12, and proprietary Quantum Spatial software developed for specific workflow steps. All data will be delivered in LAS format following ASPRS format standards v1.4. Quantum Spatial has been delivering fully compliant LAS v1.4 data to USGS including for the current Maine 3DEP BAA project near Bangor.

In greater detail, LiDAR processing steps include the following:

1. Kinematic corrections—resolve aircraft position data using kinematic aircraft GPS and static ground GPS data.
2. SBET files—develop "smoothed best estimate of trajectory" (SBET) file that blends post-processed aircraft position with attitude data. SBETs are used extensively for laser point processing.
3. Calculate laser point position—SBET position is associated to each laser point return time, scan angle, intensity, etc.
4. Create raw laser point cloud in LAS v1.4 format.
5. Convert to orthometric elevations (NAVD88) by applying appropriate Geoid model correction (Geoid12B).
6. Relative accuracy testing and calibration:
   a. Automated filter of high and low strike (noise) points.
   b. Classify ground points for individual flight lines.
   c. Conduct automated line-to-line calibrations for system attitude parameters, mirror flex, and GPS/IMU drift.
   d. Calculate calibrations on ground-classified points from paired flight lines with results applied to all points in a flight line. All flight lines are used for relative accuracy calibration.
7. Classify resulting calibrated data to ground and non-ground.
8. Assess statistical absolute accuracy via direct comparisons of ground classified points to NVA and VVA checkpoint survey data collected.
9. Generate bare earth models as triangulated surfaces
10. Generate hydro Breaklines for water and drainage features
11. Perform quality control checks. Manually inspect for any anomalies. Review all metadata and final reporting for completeness and accuracy.

PHASE IV – FINAL DELIVERABLES AND REPORTING

Once the LiDAR data has gone through Phase III, the data is ready to be tiled and provided in final data formats. Regardless of the type of technology used for data acquisition and the initial post processing steps, fully calibrated .LAS v1.4 point cloud data is ingested into Phase IV and follows the same workflow from this point forward. Point clouds, DEMs, Breaklines, intensity images, and final reports are generated and reviewed. The final FOCUS report (please see Appendix C) is generated that also provides an important QA/QC tool for header, tile, point data, and projection information. The section below discusses in more detail the final deliverables for the Western Maine project.

Classification of Point Cloud

As discussed above, the classification of points into ground and non-ground is generally thought to be a basic deliverable of any point cloud dataset. This is achieved by analyzing the last return point clouds and running a series of macros that support the removal of buildings, vegetation, and other objects that prevent the LiDAR reaching the ground. The series of macros have been developed by Quantum Spatial over a decade of analysis and are highly effective at removing noise from the signal. Some object removal needs to be completed by hand such as bridge removal. The classification of the point cloud utilizes point to point analysis and varies based on the type of surface being analyzed, i.e. forested systems require analysis of large woody debris and their removal from the ground class, whereas urban areas require the identification of structures and shrubs and their removal from the point cloud. Quantum Spatial creates a large amount of its derived datasets directly from the point cloud (as opposed to through the creation of the raster DEM or TIN) and will go through a rigorous process of quality control and editing of the point cloud to ensure the classification is accurate leading to improved derivative from the datasets when compared to other contractors.

Creation of Bare Earth Surface

Processing methodologies for DEM generation include creating a triangulated surface between ground-classified points, exporting TINs as ArcGIS ASCII grids at the specified pixel resolution (typically 1 m for high resolution LiDAR), and then mosaicking the grid into a delineation/tiling system specified by the client. In the mosaicing process, Quantum, Spatial uses protocols to ensure there are no tile edge artifacts, and we take care to ensure pixels are snapped between raster models (bare earth with highest hit DEM and/or intensity images) to a common origin of 0,0 (upper left corner of NW-most pixel). Quantum Spatial's proprietary software is used to ensure consistent model output criteria are met for each project.

Quantum is also performing edge matching of the new 3DEP BAA Maine datasets currently in production to three existing LiDAR datasets using our customized 'feathering" approach that significantly reduces vertical stepping between new and old datasets while not compromising the overall accuracy of either dataset.

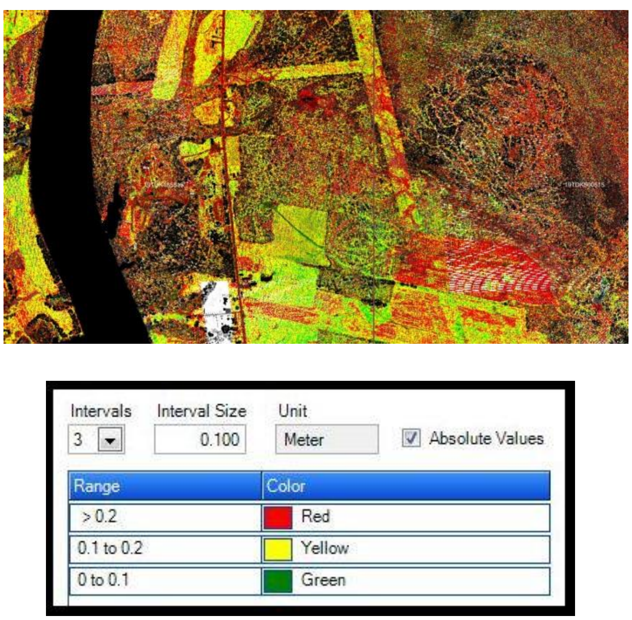


Figure 67: Before match, the red indicates the level of mismatch between 2 datasets

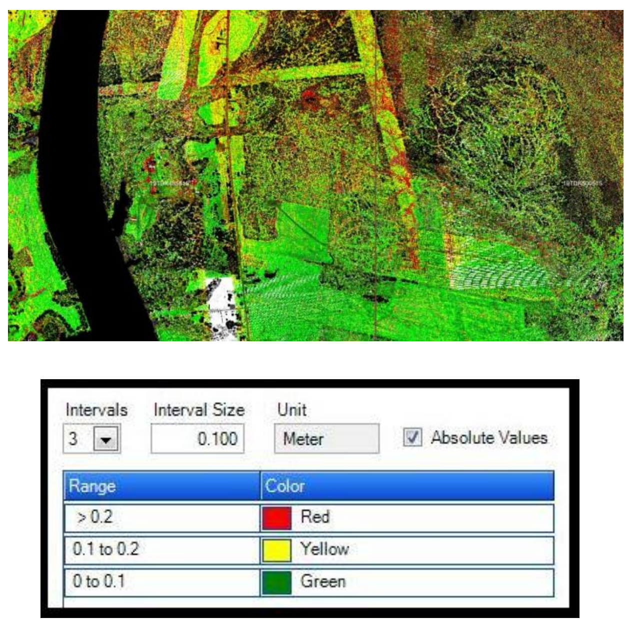


Figure 68: After match, the green indicates a match of the 2 data sets by 10 cm or less

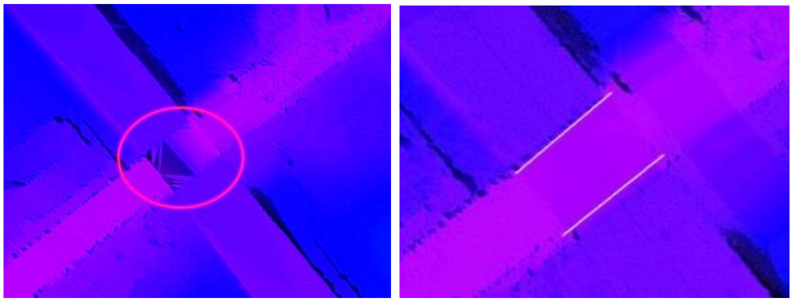


Figure 69: Quantum Spatial's Bridge Saddle Correction Process

A significant step in the bare earth DEM workflow includes proper treatment and surface representation of bridge crossings. In certain locations, a bridge that has been removed from the ground surface during automated or manual classification may create a "saddle" effect in the resulting DEM surface. This issue is influenced by factors such as bridge length, bridge width, and the characteristics of the terrain underneath and around the bridge. Our methodology involves digitizing breaklines that represent the terrain elevations underneath the bridge deck, and draping to the ground surface for integration in the final DEM. The terrain breaklines will effectively force the DEM to triangulate down to the ground beneath the bridge rather than straight across at bridge deck level. A typical location should simply require two terrain breaklines, while locations with complex freeway interchanges will require a large number in order to sufficiently reduce the saddle effect. Figure 69 shows before (left) and after (right) bridge saddle correction with breaklines for a typical bridge scenario.

Hydro-flattening of Bare Earth Surface, including Breaklines

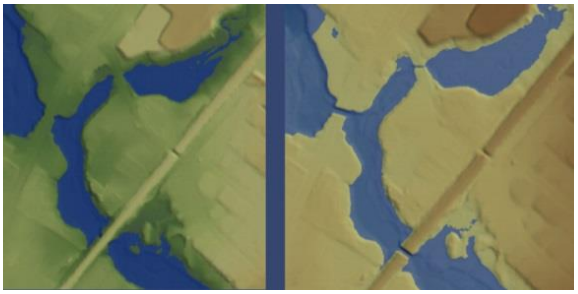


Figure 70: Example of QSI dual breakline approach demonstrating hydro flattened (L) and hydro enforced (R)

The hydro-flattened DEM is a standard USGS product to which Quantum Spatial has become accustomed and for which we have developed unique proprietary tools. In addition, Quantum Spatial also has extensive experience in simultaneously developing and delivering both hydro enforced DEM's along with USGS standard hydro flattened DEM's using a "dual purpose" breakline collection strategy where both breakline types are simultaneously collected and used alone or in combination with each other to produce the desired DEM surface. Quantum Spatial worked with USGS in 2011 to develop, evaluate, and produce two sets of these DEM types to meet both the requirements for inclusion into the NED (hydroflatten) while also supporting flood studies (hydro enforcement) for the State of Maine and FEMA Region 1. These hydro enforcement breakline collection rules first developed by Quantum Spatial and USGS have been used by USGS for many other LiDAR task orders where both DEM types are required.

Figure 70 shows the results of Quantum Spatial's dual breakline approach to hydro conditioning: two DEM covering the same area, hydro flattened on left and hydro enforced on right. Note: hydro enforcement "breaches" culverts and other land barriers using breaklines that would impede the flow of water.

Using TerraModeler and Quantum Spatial proprietary software, the hydro flattening process involves generating hydro breaklines, assigning elevation values, applying the breaklines to the DEM, and assuring proper topology and drainage monotonicity (downward flow of water). Inland ponds, lakes, streams, and rivers meeting USGS criteria (impoundments, natural or man-made greater than ~2 acres in area; all streams that are nominally wider than 100 ft; and all non-tidal boundary waters bordering the project area) are identified, and hydro-breaklines for these are digitized within the project boundary. Breaklines are developed using an algorithm which weighs LiDAR-derived slopes, intensities, and return densities to detect the water's edge. Edges are then manually reviewed and edited as necessary. Once hydrolines are developed, water body elevations are computed from the filtered LiDAR returns. Water's edge breaklines are then incorporated into the final terrain model and enforced. The initial ground classified points (class 2) falling within polygon or polyline breaklines are then re-classified as water (class 9). For hydro enforcement, all water courses are connected by breaching apparent barriers with a breakline(s) ensuring continuous downstream flow. Along shorelines, water levels will vary given changes in tide level over the course of the data collection, presenting discontinuities in the water's edge. These anomalies are retained and variations in water surface elevation from tidal variations not removed. However, Quantum Spatial generates a pseudo-line (no elevation values) along the tidal shoreline to depict a best estimate of the water's edge at time of collection. Figure 71 shows a bare earth DEM of river floodplain with irregularities in the water surface (top) and corresponding hydro-flattened DEM based on precise water's edge breakline (bottom).

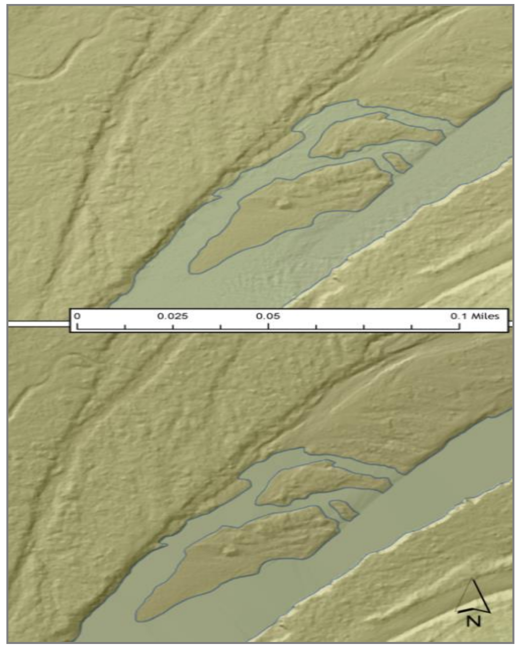


Figure 71: Bare earth DEM of river floodplain with irregularities in the water surface (top) and corresponding hydro-flattened DEM based on precise water's edge breakline (bottom).

LiDAR Intensity Images

Normalized Intensities

Laser return intensity is a unitless measure of discrete return voltage, stored as an integer value from 0 to 65535 corresponding to the surface reflectivity and composition of the target. Airborne laser systems (ALS) typically have an automatic gain control (AGC) that adjusts the receiver sensitivity depending on the intensity (or energy) of the return pulse. The AGC serves an important role in making sure that the system does not experience drop outs due to low energy returns for non-reflective targets (i.e. wet pavement, water, etc.) or saturation due to high energy returns from highly reflective objects. However, the non-linear response of the AGC produces artifacts within the raw intensity image that can confound interpretation of patterns for vegetation analysis. For example, the AGC can result in streaking as the laser scans between high and low reflective targets. In addition, the AGC will result in different intensities for the same object both within the same flight line and between flight lines.

Normalizing intensities has become an item of increasing interest in the forest and environmental LiDAR communities providing valuable data used to differentiate between classes of trees such as hardwoods, conifers, and snags, wet and not-wet areas and to distinguish the health of forest stands with respect to disease. Quantum Spatial has developed methodologies to normalize intensities with respect to gain, laser power, atmospheric transmissivity, and laser scan angle resulting in a more useable intensity image. Variability in the magnitude of intensity values across similar targets is minimized mathematically to arrive upon a normalized intensity value that approaches a true radiometric value for each discrete LiDAR return. Intensity normalization of LiDAR data can be performed as part of Quantum Spatial's standard processing workflow with no associated additional cost.

The collection of consistent intensity data for large projects requires close attention to consistent collection parameters—same sensor type and settings, consistent time of year with respect to ground conditions, and normalization of gain. To control for the intensity variation due to these factors where intensity is a key LiDAR data aspect of interest to the client, Quantum Spatial takes all precautions to ensure consistency in collection for the highest quality intensity product possible. For projects where the principal goals are to analyze above-ground features that are changeable such as vegetation structure (e.g., riparian vegetation), collecting LiDAR data in as narrow a timeframe as possible and during stable periods (with respect to leaf-on or leaf-off) is of utmost importance.

Data Deliverables

Raw Point Cloud Data (calibrated and control adjusted)

a. Fully compliant LAS v1.4, Point Record Format 6
b. Will include proper use of the LAS withheld and overlap bits.
c. Georeference information included in all LAS file headers (OGC WKT).
d. GPS times will be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return. In compliance with LAS specification requirements, the encoding tag in the LAS header will be properly set.
e. Intensity values, 16 Bit, Linear Rescaling.
f. Full swaths, all collected points will be delivered.
g. Swaths will be segmented, as described in the NGP LiDAR Base Specification.
h. A report of the assessed relative vertical accuracy of the point cloud (smooth surface repeatability and overlap consistency). Raw swath point cloud data will meet the required accuracy levels before point cloud classification and derivative product generation.
i. A report of the assessed absolute vertical accuracy (NVA only) of the unclassified LiDAR point data in accordance with the guidelines set forth in the Positional Accuracy Standards for Digital Geospatial Data (American Society for Photogrammetry and Remote Sensing, 2014). Raw swath point cloud data will meet the required accuracy levels before point cloud classification and derivative product generation.

Classified Point Cloud Data

a. Fully compliant LAS v1.4, Point Record Format 6 including "File Source ID."
b. Will include proper use of the LAS withheld and overlap bits .
c. Georeference information will be included in LAS header (OGC WKT).
d. GPS times will be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return. In compliance with LAS specification requirements, the encoding tag in the LAS header must be properly set.
e. Intensity values, 16-bit, Linear Rescaling.
f. Tiled delivery, without overlap
g. Classification Scheme (minimum):
   Class 1 - Processed, but unclassified
   Class 2 - Bare-earth ground
   Class 7 - Low Noise (low, manually identified, if necessary)
   Class 9 - Water
   Class 10 - Ignored Ground (Breakline Proximity)
   Class 17 - Bride Decks
   Class 18 - High Noise (high, manually identified, if necessary)

   Note: Classes 7 and 18 are included as a convenience for the data producer. It is not required that all "noise" be assigned to those Classes.

Bare Earth Surface (Raster DEM)

a. Cell Size will be no greater than 1.0 meter, and no less than the design Aggregate Nominal Pulse Spacing (ANPS).
b. Delivery in ERDAS .IMG, 32-bit floating point raster format
c. Georeference information will be included in raster file
d. Tiled delivery, without overlap
e. DEM tiles will show no edge artifacts or mismatch
f. Void areas (i.e., areas outside the project boundary but within the tiling scheme) will be coded using a unique "NODATA" value. This value will be identified in the appropriate location within the file header.
g. A report on the assessed absolute vertical accuracy (NVA and VVA) of the bare-earth surface in accordance with the guidelines set forth in the "Positional Accuracy Standards for Digital Geospatial Data" (American Society for Photogrammetry and Remote Sensing, 2014). Absolute vertical accuracy requirements using the ASPRS methodology for the bare-earth DEM are listed in "Absolute vertical accuracy for digital elevation models, Quality Level 0–Quality Level 3" (Table 5).
h. Depressions (sinks), natural or man-made, will not to be filled (as in hydro-conditioning and hydro-enforcement).
i. Water Bodies (ponds and lakes), wide streams and rivers ("double-line"), and other non-tidal water bodies will be hydro-flattened within the DEM. Hydro-flattening will be applied to all water impoundments, natural or man-made, that are larger than ~2 acre in area (equivalent to a round pond ~350 ft in diameter), to all streams that are nominally

wider than 100 ft, and to all non-tidal boundary waters bordering the project area regardless of size.

j. Bridges removed from the surface. However, road or other travel ways over culverts will remain intact in the surface.
k. The bare earth surface below a bridge will be a continuous logical interpolation of the apparent non-hydrographic terrain lateral to the bridge deck. Where abutments are clearly visible, the bare earth interpolation will begin at the junction of the bridge deck and approach structure. Where this junction is not clear, Quantum Spatial will use its best judgment to delineate the separation of below-bridge terrain from elevated bridge surface.
l. No geometric change will be made to the originally computed LiDAR points. Bare-earth LiDAR points that are near breaklines will be classified as Ignored Ground (class value equal to 10) and will be excluded from the DEM generation process. The proximity threshold for reclassification as Ignored Ground is typically at Quantum Spatial's discretion, but in general will not exceed the aggregate nominal pulse spacing (ANPS).
m. Streams, rivers, and water bodies meeting the criteria for hydro-flattening in the USGS LiDAR Base Specification v1.2 will be monotonically continuous where bridge decks have been removed.
n. Any breaklines used to enforce a logical terrain surface below a bridge will be delivered to USGS.

Breaklines

a. Breaklines for all hydro-flattened areas will be delivered, regardless of technique used for hydro-flattening the DEM.
b. Breaklines will be delivered in file geodatabase format, as PolylineZ and PolygonZ feature classes, as appropriate to the type of feature represented.
c. Breaklines will be developed to the limit of the project boundary area.
d. Breaklines will be in the same coordinate reference system and units (horizontal and vertical) as the LiDAR point delivery.
e. Breakline delivery will be in a single layer. Delivered data will be sufficient for the USGS to effectively re-create the delivered DEMs using the LiDAR points and breaklines without substantial editing.

Intensity Images: Intensity Images will be produced for each tile using a cell size of one meter. Intensity values will be 16-bit, linear rescaled. Imagery data format will be 8-bit, 256 color gray scale, GeoTIFF format, with world files. Images will match the tiling scheme of the Classified LAS files and DEM.

Control: Control data files with corresponding report will be delivered

Metadata: Pursuant to USGS Base LiDAR v1.2, the development and delivery of metadata will be met to include project, lift (one file per lift) and tiled deliverable product group metadata. Tile level metadata is typically not required but can be produced if the State requires. Federal Geographic Data Committee (FGDC) compliant metadata will be provided in extensible markup language (.xml) format.

Reports: The following reporting requirements USGS LBS v1.4 will be produced and delivered:
1. Project Report
2. Acquisition Report

Project Pilot: Upon completion of acquisition, control and LiDAR calibration phases, Quantum Spatial will coordinate with the State to identify a Pilot Project area that falls within the overall Western Maine AOI. A cross section of all project deliverables will be provided to Maine (or its QA contractor) for review prior to moving forward with development of the remaining portion of the AOI. Typically the pilot area is at least 5 mi^2 in size and contains a mixture of land cover types that occur with the overall AOI and have some degree of terrain relief. It is at this time that the overall NVA of the entire AOI is tested and reported using the calibrated but unclassified .LAS v1.4 data. Photo Science will also include sample metadata of all Project Pilot products.

Spatial Reference System

Maine has two zones:
- MAINE EAST ZONE FIPSZONE: 1801 ADSZONE: 4076 UTM ZONE: 19
  East zone contains Aroostook, Hancock, Knox, Penobscot, Piscataquis, Waldo, and Washington Counties.
- MAINE WEST ZONE FIPSZONE: 1802 ADSZONE: 4101 UTM ZONE: 19
  West zone contains Androscoggin, Cumberland, Franklin, Kennebec, Lincoln, Oxford, Sagadahoc, Somerset, and York Counties.

Quantum Spatial will work with Maine to define which coordinate system will be used to produce and deliver the data products. UTM meters is the standard spatial reference system for USGS and Quantum Spatial typically delivers data in both SPCS and UTM to satisfy federal and state/local stakeholders. To do this the products would be produced in one primary coordinate system then data would be converted to the secondary system after full data acceptance of the primary system by the State.

Automated QS and Reporting Tools

Quantum Spatial has developed a comprehensive set of testing and reporting tools that are employed on every LiDAR project undertaken by the firm. This suite of tools is known as FOCUS, which is an acronym for Final Observed and Calculated User Statistics. The tools within FOCUS are used by our LiDAR technicians during all phases of the office processing. As such, they are a vital link to the production of highly accurate and complete LiDAR elevation surfaces. Once the project is complete and the final deliverables written to the storage medium (typically a hard drive for LiDAR projects), FOCUS is employed on this delivery and project reports are completed from that final test These reports are provided in both a PDF and HTML format. The HTML files can be opened in any browser and serve as a very important data exploitation tool for the delivery. A number of the tests provided in these reports are required in the newly released v1.2 of the USGS Base LiDAR Specifications. These includes tests for voided areas (at NPS * 4) and spatial distribution (clustering – at NPS * 2) of the LiDAR returns, and also both relative and absolute accuracy statistics for the point cloud. The project summary within FOCUS includes a detailed accounting of LAS versioning, projection, datum, units, point formats, return information, point classification, the location of high and low points, and other useful project information on a tile-by-tile basis. There is also a detailed accounting and intuitive graphic for the final calibration of the elevation surface.

FOCUS helps us to achieve a first time right project delivery, while providing considerable information to our clients regarding their project. Please see the Appendix of our proposal for a copy of a previously provided report. Quantum Spatial's LiDAR quality assurance solution (FOCUS) includes a rigorous 17 step analysis process as a final validation of the deliverable dataset. Key analysis includes the following:

1. **Summary Statistics** – Each of the LAS headers is carefully checked LAS version, point data format, units, projection, geoid model, and datums. A quick test is also performed to verify that all points within a tile fit within the exact boundary of the tile.
2. **Shaded Relief Map** – A shaded relief map is generated from each of the actual tiles on the delivery media. It is useful deriving an overall view of the project area along with the terrain captured by the LiDAR acquisition. The shaded relief is draped over the tile layout and project boundary (when available). This graphic provides a quick visual check for missing or corrupt tiles.
3. **Minimum Elevation** – This graphic depicts the minimum elevation within the ground class for each of the tiles in the delivery. The ground class is defined as Class 2 and Class 8 (present when the model key class is part of the project requirements). This graphic is very useful for making a quick determination of unusually low points or other elevation anomalies.
4. **Maximum Elevation** – This graphic depicts the maximum elevation within the ground class for each of the tiles in the delivery. As with the minimum elevation graphic described above, the ground class is defined as Class 2 and Class 8 when present.
5. **First Return Density** – This graphic depicts the point density of first returns for each of the tiles in the delivery. This density is determined by dividing the total number of returns within a tile, using classes 1-6, 8-10, and 13-15, by the area of the tile. This value is expressed in the units of points per square meter (ppsm) regardless of the units selected (feet or meters) for the project.
6. **Relative Terrain Change** – This graphic represents the amount of elevation change within the project area using the difference between the maximum and minimum ground surface elevations. Flat areas will exhibit very little difference between min and max surface elevations and steep areas will exhibit substantial differences between these surface elevations.
7. **Collection Date Analysis** – This graphic provides information relating to how the data was collected. The graphic shows the collection date based on UTC time. Multiple acquisitions dates will be rendered with multiple colors. A statistical summary is also provided.
8. **Second, Third, and Fourth Return Locations** – The graphic will provide detailed information for the location of all 2nd, 3rd, and 4th returns in the project area.

9. **Ground Return (Bare Earth) Density** – This graphic depicts the point density for each of the bare earth returns by tile in the delivery, which are defined as Class 2 (ground) and Class 8 (model key), if applicable. This density is determined by dividing the total number of ground returns within a tile by the area of the tile.

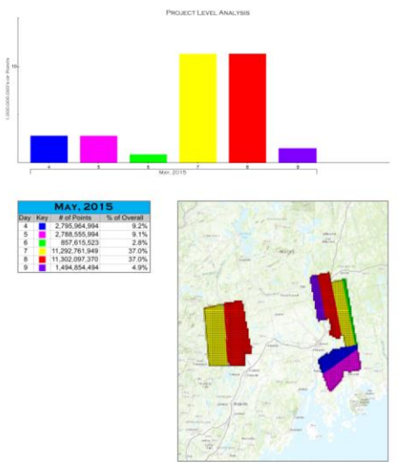


Figure 72: Example of collection data analysis

10. **Breakline Map** – This graphic depicts the location of all hydro breaklines collected for the project. The area within closed breaklines around ponds and lakes, and double line drains for large streams are rendered in blue and overlain on a screened background map for quick orientation.
11. **Overlap Shaded Relief** – Side overlap that remains consistent throughout a project area is a trademark of quality acquisition. Some variation in the overlap is to be expected, however, and this variation can be caused numerous factors. This graphic provides a clear view of swath coverage outside of the side overlap zone.
12. **Intensity Map** – Our Intensity Map is generated from each of the actual tiles on the delivery media. It is useful to get an overall view of the project area along with the intensity captured by the LiDAR acquisition. The intensity is draped over the tile layout and project boundary (when available). This graphic can isolate potential problems with the intensity values found in the LAS files.

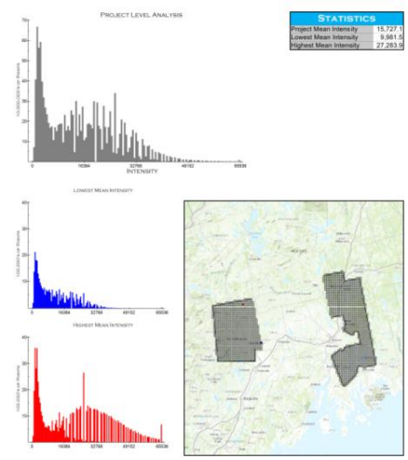


Figure 73: Example of the intensity map an histogramas

13. **Intensity Histograms** – Our intensity histograms provide detailed graphical information about all first return intensities recorded by the LiDAR sensor during acquisition. This provides an accurate snapshot of the range of these intensities on a tile-by-tile, as well as a project level basis.
14. **Calibration** – LiDAR point clouds are affected by both systematic errors or scaling, as well as variable errors that can be affected by GNSS conditions that might include baseline length, number of satellites tracked, values of positional dilution of precision (PDOP), etc. The surface is fit to ground through the using of calibration points located throughout the project area. This graphic depicts the results of the final calibration of this surface. The graphic is used to analyze the distribution of the calibration points within the project area isolate systematic errors that might remain in the LiDAR surface after calibration.
15. **Spatial Distribution Test** – This graphic provides the results of a spatial distribution test as required by the US Geological Survey (USGS) LiDAR Base Specification v1.0. A

uniform grid is overlaid on the LiDAR returns (first returns). The USGS specification requires at least 90% of the tested cells to contain at least one return. All individual void cells are illustrated within this graphic by color. This provides a very clear understanding of the location, density, and grouping of any void areas.

16. **First Return Void Test at NPS x 2 and NPS x 4** – This graphic provides the results of a test for void areas within the elevation dataset. The USGS specifications defines data voids within a single swath as unacceptable, except when caused by water bodies, areas of low near infra-red reflectivity such as asphalt or composition roofing, or where filled in by another swath.
17. **Drive Contents** – This illustration provides a quick look at the directory structure and location of all electronic files on the delivery media. All contents under the FOCUS directory are written onto the delivery media during the final checks and provide all results of these tests, including this document.

Data collected and processed for the State of Maine LiDAR program will meet the National Standard for Spatial Database Accuracy (NSSDA) accuracy standards. The NSSDA standards specify that vertical accuracy be reported at the 95% confidence level for data tested by an independent source of higher accuracy.

1. **Accuracy of the LiDAR Point Cloud Data** – The Non-Vegetated Vertical Accuracy (NVA) of the LiDAR Point Cloud data will be calculated against TINs derived from the final calibrated and controlled swath data. The required accuracy (ACCZ) is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSEz of 10 cm in the “open terrain” and/or “Urban” land cover categories.
2. **Accuracy of the Derived DEM** – The accuracy (ACCZ) of the derived DEM will be calculated and reported in three ways:
   a. **RMSEz (Non-Vegetated) –** The required RMSEz is: ≤10 cm.
   b. **Non-Vegetated Vertical Accuracy (NVA) –** The required NVA is: ≤19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSEz of 10 cm in the “open terrain” and/or “Urban” land cover categories.
   c. **Vegetated Vertical Accuracy (VVA) –** The required VVA is: ≤29.4 cm at a 95th percentile level, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for LiDAR Data, i.e., based on the 95th percentile error in Vegetated land cover categories combined (Tall Grass, Swamp/Marsh, Forested Areas).

FOCUS for LiDAR

Quantum Spatial is still in its final stages of development with its exciting new cloud based collaborative quality control tool for large geospatial data projects. LiDAR Virtual On-line Inspection, Checking, and Editing tool (VOICE) provides accuracy assessment tools, visualizations, and on-demand delivery of finished LiDAR data products through any modern data browser. As this tool is in its final stages of development costs associated with its deployment have not been included in this cost proposal for the State of Maine. We would welcome the opportunity to discuss the implementation of VOICE for LIDAR to support the Maine LiDAR program in support of the independent QA/QC contract that will also be issued to a third party.

Public and private organizations across the world are harnessing the power of geospatial data, but massive files, costly desktop software, and inefficient vendor review processes make LiDAR projects slow and painful. Quality control requires mailing hard drives, copying huge files, and tracking issues with email, spreadsheets, and screenshots. QC teams are restricted by desktop licenses, configuration times, and other IT resources. Communication and data distribution can delay projects by weeks or months.

LiDAR VOICE, powered by the Quantum inSITE software platform, allows geospatial data end users and vendors to collaborate in real time on large datasets. Cloud-based quality control increases the speed of projects by eliminating shipping and on-site distribution and reduces costs by replacing specialized desktop software. inSITE scales with your team so you can assign QC work to an unlimited amount of reviewers through VOICE's cross-platform web application. In VOICE, your team and Quantum Spatial view the same data at the same time to ensure project perfection in a single pass.

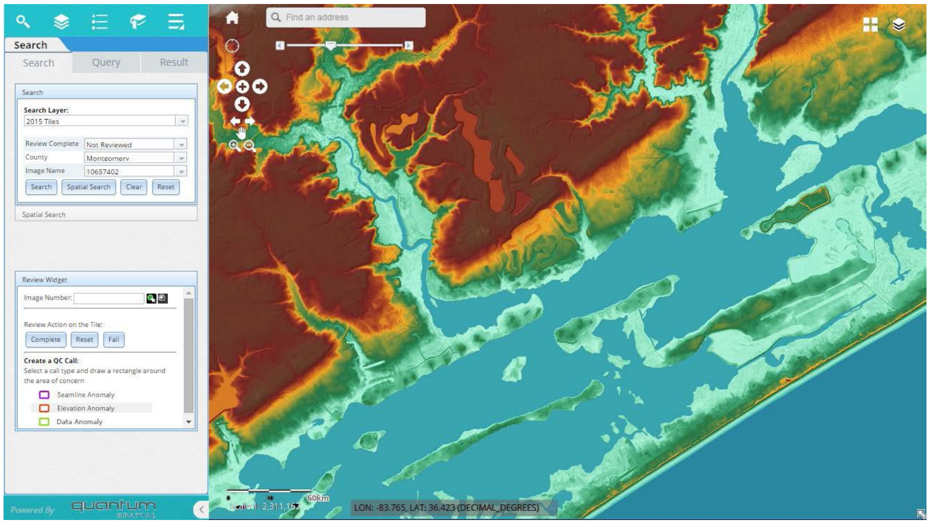


Figure 74: Screenshot from Quantum Spatial's inSITE VOICE application

The Virtual On-line Inspection, Checking, and Editing tool (VOICE), is a cloud-based application for seamless, centralized, multi-stakeholder, quality review and acceptance. This proprietary tool in current development by Quantum Spatial allows clients to visualize and review LiDAR data, as well as run independent accuracy assessments using a client's own ground control on the data prior to delivery. Clients can download individual data tiles to their local computer from VOICE. Access permissions can be set by Administrators of the tool so that specific users have access to unique functions which makes this tool ideal for State or joint stakeholder projects. VOICE for LiDAR can run on public or private clouds depending on the State's specific needs.

VOICE Highlights:

- Real-time quality control for any size dataset or team
- Reduce software deployment and maintenance costs
- Stop shipping hard drives
- Decrease time to delivery
- Ensure one-pass perfection
- Run independent accuracy assessments before delivery
- Cloud-based application provides instant web access
- Public or private cloud hosting to meet any security need
- Spatial indexing provides fastest possible LiDAR access
- Role-based privileges

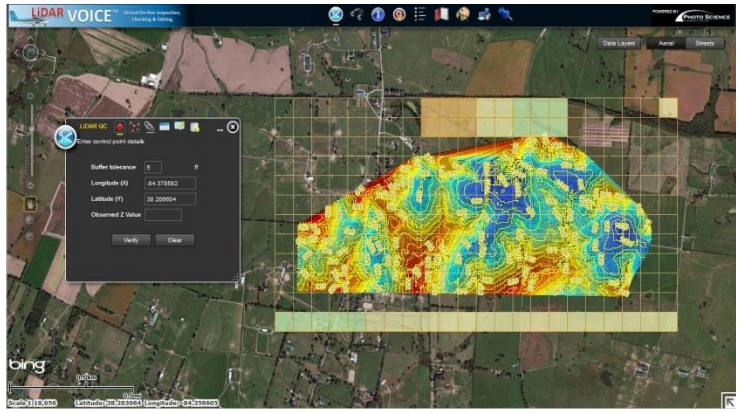


Figure 75: Sample VOICE screenshot. Client QC inspections are more efficient and effective through the use of VOICE functions for issue identification and status.

2.2.2. Mobile LiDAR Acquisition Work Plan

Quantum Spatial owns and operates the Optech Lynx M-1 Mobile Mapping System. This system is a survey grade LiDAR unit that consists of two LiDAR sensor heads, four 5-MP digital cameras, GPS, IMU and DMI sensors to orientate the unit. Each of the sensor heads is capable of emitting 500,000 pulses of light per second. This allows for typical density values of 3,000-4,000 ppsm.

Quantum Spatial is pleased to submit this technical proposal to provide mobile mapping services for the Route 302 Sample Mobile Mapping Project.

The south end of this project begins at the intersection of I-95 and Route 302, in Westbrook, Cumberland, County, Maine and follows Route 302 in a northwesterly direction for approximately 8.9 miles. The north terminus of this sample project will be the traffic circle intersection of Route 302 and Route 4/202 in Windham.

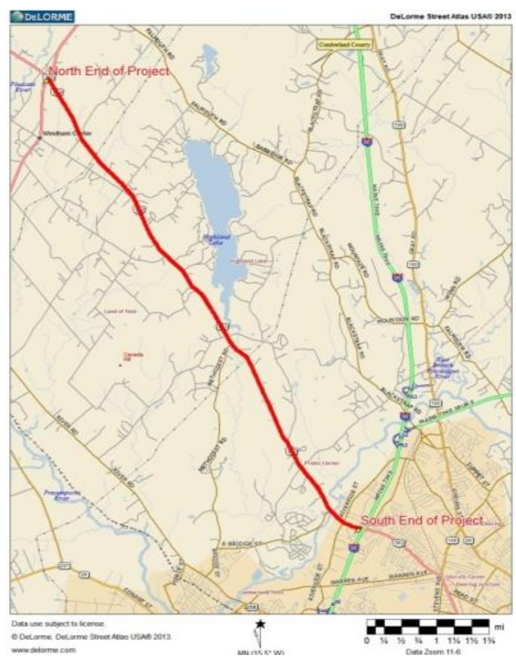


Figure 76: Sample mobile mapping project AOI

The roadway is typically bituminous pavement; primarily a two-lane cartway with turn lanes, and occasionally adding a third travel lane. From the south end, north to the "Park and Ride" lot, there is a curb on either side of the cartway with a bituminous sidewalk behind the curb along the west side of the roadway. From the "Park and Ride" north to the termination of the project, there is no curb or sidewalk.

There is a section from Riverside Street north to East Bridge Street that is four-lanes. From the East Bridge Street north to the terminus point of the project a cross section shows the roadway to be a two-lane roadway with eight-to ten foot paved shoulders on either side.

Figure 77: Looking South along 302 at I-95 overpass

Posted speed limits vary from 35 miles per hour to 50 miles per hour. The approximate length of the project is 8.9 miles.

Due to the nature and length of the project, safety of the traveling public and survey personnel is of upmost importance. Mobile mapping presents an ideal situation as it does not require lane closures nor are field personnel impeding traffic flow.

All scanning will be performed with an Optech Lynx M-1 Mobile Mapping System mounted on our Suburban vehicle and will meet or exceed the National Map Accuracy Standards (NMAS) for horizontal mapping scale of 1″=30′ and a 1 ft contour interval. The project will be driven at approximately 40 mph with a scan rate of 500,000 points per second.

The mapping bandwidth will be sufficient to capture a minimum of utility poles, road signs, fire hydrants and fence poles greater than 3 inches within 25 ft of pavement and tree lines and bush lines within 50 ft of pavement.

Images will be collected from each of the four cameras mounted on the system at one-second intervals. These images will be processed as jpeg files and utilized during the feature extraction process to assist the operator in labeling physical features. At the completion of the project these images, along with an image viewer program, will be supplied to the State.

The Optech Lynx M-1 Sensor is a survey grade sensor however; accuracies will be dependent upon the accuracy and amount of field control that is established. The QSI project manager will review all the parameters prior to setting of control so all issues can be considered and planned for. It is understood that a maximum RMSE requirement of 0.10 ft for X, Y and Z is to be assumed for the purposes of Quantum's proposal response. However, greater horizontal and verical accurcaies are routinely achieved (0.05 ft) by Quantum Spatial in support of Departments of Transportation and other clients requiring survey grade accuracies.

Mission Planning

It is suggested a kick-off meeting between the stakeholders and Quantum Spatial be held to review all the project parameters, specifications and final output. Of importance to Quantum SpatialI is the end use of the product that is to be delivered. This allows us the opportunity to make adjustments in the collection and processing of the datasets to assure the stakeholders are delivered the ultimate product.

Figure 78: Looking North along 302 at Bridge over Presumpscot River

Prior to beginning this mobile mapping project, the Quantum Spatial staff will complete a mission planning phase internally. During this phase, a detailed project scope will be developed that includes: deliverables; a safety plan; QC plan, a drive and collection plan; and a processing plan. This plan along with any additional information obtained at the kick-off meeting will be determined and reviewed by both the in-house processing staff as well as the acquisition crew.

Pre-planning will be completed so the acquisition crew can be assured there will be adequate satellites available during the data collection and that the PDOP (Position Dilution of Precision) meets the needs of the project. Typically, our planning is predicated on there being a minimum of six satellites in view for the GNSS control stations as well as the GNSS unit in the mobile mapping vehicle; PDOP value during acquisition should be no greater than 4.0.

Field Survey

As stated in the RFP and further clarified in the State's response to submitted questions and awnsers, all field ground control and base stationing survey efforts will be provided the State of Maine or its designated contractor. As a general note, we require targets be placed on the outside berm along the north bound lanes as well as along the outside berm of the south bound lanes. These targets shall be painted with a template so all targets are the same dimension (see the template design at the end of this proposal). These targets shall be spaced approximately 500-foot apart and a PK nail should be driven into the point of the chevron target as the point of control. It is estimated 190 control targets will be required.

Figure 79: Typical Target installation

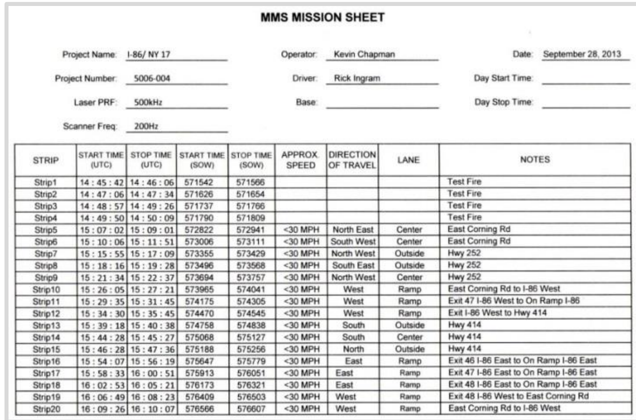
For this project, we recommend utilizing RTK duel vectors for the horizontal collection; however, vertical control will need to be completed utilizing a digital level.

Additionally, we recommend thatone permanent control point (re-bar with cap driven flush to the ground) be set mid-way through the project in a safe location (in the vicinity of Hardy Road). This station can be utilized by State survey crew to set the GNSS receivers during the actual Mobile LiDAR collection mission. Preferably close to the right-of-way line, but in a safe location to prevent theft.

Data Collection

Field collection will be dependent on having the control targets in place prior to beginning collection. The data collection proportion of any project begins with the mobilization of the mobile mapping unit and crew to the project site. Once on site, a reconnaissance of the project will be accomplished. The primary purpose of this is to:

- Locate start and stop points of the project.
- Locate all the local transformation control targets.
- Set up GNSS base station receiver(s).
- Determine any non-accessible areas.
- Determine any safety issues.
- Determine any areas of possible GPS obstructions.



MMS MISSION SHEET

Project Name: I-86/ NY 17 | Operator: Kevin Chapman | Date: September 28, 2013

Project Number: 5006-004 | Driver: Rick Ingram | Day Start Time:

Laser PRF: 500kHz | Base: | Day Stop Time:

Scanner Freq: 200Hz

STRIP	START TIME (UTC)	STOP TIME (UTC)	START TIME (SOW)	STOP TIME (SOW)	APPROX. SPEED	DIRECTION OF TRAVEL	LANE	NOTES
Strip1	14 : 45 : 42	14 : 46 : 06	571542	571566				Test Fire
Strip2	14 : 47 : 06	14 : 47 : 34	571626	571654				Test Fire
Strip3	14 : 48 : 57	14 : 49 : 26	571737	571766				Test Fire
Strip4	14 : 49 : 50	14 : 50 : 09	571790	571809				Test Fire
Strip5	15 : 07 : 02	15 : 09 : 01	572822	572941	<30 MPH	North East	Center	East Corning Rd
Strip6	15 : 10 : 06	15 : 11 : 51	573006	573111	<30 MPH	South West	Center	East Corning Rd
Strip7	15 : 15 : 55	15 : 17 : 09	573355	573429	<30 MPH	North West	Outside	Hwy 252
Strip8	15 : 18 : 16	15 : 19 : 28	573496	573568	<30 MPH	South East	Outside	Hwy 252
Strip9	15 : 21 : 34	15 : 22 : 37	573694	573757	<30 MPH	North West	Center	Hwy 252
Strip10	15 : 26 : 05	15 : 27 : 21	573965	574041	<30 MPH	West	Ramp	East Corning Rd to I-86 West
Strip11	15 : 29 : 35	15 : 31 : 45	574175	574305	<30 MPH	West	Ramp	Exit 47 I-86 West to On Ramp I-86
Strip12	15 : 34 : 30	15 : 35 : 45	574470	574545	<30 MPH	West	Ramp	Exit I-86 West to Hwy 414
Strip13	15 : 39 : 18	15 : 40 : 38	574758	574838	<30 MPH	South	Outside	Hwy 414
Strip14	15 : 44 : 28	15 : 45 : 27	575068	575127	<30 MPH	South	Center	Hwy 414
Strip15	15 : 46 : 28	15 : 47 : 36	575188	575256	<30 MPH	North	Outside	Hwy 414
Strip16	15 : 54 : 07	15 : 56 : 19	575647	575779	<30 MPH	East	Ramp	Exit 46 I-86 East to On Ramp I-86 East
Strip17	15 : 58 : 33	16 : 00 : 51	575913	576051	<30 MPH	East	Ramp	Exit 47 I-86 East to On Ramp I-86 East
Strip18	16 : 02 : 53	16 : 05 : 21	576173	576321	<30 MPH	East	Ramp	Exit 48 I-86 East to On Ramp I-86 East
Strip19	16 : 06 : 49	16 : 08 : 23	576409	576503	<30 MPH	West	Ramp	Exit 48 I-86 West to East Corning Rd
Strip20	16 : 09 : 26	16 : 10 : 07	576566	576607	<30 MPH	West	Ramp	East Corning Rd to I-86 West

Figure 80: Typical Field Collection Mission Sheet

At the completion of this reconnaissance, the crew will then locate a suitable location for the required bore site. The crew will complete a 5 minute (minimum) static secession with the mobile mapping unit and at the completion will perform an "IMU wakeup" maneuver. This maneuver consists of driving the mobile mapping unit in a figure eight configuration, while varying the speed for approximately 3-5 minutes. At the completion of this maneuver, another 5 minute static session will be completed to prepare and orientate the mobile unit for collection.

At the completion of the IMU wake up procedures, Quantum Spatial will perform a sensor alignment (bore sighting) procedure to address misalignments between the laser heads and the IMU axes. This bore sight will be accomplished by collecting LiDAR data along a minimum of three sides of a building clockwise and then reversing the procedure and collecting the data in a counter-clockwise direction. This will allow the LiDAR technician to complete a least squares procedure and apply a geometric correction or adjustment to correct for errors in the GNSS and IMU positioning information by adjusting the scan data to the adjacent passes. This will assure good alignments that produce consistency on the building wall edges. When viewing the edges of the structure, they must be clear with no duplicate lines in sight. This output of information will allow calibration of the data so that both sensors will be in the same alignment.

During the mission, we will maintain a GNSS GPS units on established ground control station to provide a strong triangulation network for the mobile mapping unit.

At the completion of the mission the operator will review all the collected datasets to assure full coverage, with no holidays and that all issues had been documented.

Figure 81: Looking North along 302 at Albion Road

The collected data will also be reviewed against the driving plan developed during the mission planning phase to assure that there is redundancy and overlap in the collection process. It is important that the mission be conducted in such a manner as to ensure redundancy of the data. This overlapping of the data can be accomplished by overlapping passes driven in the opposite direction or overlapping passes driven in the same direction. Additionally, side lap of at least 25% should be accounted for in the drive plan. This overlapping and redundancy will help the dataset processor eliminate the laser shadowing and obstructions from vehicles, etc.

The data then is downloaded from the mobile mapping vehicle hard drives onto external hard drives and shipped overnight to the office for data processing. The data is not deleted from the vehicle hard drive until notice is received that the office has received the hard drive and copied it successfully onto Quantum Spatial's server.

Processing

The mobile LiDAR processing technician in the office will begin the processing of the data by developing a final SBET (Smoothed Best Estimate of Trajectory) and Optech DASHmap software will be used in the post-processing of the GPS and inertial data. Following this step, the technician will process the raw data (Range) files into LAS for both the bore sight and mission. TerraScan and TerraModeler software, coupled with proprietary Quantum Spatial filtering routines, will be used for this operation. The TerraScan software reads raw laser points as X, Y, Z text files or binary files, and provides automated and semi-automated tools used to calibrate, check, and correct the data for systematic errors.

A tile layout will be created of the dataset so as to have more manageable file sizes. These tiles will then be populated and adjusted to the field control. The LiDAR technicians will calibrate the mobile data point cloud to the established field survey control. Control stations are set every 500 ft and will be used as both calibration points and quality control points. To complete the calibration, technicians will use every other control point (1,000 ft apart) for this purpose and then complete a quality control check using the remaining points not utilized in the calibration. This will allow for a check of the data set accuracies to be assured that it meets or exceeds the NSSDA 95% confidence level threshold.

Next project specific macros will be created and run by the technician to semi-automatically classify the data into discrete feature classes (i.e. noise, vegetation, ground, etc.). Quantum Spatial's automated LiDAR filtering methodology will be run which effectively eliminates 75-80% of "above" terrain LiDAR postings, with the remainder removed by Quantum Spatial LiDAR technicians during manual filtering QC operations to obtain a bare earth model.

All data will be manually reviewed and any remaining artifacts removed. QT Modeler will be used as a final check of the bare earth dataset. The final step is to create the deliverable LAS for the point cloud data and finalize the bare earth model.

Limiting Factors

Due to the rural nature and project length, it is necessary to establish GPS receiver set along the roadway that will need monitoring during the collection mission. For that reason, the State should anticipate providing a three man survey crew versus the typical two man collection crew during data collection. The ground conditions will be reviewed during the reconnaissance drive to be assured there were no issues with weather, or standing water from recent rains, or excessive "ponding"/"pooling" of water which affect the accuracy of the LiDAR returns.

Mobile 3-D Scanning is line of sight equipment and will only obtain information on features, structures or facilities that are visible. Quantum Spatial will extract map features visible from the LiDAR datasets, including contours, to US National Map Accuracy Standards or in accordance with specifications provided. Any features not discernible from the LiDAR dataset, due for example, to vegetation, obstructions, overhanging rooflines, or shadows may not be plotted within U.S. National Map Accuracy Standards.

All mapping should be field checked prior to use. Unless specifically included as part of this project, field checking is the responsibility of the State at its own cost.

Feature Extraction

Quantum Spatial utilizes TopoDOT software for feature extraction. This program has become the standard for feature extraction for mobile LiDAR point clouds. We further understand the State will supply all necessary seed files, line and weight tables, CADD standards, etc that are to be utilized in this collection.

Quantum Spatial will provide feature extraction of all visible planimetric features shown in "Appendix E" Mobile LiDAR Feature Names as part of RFP #201508142. The amount of data that can be mined from the point cloud and accompanying images is far reaching. We have listed a few of the generic items that QSI typically extracts for transportation related projects, but by all means this list is not all inclusive. Typical visual items to be collected include:

- Pavement Edges
- Pavement Centerline
- Shoulder Edges
- Bridge Attributes
- Guardrails
- Driveways
- Breaklines
- Highway Striping (polygon or single line)
- Signs

- Sidewalks
- Handicap Ramps
- Curb and Gutter
- Tree Lines and Individual Trees
- Fences
- Buildings
- Poles
- Street Lights
- All Overhead Utilities
- Fire Hydrants
- Manholes and Valves
- Headwalls
- Catch Basins
- Mailboxes

The following deliverable will be made by Quantum Spatial:

- Calibrated Point Cloud in LAS v1.2
- Classified LAS Files
- All feature Extraction in MicroStation v8i CADD Format
- DEM at specified grid pattern
- DTM/TIN with Breaklines in .dgn and InRoads formats Respectively
- 1 ft contour file in InRoads Format
- Images and Image Viewer
- Trajectory Data
- Survey Report, including narrative and control survey report received from others

Delivery Schedule

Although there are many factors that affect the delivery schedule for individual projects, Quantum Spatial is prepared to deliver the final deliverables for this sample project based on several assumptions:

- All side/cross roads (not driveways) will be collected a maximum distance of 200 ft from mainline
- Survey control will be by others
- The client will provide an individual to stay with the ground GPS unit (one day)
- Limits of coverage will be 20 ft from edge of paved shoulders
- Pavement cracks will not be collected
- No underground or inverts will be collected
- 3 ft DEM will be delivered
- 1 ft contours will be delivered
- Planimetric mapping in CADD will be delivered
- Images will be collected at 1-second intervals

With these assumptions, Quantum Spatial would deliver this project to the State of Maine within 60 days from the completion of the actual field collection, or, receipt of the control target values, whichever is later.

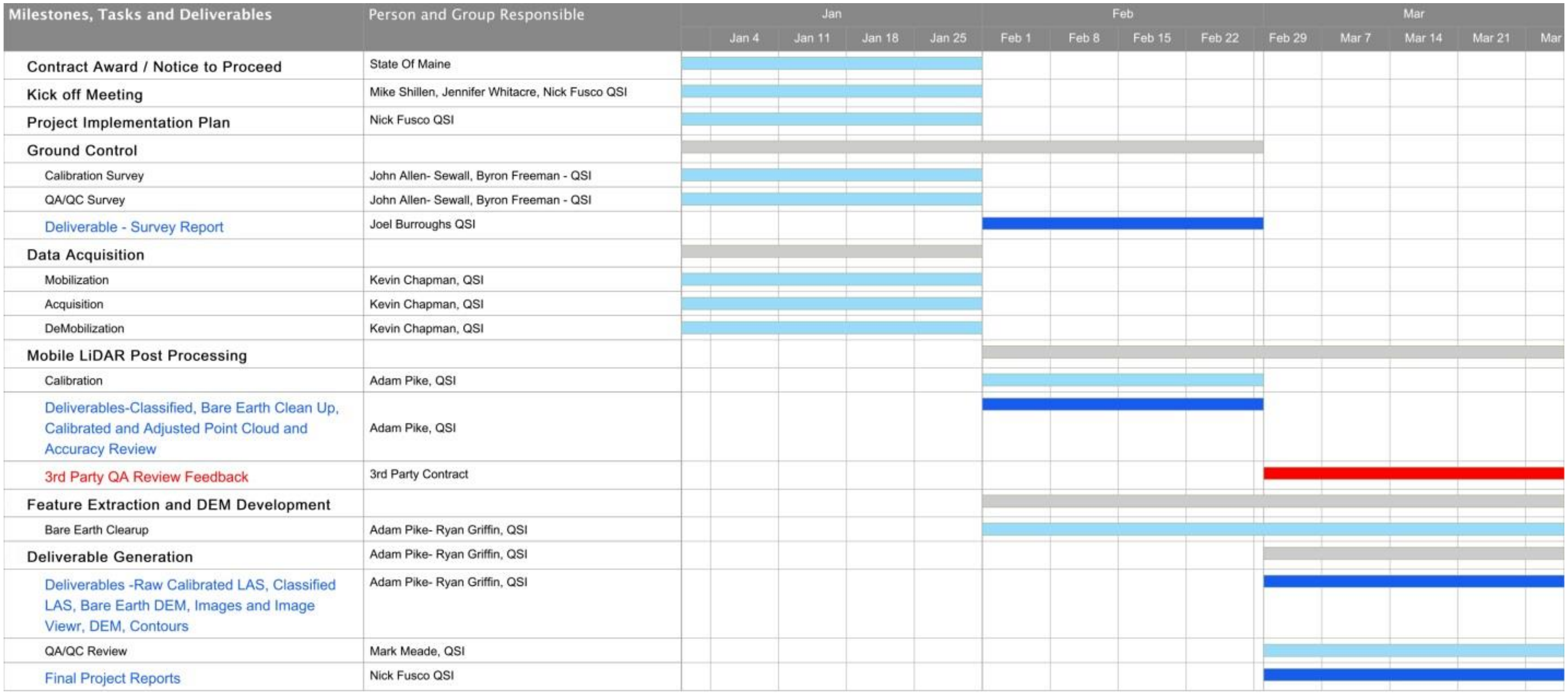


Figure 82: Mobile LiDAR Schedule for the Route 302 project

2.3. Buy Up Options

Linear-mode LiDAR

Optional QL1 (8 ANPD) Pricing

We are providing an optional QL1 buy up for Linear mode LiDAR collection. This will follow the same work plan as stated above except the data will be collected at ≥ 8 ppsm and data will be accurate to 10 cm RMSEz. Control plans will remain the same but flight plans will change. Data will be collected with a 60% sidelap. By overlapping the lines with >60% sidelap and flying opposing flight lines, the pulses hit remaining vegetation at different angles to essentially get more returns under the canopy. Time to collect this area will increase due to lower flight altitude, narrower swath, and greater side lap, which add additional flight lines. Total flight lines will be 507, these will be flown at 6900 ft AGL. Quantum Spatial would deploy three aircraft/sensors, as well as double flight crews (two crews per aircraft) to allow for up to three flights per day.

It is anticipated it will take approximately 32 days for QL1 data collection utilizing three sensors with a conservative two lifts per day. Also figured into this timeframe is downtime for clouds and weather.

Geiger-mode LiDAR

Optional QL1 (8 ANPD) Pricing

One of the benefits of Geiger mode LiDAR is the ability to collect large areas of data rapidly. Other benefits include:

- Higher resolution and higher data point density collections compared to conventional Linear-mode aerial LiDAR mapping
- Faster data collection compared to conventional Linear-mode aerial LiDAR mapping at similar point densities
- Volume data processing and early delivery of Point Cloud (and other raster elevation products, if required)
- Better penetration of intervening vegetation clutter over terrain and better ground object detection

Harris can collect QL1 data with 8 ppsm for Western Maine AOI in 15 days utilizing one sensor. Figure 83 shows a comparison of flight hours and number of days for Harris Geiger-mode LiDAR collection against traditional Linear-mode LiDAR collection at 8 ppsm for the Western Maine AOI. Flight hours shown is for on station for each sensor type. With an assumption of a nominal 5 hours a day collection and 50% weather and aircraft maintenance contingency, the number days required for the collections is also presented in Figure 83. It can be seen that Harris Geiger-mode offers about 5x better collection efficiency compared to traditional Linear-mode LiDAR systems for Western Maine AOI.

Area (mi²)	Traditional LiDAR Mapping (8 ppsm)		Harris' Geiger-mode LiDAR (8 ppsm)	
	Flight Hours	Days	Flight Hours	Days
7,647	507	32	59	15

Figure 83: Comparison of traditional and Harris Geiger-mode LiDAR collection times for the Western Maine AOI mapping project. Geiger-mode one sensor. Three sensors for traditional LiDAR

Optional 20 ANPD pricing

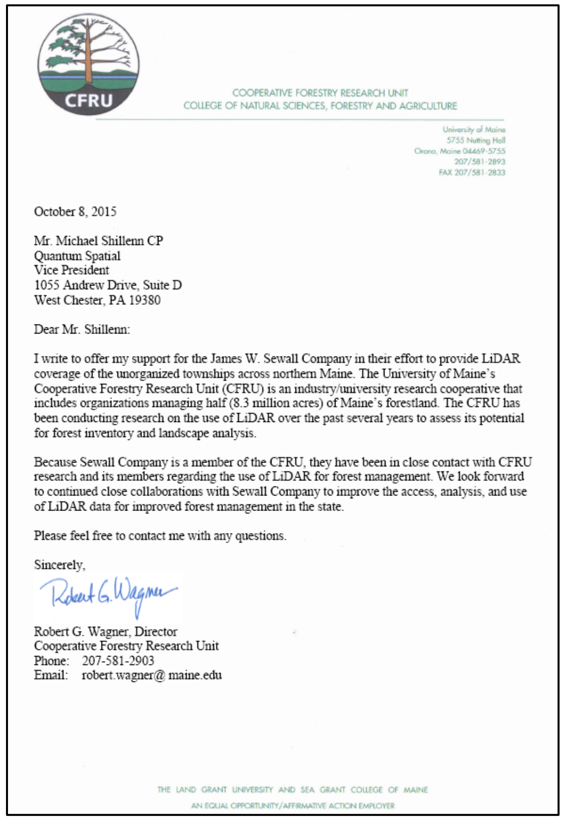
Higher ANPD collections (e.g. >20 ppsm) is feasible and advantageous for some applications such as Utility and Forestry. Geiger-mode LiDAR is collected with >50% overlap which allows signals to penetrate through vegetation clutter and detect critical structures and obscured objects underneath and on the ground. It is anticipated that it will take approximately 75 flight hours and 20 days to collect with weather factored into the schedule.

Forestry Analytics Buy Up Option and Work Plan

Our Team is comprised of highly experienced forestry management experts from both Quantum Spatial and James W Sewall Company have scoped and are providing two sets of forestry offerings for the State of Maine Proposal. Our team of experts will also collaborate with the Maine's leading forestry research body, the University of Maine's Cooperative Forestry Research Unit (CFRU). As illustrated (Figure 84) in a letter to Quantum Spatial, the CFRU has confirmed its interest in establishing a collaborative partnership in support of forestry analytics that may be contracted through the State's RFP process.

The first offering will be based on the LiDAR and available imagery data (Quantum Spatial collected 4-band NAIP imagery for the entire State of Maine in 2015, 1 m imagery is available at no cost and 1 ft. imagery is available at a charge). The second is based on LiDAR and field data. This option will be priced on a case by case basis.

The second is based on LiDAR and field data. This option will be priced on a case by case basis.



CFRU
COOPERATIVE FORESTRY RESEARCH UNIT
COLLEGE OF NATURAL SCIENCES, FORESTRY AND AGRICULTURE

University of Maine
5755 Nutting Hall
Orono, Maine 04469-5755
207/581-2893
FAX 207/581-2833

October 8, 2015

Mr. Michael Shillenn CP
Quantum Spatial
Vice President
1055 Andrew Drive, Suite D
West Chester, PA 19380

Dear Mr. Shillenn:

I write to offer my support for the James W. Sewall Company in their effort to provide LiDAR coverage of the unorganized townships across northern Maine. The University of Maine's Cooperative Forestry Research Unit (CFRU) is an industry/university research cooperative that includes organizations managing half (8.3 million acres) of Maine's forestland. The CFRU has been conducting research on the use of LiDAR over the past several years to assess its potential for forest inventory and landscape analysis.

Because Sewall Company is a member of the CFRU, they have been in close contact with CFRU research and its members regarding the use of LiDAR for forest management. We look forward to continued close collaborations with Sewall Company to improve the access, analysis, and use of LiDAR data for improved forest management in the state.

Please feel free to contact me with any questions.

Sincerely,

Robert G. Wagner

Robert G. Wagner, Director
Cooperative Forestry Research Unit
Phone: 207-581-2903
Email: robert.wagner@ maine.edu

THE LAND GRANT UNIVERSITY AND SEA GRANT COLLEGE OF MAINE
AN EQUAL OPPORTUNITY/AFFIRMATIVE ACTION EMPLOYER

Figure 84: Letter of comment from the University of Maine's CFRU to the Quantum Spatial team.

Our team's philosophy is not to make claims about the technology that cannot be substantiated over large areas and the multiple environments within Maine and so we do not believe that there is a universal equation that can provide accurate inventory statistics across the state without supporting field data. Consequently, Option 1 provides automated datasets that can be used by forestry companies to support their operations and analysis and Option 2 provides forest inventory solutions that will provide inventory information that will answer standard inventory questions. Both these options can be implemented using linear and Geiger mode LiDAR and can be implemented at a QL2 level but are generally more accurate when implemented using LiDAR at the QL1 level or at other higher densities (i.e. 20 ppsm). Accuracy of certain variables such as forest typing will also be increased when integrated with the NAIP 2015 imagery.

1. **Option 1: Forestry Datasets** – Forestry datasets derived from the LiDAR that support forest mapping and inventory
2. **Option 2: Forest Inventory Solutions** – Project specific datasets that provide forest inventory solutions

Option 1: Forestry Datasets

These datasets are designed to support forest analysis and inventory; they do not require on the ground calibration and are extracted directly from the LiDAR point cloud for forested locations. The underlying process for creating these datasets is explained below.

Data Processing (Tree/Stand Segmentation & Variable Attribution)

Refining methodologies for modeling and parameterizing forests accurately and efficiently is an active area of research in geospatial sciences. Traditionally quantified using intensive ground surveys, a number of forest characteristics can now be directly measured or indirectly modeled using LiDAR and other remote sensing technologies. QSI has been at the forefront of evaluating, developing and implementing methods to quantify forest characteristics and to inventory forest resources at a fine scale over broad areas using LiDAR and spectral imagery.

QSI has taken a forward-leaning approach to refinement of methodologies for forest characterization in a diversity of forest types across the U.S. Recent contracts have involved definition and attribution of forest stands on over 2 million acres of timber lands in northern California, coastal and central Oregon, Maine and Florida. Our approach to model forest-remote sensing relationships has progressed with each project to incorporate contemporary knowledge -- from peer-reviewed publications, collaboration with the LiDAR research community, and our own in-house expertise, research and development.

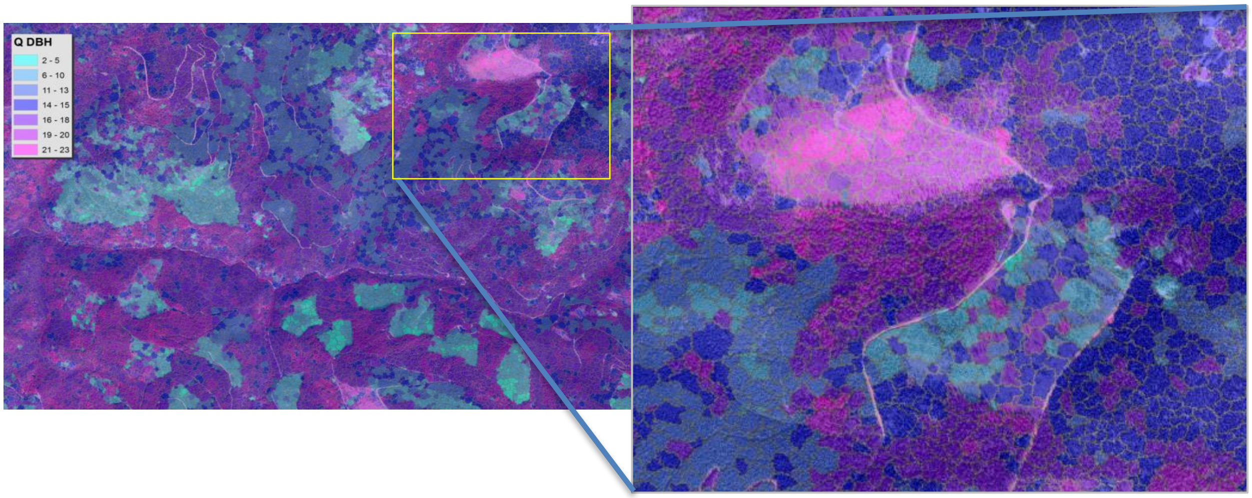


Figure 85: Example of segmented stands illustrating variation in modeled quadratic mean DBH (Q DBH), Middle Fork East River, ID.

Our approach to developing a rigorous analytical approach includes bringing in expertise from collaborators in the forest research community for any particular project including James Sewall Company and the CFRU.

The protocol developed incorporates remote sensing information for tree and stand segments to perform area-level prediction of forest attributes. This is an extension of traditional area-based inventory approaches with LiDAR to include contextual information derived from individual trees and relatively homogeneous groups of trees. Our approach works directly on the point cloud rather than the derived rasters and so has improved analytical depth over raster analysis.

The general workflow to generate stand and tree approximate polygons for the Maine forested areas includes:

1. **Generate data layers from LiDAR point cloud and imagery (where available and of** sufficient quality to incorporate into the analysis) as inputs for defining trees and stand objects

2. **Delineate trees and stands (segmentation)** using Object Based Image Analysis. Assign attributes (variables list identified below), as modeled or directly derived from LiDAR and imagery, to delineated trees and stands. In general, the attribution process involves, generating and assigning a suite of metrics (predictors) directly from LiDAR and imagery (where available) to delineated trees and stands. The tree delineation routines are based on the LiDAR and not the imagery.

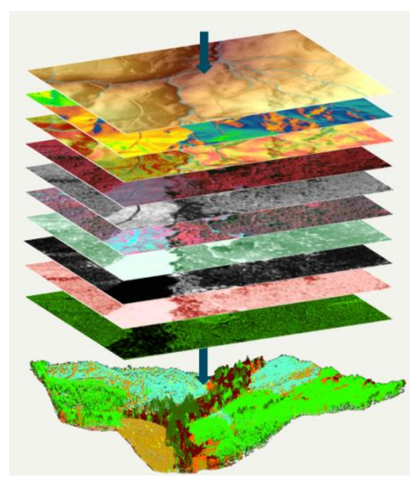


Figure 86: Model of data layer that are created to support the classification of segments

Generated Data Layers

After preparation of the dataset to isolate informative data on vegetation (filter out non-vegetation), using custom tools Quantum Spatial will generate a number of layers from the LiDAR data and imagery describing spectral and structural characteristics of the forest vegetation. LiDAR-derived layers will include (but not be limited to) the bare earth DEM and ground slope DEM, canopy surface representing height above ground (nDSM; canopy height model) and slope of nDSM, and local variability in elevation values of canopy classified points (canopy roughness). Where imagery is available spectral layers that may be useful as inputs to the segmentation will be used. These include 4-band imagery rectified to canopy surface (band values). These same input layers (along with others; see below) will be used to develop proxy descriptors (metrics) for variable model estimation.

Delineate Trees and Stands (Segmentation)

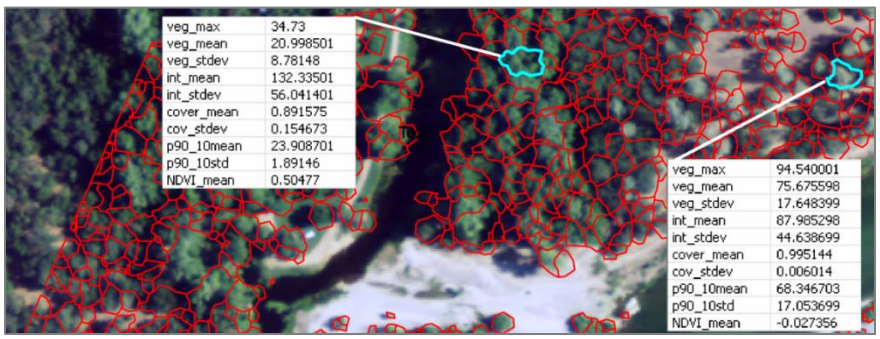


Figure 87: Example of tree segmentation, showing associated metrics for each polygon, Yuba River vegetation analysis, CA.

A first step in the segmentation process includes delineating an initial vegetation layer. Vegetation patches are created with a height from ground threshold excluding areas with no vegetation based on the nDSM. Through filtering and analysis of the canopy surface, crown peaks are identified and attributed with height and spectral information. Tree crowns are then delineated by a custom iterative region growing algorithm employing structural and spectral information for the canopy inherent in the data layers. In mature well-spaced forests, each tree crown polygon will be represented by a single stem. However, in more complex forests, a single polygon may represent a “tree approximation” which may represent a grouping of similar trees with several stems. This is especially true in dense stands with multi-tiered canopies or in multiple stem clone species.

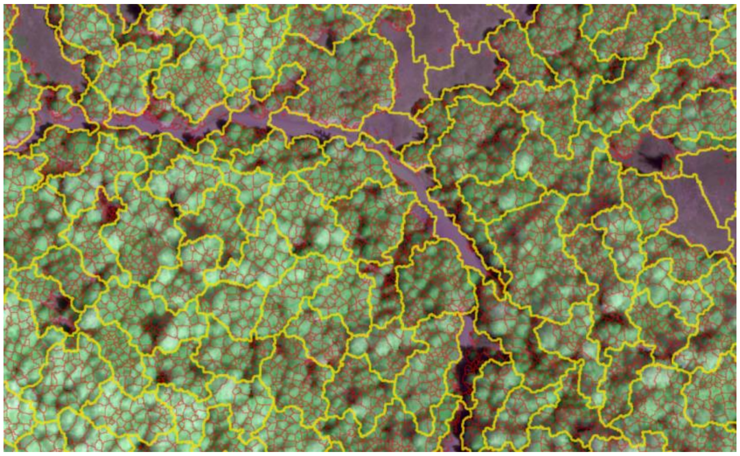


Figure 88: Example of tree (red) and stand (yellow) segmentation, overlaid on false color aerial photo, Garcia River Forest, northern CA.

Quantum Spatial will then segment the forest into discrete homogenous "stands" by agglomerating tree objects into patches based on coarsely filtered canopy height and intensity surfaces. Within the eCognition environment, "rule-sets" are developed that weigh different data layers to identify and map homogeneous regions with similar values. Quantum Spatial will work with the client to develop a stand scale that is relevant to management goals (e.g., 'microstand') and that coordinates spatial scale of salient forest features with the spatial and spectral resolution of the acquired LiDAR and imagery. This method is better at identifying gaps in the canopy than traditional grid based methods and can create better stand delineation base datasets than rasters.

Deliverable datasets could include any of the following LiDAR derived metrics (imagery derived metrics would depend on available imagery) for the sub-stand polygons. These datasets could be provided as vector sub-stand polygons or raster 10 m grid summaries.

LiDAR Derived Metrics	
Terrain surface metrics	Description
Elevation (mean)	Average ground surface elevation with vegetation and man-made structures removed
Elevation (stdev)	Standard deviation of ground surface elevation with vegetation and man-made structures removed
Slope (mean)	Average slope of bare earth surface
Slope (stdev)	Standard deviation of slope of bare earth surface
Aspect (mean)	Average aspect of bare earth surface
Aspect (stdev)	Standard deviation of aspect of bare earth surface

LiDAR Derived Metrics	
Canopy surface metrics	Description
Height	Max canopy height above ground
Canopy height (mean)	Average canopy surface height above ground
Canopy height (stdev)	Standard deviation of canopy surface height above ground
Canopy slope (mean)	Average slope of canopy surface model (nDSM)
Canopy slope (stdev)	Standard deviation of slope of canopy surface model (nDSM)
Canopy rumple	Area of canopy surface model / ground surface model
Canopy roughness	Local variability in elevation values of canopy classified first return points.
Spectral metrics	Description
Intensity (mean)	Average intensity of vegetation classified laser pulses as they return to the system (low intensity indicates lower reflectivity of the surface from which the pulse was returned)
Intensity (stdev)	Standard deviation of intensity of vegetation classified laser pulses as they return to the system
Point metrics	Description
Canopy cover	Proportion of first returns >= 20ft above ground
Vegetation cover	Proportion of first returns >=2m above ground
Echo ratio	Ratio of secondary and tertiary return to all returns
Sub-object metrics	Description
Stand density	# of tree objects per hectare
Proportion tree	Proportion of stand covered by polygons with height >=20ft
Proportion vegetation	Proportion of stand covered by polygons with height >=2m

LiDAR Derived Metrics	
Tree type metrics	Description
Fraction deciduous	Fraction of canopy that is deciduous (hardwoods)
Fraction evergreen	Fraction of canopy that is evergreen (softwoods)
Max height deciduous	Maximum height of the deciduous canopy
Max height evergreen	Maximum height of the evergreen canopy

Each of these data layers will be built from the LiDAR and can be complemented with 2015 imagery data. These datasets are not calibrated using field data at this stage in the process. Hayashi et. al, 2014[1], suggests that LiDAR derived heights using QL2 LiDAR will generally be underestimation of actual measured field height. These data will however accurately depict relative heights and forest density (stocking) variables. The calibration of these data into inventory variables can be achieved through the services offered in Option 2. Use of QL1 data can improve the direct measurement of height, canopy closure and type classification.

The deliverables offered by Option 1 are:

1. Tree approximate and sub-stand segmentation
2. 1) with LIDAR metrics listed above
3. 1) with LiDAR metrics and 2015 summer 1 m imagery metrics
4. 1) with LiDAR metrics and 2015 summer 1 ft imagery metrics
5. Summarization of LiDAR metrics in a 10 m raster grid

Option 2: Forest Inentory Solutions

Option 2 solutions are generated from the integration of LiDAR data with client provided or contractor collected field data. Since each project would be different these projects would be custom priced. The role of LiDAR and imagery can be used two ways.

1. To create an inventory variable response surface by the building of a regression tree relationship between the forest inventory variable of interest and the LiDAR and imagery metric.
2. Utilize the LiDAR and imagery to create a stratification of the forest and then utilize standard stratified inventory sampling approaches to create forest reports.

For a continuous variable such as volume the surface approach may be appropriate, but for a stand tables that shows species by size class by stocking for growth productions the stratified inventory approach would be more appropriate. The key to providing a successful forest inventory solution using Option 2 will be the scoping meeting that will take place prior to analysis being undertaken.

---

[1] Hayashi, R., Weiskittel, A., Sader, S., 2014. Assessing the feasibility of low-density LiDAR for stand inventory attribute predictions in complex and managed forests of Northern Maine, **Forests, 5**, 363-384.

Option 2 solutions would build off the work completed in Option 1 and continue with the analysis provided below.

a. Scoping meeting and deliverables definition
b. For forest inventory response surfaces
    a. Design field data collection
    b. Implement field data collection design or utilize plot data provided by client
    c. Compute plot-level variables (responses) from field data
    d. Spatially associate tree points and field plots with delineated trees and stands, respectively.
    e. Reduce number of model predictors through an ordination technique
    f. Develop statistical models (multivariate regression) between refined list of metrics (predictors) and true values from field plot data (response variables)
    g. Evaluate model performance to determine reliability of predictive equations for variable estimation
    h. Attribute trees, sub-stands and stands with requested list of variables
c. For stratified inventory solutions
    a. Use LiDAR and imagery to create stratification of forest type, tree size and stocking, this may require photo-interpretation if classification beyond evergreen-deciduous is needed
    b. Calculate required number of plots per stratum
    c. Design field data collection
    d. Implement field data collection design or utilize plot data provided by client
    e. Create stratified inventory reports

The deliverables for these projects would be determined with the client but could be selected from the list below.

- Forestry canopy closure layer
- Fraction of canopy deciduous (hardwood)
    - Further classification into tree type can be developed
- Fraction of canopy evergreen (softwood)
    - Further classification into tree type can be developed
- Biomass and volume based on relationships developed from client's data sets
- Size class based on relationships developed from client's data sets
- Full stratified forest inventory using the LiDAR and imagery to develop the stratification

3. COST PROPOSAL

State of Maine
Department of Administration and Financial Services
COST PROPOSAL FORM
RFP# 201508142
LiDAR Data Acquisition

Bidder's Organization Name:

Quantum Spatial, Inc.

LiDAR Acquisition

Product	Project Area - Cost/Sq. Mi.		
USGS QL2 Specification Aerial LiDAR acquisition and standard deliverables	< 2,000 sq. mi.	2,000 to 4,000 sq. mi.	> 4,000 sq. mi.
Cost per Square Mile	$ **193.54**	$ **170.26**	$ **165.42**

LiDAR Quality Assurance/Quality Control

Product	Project Area - Cost/Sq. Mi.		
QA/QC for USGS QL2 Specification Aerial LiDAR acquisition deliverables	< 2,000 sq. mi.	2,000 to 4,000 sq. mi.	> 4,000 sq. mi.
Cost per Square Mile	$ **N/A**	$ **N/A**	$ **N/A**

Note: The Department anticipates making two award(s) as a result of this RFP process, one contract award for LiDAR acquisition and one award for LiDAR Quality Assurance services. Vendors may bid on both components; however, a vendor will not be awarded both service areas.

Quantum Spatial QL2 LiDAR Cost Proposal Assumptions:

1. Per State's Q&A Response, the minimum square miles for the <2000 square mile category shall be 1,000 sq. miles.
2. QL2 pricing shown in the pricing table above applies to both linear-mode LiDAR and Geiger-mode LiDAR acquisition technology options and includes the use of both on shore and offshore resources to support manual editing of point cloud data.

An alternative QL2 cost table is provided on the next page that utilizes 100% on-shore resources.

3. The QL2 units costs shown in the table above are based on the costs associated with the Western Maine and Down East AOI's. Due to the remote and inaccessible nature of the Northern Maine AOI identified in the State's RFP it may be necessary to minimally increase these unit costs to accommodate the additional level of effort expected to establish GPS base stations during acquisition missions and to establish both calibration and QA control points per USGS Base LiDAR Specifications v1.2.

Alternative Pricing and Optional Buy Ups

1. **QL2 LiDAR Acquisition- On Shore Only**

Product	Project Area - Cost/Sq. Mi.		
USGS QL2 Specification Aerial LiDAR acquisition and standard deliverables	< 2,000 sq. mi.	2,000 to 4,000 sq. mi.	> 4,000 sq. mi.
Cost per Square Mile	$ 248.46	$ 228.85	$ 215.77

2. **QL1 Buy Up Pricing – Geiger-mode Lidar**

Product	Project Area - Cost/Sq. Mi.		
USGS QL1 Specification Aerial LiDAR acquisition and standard deliverables	<2,000 sq. mi.	2,000 to 4,000 sq. mi	> 4,000 sq. mi.
Cost per Square Mile	$ 294.85	$ 261.69	$ 231.15

3. **QL1 Buy Up Pricing – Linear-mode LiDAR**

Product	Project Area - Cost/Sq. Mi.		
USGS QL1 Specification Aerial LiDAR acquisition and standard deliverables	<2,000 sq. mi.	2,000 to 4,000 sq. mi	> 4,000 sq. mi.
Cost per Square Mile	$ 326.93	$ 307.31	$ 300.77

4. **20 ANPD (ppsm) Geiger Buy Up Pricing**

Product	Project Area - Cost/Sq. Mi.		
USGS QL1 Specification Aerial LiDAR acquisition and standard deliverables	<2,000 sq. mi.	2,000 to 4,000 sq. mi	> 4,000 sq. mi.
Cost per Square Mile	$ 449.23	$ 362.00	$ 324.92

5. **Mobile LiDAR Optional Pricing, Route 302 Sample Project - Quantum Spatial's fee for** the Route 302 Sample Project is a total of $60,756.00. This cost is developed based on the assumptions stated in the Mobile work plan and does not include control surveys, which we understand will be provide by others.

6. Forest Analytics Buy Up Pricing

		10-100,000 acres		100,000-500,000 acres
Deliverable	**Minimum Order**	**Cost per sq. mile**	**Cost per acre**	**Discount on area > 100,000 acres**
1. Tree approximate and sub-stand segmentation	$10,000.00	$135.96	$0.21	25%
2. Segmentation with LiDAR metrics	$10,000.00	$208.33	$0.33	25%
3. Segmentation with LiDAR metrics and 1 m summer 2015 metrics	$10,000.00	$232.02	$0.36	25%
4. Segmentation with LiDAR metrics and 1 ft summer 2015 metrics	$10,000.00	$245.66	$0.38	25%
Cost Per AOI				
5. Summarization of metrics in a raster grid (size to be selected by client)	$1,000.00	$800.00		

4. ECONOMIC IMPACT WITHIN THE STATE OF MAINE

Commissioned by the USGS, The National Enhanced Elevation Assessment Study (NEEA; Dewberry, 2011) assessed the need and impact of QL2 LiDAR data nationwide. It estimated that the State of Maine will realize benefit/ cost ratio of 3.5 to 1 over the 8-year period associated with the implementation of the 3D Elevation program (3DEP). The State of Maine is coordinating with USGS on the realization of Statewide LiDAR through the use of a state managed LiDAR acquisition contract for which Quantum Spatial is submitting this proposal.

The Quantum Spatial Team will have a significant economic impact upon and within the State of Maine over the course of the five year contract period. Maximum impact will result from the utilization of its three Maine based sub consultants, James W. Sewall Company located in Old Town, Kappa Mapping Inc. and Shyka, Sheppard & Garster Land Surveyors both located in Bangor. All three firms are small businesses with Sewall located in a HubZone and Kappa being certified as a DBE/WBE. Each firm has been assigned critical roles supporting the development of LiDAR datasets acquired and processed over the life of the contract.

All three firms currently employ 77 individuals who live in the state. These firms and their staff pay corporate, individual, sales and property taxes, as well as, portions of their health care insurance premiums, short- and long-term disability insurance, retirement, and fitness club memberships. These individuals each contribute to the Maine economy through taxes such as automobile and property, as well as daily living expenses. As the economy continues to improve and with a well-funded statewide LiDAR program, these groups expect to add new positions each year. Currently, Sewall is advertising for 7 more positions. These companies belong to state chapters of associations and attend conferences held within the State of Maine. All three firms pay local taxes including property taxes. To the State of Maine, all three pay corporate taxes; professional license fees; aircraft registration fees; vehicle registration fees; and sales tax on all purchases. Partners, subcontractors and vendors that each firm regularly works with are primarily located within the State of Maine. The staff of all three firms patronize businesses in Old Town (Sewall) and Bangor (Kappa, SSG) supporting those local economies. Together all three firms contribute thousands of dollars per year to local charities and for advertising in local publications.

Quantum Spatial has conservatively estimated that the utilization of these three firms will conservatively generate in excess of $1,500,000 in revenue based on the completion of the remaining 20,000 mi^2 of LiDAR envisioned by State. Additional revenue opportunities for these three firms are highly likely from services and deliverables that have yet to be identified or cultivated by the State and/or by the Quantum Team, led by these Maine firms, in partnership with other public and private stakeholders.

In of itself, Quantum Spatial will contribute to Maine’s economy over the life of the contract paying taxes, fees, and aircraft expenses such as hangar space rent, aircraft fuel, and routine maintenance while mobilized in the State during the acquisition phase. Our flight crews will be stationed in Maine during active acquisition supporting the local economy with living expenses (food, lodging, etc).

APPENDIX

Please find attached on the following pages the required forms requested for this response. For your ease, the documents are in the following order:

A. Debarment, Performance, and Non-Collusion Certification Form

B. Resumes for Key Personnel

C. Example FOCUS Report

APPENDIX A

DEBARMENT, PERFORMANCE, AND NON-COLLUSION CERTIFICATION FORM

Debarment, Performance, and Non-Collusion Certification

By signing this document I certify to the best of my knowledge and belief that the aforementioned organization, its principals, and any subcontractors named in this proposal:

a. *Are not presently debarred, suspended, proposed for debarment, and declared ineligible or voluntarily excluded from bidding or working on contracts issued by any governmental agency.*
b. *Have not within three years of submitting the proposal for this contract been convicted of or had a civil judgment rendered against them for:*
   i. *fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a federal, state or local government transaction or contract.*
   ii. *violating Federal or State antitrust statutes or committing embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property;*
   iii. *are not presently indicted for or otherwise criminally or civilly charged by a governmental entity (Federal, State or Local) with commission of any of the offenses enumerated in paragraph (b) of this certification; and*
   iv. *have not within a three (3) year period preceding this proposal had one or more federal, state or local government transactions terminated for cause or default.*
c. *Have not entered into a prior understanding, agreement, or connection with any corporation, firm, or person submitting a response for the same materials, supplies, equipment, or services and this proposal is in all respects fair and without collusion or fraud. The above mentioned entities understand and agree that collusive bidding is a violation of state and federal law and can result in fines, prison sentences, and civil damage awards.*

Failure to provide this certification may result in the disqualification of the Bidder's proposal, at the discretion of the Department.

To the best of my knowledge all information provided in the enclosed proposal, both programmatic and financial, is complete and accurate at the time of submission.

Name: Michael B. Shillenn, CP		Title: Vice President
Authorized Signature:		Date: October 23, 2015

APPENDIX B
RESUMES FOR KEY PERSONNEL

Michael B. Shillenn, CP

Project Assignment
Principal-in-Charge, Quantum Spatial

Education
BS, Geography, Pennsylvania State University, 1987
Retired, Pennsylvania Army National Guard - Logistics, Fort Indiantown Gap, 2003

Registration
ASPRS Certified Photogrammetrist No. R1027

Years of Experience: 28

Years with Quantum Spatial: 11

As a Vice President of Photo Science, Mr. Shillenn has a strong management background with more than 24 years of experience in photogrammetric mapping including the application of softcopy photogrammetric processes, airborne GPS (ABGPS), and Inertial Measurement technologies. He is also experienced in the application of LiDAR, non-photogrammetric data conversion, GPS, and GIS technologies.

His responsibilities include Quality Assurance and Quality Control for photogrammetric and GIS projects, project design and estimation, contract administration and scheduling, and client liaison. He coordinates project activities with assigned project managers and technical staff.

At his present capacity, Mr. Shillenn provides management, marketing, and technical directions to project teams and their clients. He has in depth knowledge and experience in meeting pre-determined specification and procedures to meet or exceed client expectations. He has been instrumental in focusing on large complicated, federal government programs and projects and works with all offices to support quality deliveries.

Geospatial Products and Services (GPSC), U.S. Geological Survey. Program Manager. Mike is providing contract management, budget oversight, subcontractor coordination, and personnel oversight of Quantum Spatial's GPSC 2. Since assigned as the USGS Program Manager in 2010, Mike has managed the successful completion of 45 task orders with overall qualitative performance rating of "very good" to "excellent" on 96% of evaluated task orders. He is highly proficient with USGS's specifications, particularly the USGS LiDAR Base Specifications v1.2, tasking and QA standards, requirements, deliverables, and contractual/SOP requirements associated with USGS's Commercial Partnerships Team. Mr. Shillenn is currently working with technology and operations teams on 18 active task orders that span a wide variety of services and technologies.

3DEP BAA: Maine & Massachusetts QL1 & QL2 LiDAR, U.S. Geological Survey. Program Manager. Mike is providing contract management, budget oversight, subcontractor coordination, and personnel oversight of Quantum Spatial's GPSC 2. In the spring of 2015, Quantum Spatial commenced acquisition, process and delivery airborne topographic LiDAR data covering specified Areas of Interest (AOI) located in Massachusetts and Maine totaling approximately 5,967 mi^2. LiDAR data is being collected at an aggregate nominal pulse spacing (ANPS) of 0.35 meters with a point density of 8 ppsm (QL1) for an 815 mi^2 AOI in MA and 0.7 meters ANPS with a point density of 2 ppsm (QL2) for the remaining 2,270 mi^2 AOI in MA, as well as, a 2,882

mi^2 AOI in ME. A non-vegetated, bare earth vertical accuracy (NVA) of ≤ 19.6 cm at the 95% confidence level (10 cm RMSEz) will be achieved for all AOIs.

North East LiDAR, U.S. Geologic Survey. Program Manager. As Program Manager, Mike provided task order management, budget oversight, subcontractor coordination, and personnel oversight. Quantum Spatial (as Photo Science) collected and processed LiDAR data of a coastal zone spanning six North Eastern states, including Maine, New Hampshire, Massachusetts, Connecticut, Rhode Island, and New York. This multi-task order approach by USGS and participating federal, state and local agencies resulted in LiDAR acquisition and processing of over 8,000 mi^2 including enhanced vertical accuracies, post spacing and tide-coordinated acquisition of selective areas. Quantum Spatial provided all aspects of the project including project management, data collection and processing, control surveys, product development, and quality control.

LiDAR Data Enhancement, U.S. Geologic Survey. Androscoggin County, ME. Program Manager. As Program Manager, provided task order management, budget oversight, subcontractor coordination, and personnel oversight. The project included supplemental processing of existing LiDAR data covering Androscoggin County, Maine to include delivery of 2.5 foot, hydro flattened, DEM, classified .LAS files, metadata and reports. Quantum Spatial (as Photo Science) initially performed the LiDAR acquisition and bare earth processing of the dataset for FEMA Region 1 as a subconsultant working for the Region's assigned RiskMap Contractor.

State of North Carolina LiDAR Program, State of North Carolina. Account Manager. As Account Manager, Mike served as a client liaison and performed budget oversight and overall management of the program. In the spring of 2014, Quantum Spatial (as Photo Science) coordinated and collaborated with the State of North Carolina Emergency Management's (NCEM) Statewide Topographic Data Acquisition Program to collect and process 20 coastal North Carolina counties. This Phase 1 project was done in partnership and with funding from USGS. The LiDAR data was collected to assist in evaluation of storm damage and erosion of coastal systems from Hurricane Sandy. In 2015, Quantum Spatial was tasked to collect an additional 13 counties for the State. This was for Phase 3 of the statewide LiDAR which comprised of approximately 6,950 mi^2 of additional data collection. As with Phase 1, LiDAR data was collected at QL2 specifications. Data collection began in January 10, 2015 and continued through March 22, 2015.

LiDAR NRCS New York, AMEC. Project Manager. As Project Manager, Mike provided task order management, budget oversight, subcontractor coordination, and personnel oversight. As a subconsultant, Quantum Spatial (as Photo Science) provided the USDA's Natural Resources Conservation Service (NRCS) New York State office with high-resolution digital elevation model developed from LiDAR data for three (AOIs in south central and western New York 1,032 mi^2. The south-central AOI is south of Syracuse in Tioga County (Dean Creek) totaling 57 mi^2. The western AOI's include portions of Genesee County totaling 335 mi^2 and all of Livingston County totaling 640 mi^2. Acquisition and processing of LiDAR data has been designed to adhere to USGS's NGP Base LiDAR Specification v13.

Jennifer Whitacre, GISP

Project Assignment
Contract Administrator, Quantum Spatial

Education
BA, Geography, Indiana University, 1994

Registration
GISCI Certified GIS Professional No. 62163

Years of Experience: 14

Years with Quantum Spatial: 8

As an Account Manager, Jen is responsible for business development efforts as it relates to geospatial state and local programs. Jen has an established relationship with numerous agencies throughout the United States. Jen spends most of her time serving as a client liaison and collaborating with stakeholders on Quantum Spatial's more complex programs.

In the past, Jen's responsibilities have included project management, production supervision, and quality control for LiDAR, DEM data processing, cartographic production, planimetric mapping, and digital orthoimage processing. Jennifer has also worked with production teams to coordinate and facilitate the creation, editing, and quality checks of the surface data from the data acquisition phase through delivery to the client. Jen ensured that all tasks in the project scope were adhered to and all contract specifications were met. Jen resolved technical and/or quality issues during projects to ensure all phases meet with success. Jen has managed various projects for USCOE, NRCS, FEMA, USGS, USDA, and other state and County clients.

Beaverhead County LiDAR, MT. Account Manager. Jen pursued and won the State of Montana project award for aerial LiDAR collection and aerial imagery collection services, data processing and deliverable generation performed in compliance with project specifications. LiDAR will be collected at 8 points per square meter to ensure at a minimum 8 ppsm first return. All overlapping flight lines will be flown in opposing directions to maximize detection of swath-to-swath inconsistencies and to minimize any off-NADIR shadowing from vegetation or terrain. LiDAR data accuracy will be 9.25 cm RMSEz (18.2 cm Accuracyz) and suitable for 1 foot contour generation.

LiDAR of Buttermilk Creek Watershed & Western New York Nuclear Service Center. Account Manager. Jen pursued and won the project award for aerial LiDAR collection and aerial imagery collection services, data processing and deliverable generation performed in compliance with project specifications and FEMA, Appendix A, Guidelines. Deliverables included: Color orthoimagery at 0.25-ft and 0.5-ft GSD in MrSID & GeoTiff formats; classified LiDAR point clouds in ASCII & LAS formats; Filtered Bare Earth Point Clouds in ASCII & LAS; Breaklines in Esri Feature Class (pGDB); Bare Earth DTM (0.5m grid &1.0m grid) in ASCII & ESRI.

Los Angeles County LiDAR, OMGFAST. Account Manager. Jen led the new business opportunity and coordinated with the client during the project. The project required aerial LiDAR collection services, data processing and deliverable generation of 2,182 mi^2 performed in compliance with project specifications and FEMA, Appendix A, Guidelines. Deliverables included raw and classified LiDAR point clouds in LAS formats, Bare Earth DEM in Esri format, First Return DSM in Esri Format, reports, and FGDC metadata. Data was collected at 2 ppsm and accurate to 12.5 cm RMSEz.

Gallatin River & Bozeman Creek LiDAR & Aerial Mapping, Montana DNRC. Account Manager. Jen led the new business opportunity and coordinated with the client during the project award to collect aerial LiDAR data at 8.4m NPS. Deliverables included LAS data, 1 m DEM, hydroenforced breaklines, DTMs, 0.5 m intensity images, 1-foot contours, bathymetric cross section data, merged LiDAR/bathy elevation model, reporting and metadata. Projects were collected and processed following USGS and FEMA PM61 Guidelines.

Monroe County, Indiana LiDAR. Account Manager. Jen led the new business opportunity and coordinated with the client for the 411 square mile project area. Services include aerial LiDAR and digital imagery collection. LiDAR acquired to FEMA Guidelines at 1.4m NPS & a planned vertical accuracy of better than 15cm RMSEz. Final deliverables included: Classified LiDAR point cloud data in LAS file format, Bare earth DEM in ESRI 5-ft grid format; LiDAR DTM in shapefile format; 2-ft contours in shapefile and CAD formats; 6-in color digital orthoimagery in GeoTIFF & MrSID formats.

LiDAR of 23 Mining Sites in Newton County, MO, Black & Veatch. Account Manager. Jen served as a liaison with client on project award to perform aerial imagery and LiDAR data collection services and produce the following deliverables: planimetrics at 50-ft map scale; color orthoimagery at 0.5-ft GSD in TIFF file format; 1-ft contours.

LiDAR BiFrost & Lake St. Martin, Manitoba, Canada, Atlis. Account Manager. Jen led the new business opportunity and coordinated with the client during the project award to collect aerial LiDAR data at 1.1m NPS. Ground control provided by client. Processed LiDAR data and delivered classified LAS files, bare earth data and metadata and achieve 15cm vertical accuracy requirement for this floodplain mapping project.

Mark Meade, PE, PLS, CP

Project Assignment
QA/QC Manager,
Quantum Spatial

Education
MBA, Business Administration, University of Kentucky, 1987
BS, Civil Engineering, University of Kentucky, 1983

Registration
ASPRS Certified Photogrammetrist No. R1050
Professional Engineer: KY No. 15056, NE No. E14837, No. WV
Professional Land Surveyor: GA No. 2750, KY No. 2970, SC No. 24536, WV No. 1139

Years of Experience: 14

Years with Quantum Spatial: 8

Mark has a strong management background with extensive experience serving as a technology advisor on numerous large-scale and complex contracts with Quantum Spatial. As an ASPRS Certified Photogrammetrist, Mark is knowledgeable of national mapping guidance and policy. Currently, Mark serves as the Chief Technology Officer where he works very closely with Quantum Spatial's Professional Services and Product & Technology (P&T) teams to develop, implement and monitor Quantum Spatial's Quality Management Plan.

Mark has authored numerous publications on innovative technologies in the geospatial field for Point of Beginning Magazine. Mark is past-president and served as National Director of the Kentucky Chapter of the American Council of Engineering Companies (ACEC). He is also the past-president of the Kentucky Engineering Foundation (KEF). Mark has expertise in surveying (all types), bathymetry, aerial imagery, GPS & LiDAR data collection and processing, orthophoto generation, DEM/DTM development, AT, compilation, CAD, GIS, and metadata documentation.

Statewide LiDAR & Orthophotography, State of Kentucky. Quality Manager. Mark has overall responsibility of ensuring all deliverables meet or exceed contract requirements. Quantum Spatial was tasked to provide 4-band leaf-off, digital aerial imagery acquired using our DMC cameras. Additionally, Quantum Spatial has collected and processed over 7,000 mi^2 of airborne LiDAR as part of the program. Program deliverables include leaf-off natural color and near infrared digital orthophotos at 1 foot and 0.5 foot GSDs, numerous digital elevation products derived from LiDAR and selective planimetric and topographic mapping updates. Quantum Spatial's cloud based ortho QA tool, VOICE, has been customized and deployed to support collaborative QA review of the orthoimagery across state, and local agencies. To date, a total of 11,000 ortho image tiles have been delivered to the State at a first time acceptance rate of 97%.

3DEP BAA: Maine & Massachusetts QL1 & QL2 LiDAR, U.S. Geological Survey. Technical Lead. Mark is providing technical support and process improvements on Quantum Spatial's (as Photo Science) Geospatial Products and Services Contract 2 (GPSC2) contract overseeing technical support and process improvements. In the spring of 2015, Quantum Spatial commenced acquisition, process and delivery airborne topographic LiDAR data covering specified Areas of Interest (AOI) located in Massachusetts and Maine totaling approximately 5,967 mi^2. LiDAR data is being collected at an aggregate nominal pulse spacing (ANPS) of 0.35 meters with a point density of 8 ppsm (QL1) for an 815 mi^2AOI in MA and 0.7 meters ANPS with a point density of 2 ppsm (QL2) for the remaining 2,270 mi^2 AOI in MA, as well as, a 2,882 mi^2 AOI in ME. A non-vegetated, bare earth vertical accuracy (NVA) of ≤19.6 cm at the 95% confidence level (10 cm RMSEz) will be achieved for all AOIs.

State of North Carolina LiDAR Program, State of North Carolina. Quality Manager. Mark has overall responsibility of ensuring all deliverables meet or exceed contract requirements. In the spring of 2014, Quantum Spatial (as Photo Science) coordinated and collaborated with the State of North Carolina Emergency Management's (NCEM) Statewide Topographic Data Acquisition Program to collect and process 20 coastal North Carolina counties. This Phase 1 project was done in partnership and with funding from USGS. The LiDAR data was collected to assist in evaluation of storm damage and erosion of coastal systems from Hurricane Sandy. In 2015, Quantum Spatial was tasked to collect an additional 13 counties for the State. This was for Phase 3 of the statewide LiDAR which comprised of approximately 6,950 mi^2 of additional data collection. As with Phase 1, LiDAR data was collected at QL2 specifications. Data collection began in January 10, 2015 and continued through March 22, 2015.

North East LiDAR, U.S. Geologic Survey. Quality Manager. Mark has overall responsibility of ensuring all deliverables meet or exceed contract requirements. Quantum Spatial (as Photo Science) collected and processed LiDAR data of a coastal zone spanning six North Eastern states, **including Maine**, New Hampshire, Massachusetts, Connecticut, Rhode Island, and New York. This multi-task order approach by USGS and participating federal, state and local agencies resulted in LiDAR acquisition and processing of over 8,000 mi^2 including enhanced vertical accuracies, post spacing and tide-coordinated acquisition of selective areas. Quantum Spatial provided all aspects of the project including project management, data collection and processing, control surveys, product development, and quality control.

LiDAR NRCS New York, AMEC. Project Manager. Quality Manager. Mark has overall responsibility of ensuring all deliverables meet or exceed contract requirements. As a subconsultant, Quantum Spatial (as Photo Science) provided the USDA's Natural Resources Conservation Service (NRCS) New York State office with high-resolution digital elevation model developed from LiDAR data for three Areas of Interest (AOI) in south central and western New York 1,032 mi^2. The south-central AOI is south of Syracuse in Tioga County (Dean Creek) totaling 57 mi^2. The western AOI's include portions of Genesee County totaling 335 mi^2 and all of Livingston County totaling 640 mi^2. Acquisition and processing of LiDAR data has been designed to adhere to USGS's NGP Base LiDAR Specification v13.

LiDAR Data Enhancement, U.S. Geologic Survey. Androscoggin County, ME. Quality Manager. Mark has overall responsibility of ensuring all deliverables meet or exceed contract requirements. The project included supplemental processing of existing LiDAR data covering Androscoggin County, Maine to include delivery of 2.5 foot, hydro flattened, DEM, classified .LAS files, metadata and reports. Quantum Spatial (as Photo Science) initially performed the LiDAR acquisition and bare earth processing of the dataset for FEMA Region 1 as a subconsultant working for the Region's assigned RiskMap Contractor.

Joel Burroughs

Project Assignment
Project Manager, Quantum Spatial

Education
BS, Business Management, Athens State University, 2010
Training, LiDAR Classification Strategies, GeoCue, 2009

Years of Experience: 9

Years with Quantum Spatial: 4

Joel has over six years of experience with project management and project control, primarily within the State and Local practice area with additional experience in Energy, Federal, and Transportation. His duties include management and oversight of flight acquisition, field surveying, stereo compilation, software application development, LiDAR, and digital orthoimagery production.

Joel has extensive experience in managing multiple projects that range in scale from small mapping projects to large regional and statewide programs. In addition to his project management duties, Joel provides leadership and technical guidance to our LiDAR production teams.

State of North Carolina LiDAR Program, State of North Carolina. Project Manager. As Project Manager, Joel is responsible for project planning, cost estimation, scope management, client reporting, and invoicing. In the spring of 2014, Quantum Spatial (as Photo Science) coordinated and collaborated with the State of North Carolina Emergency Management's (NCEM) Statewide Topographic Data Acquisition Program to collect and process 20 coastal North Carolina counties. This Phase 1 project was done in partnership and with funding from USGS. The LiDAR data was collected to assist in evaluation of storm damage and erosion of coastal systems from Hurricane Sandy. In 2015, Quantum Spatial was tasked to collect an additional 13 counties for the State. This was for Phase 3 of the statewide LiDAR which comprised of approximately 6,950 mi^2 of additional data collection. As with Phase 1, LiDAR data was collected at QL2 specifications. Data collection began in January 10, 2015 and continued through March 22, 2015.

Statewide LiDAR & Orthophotography, State of Kentucky. LiDAR Technical Lead. Joel provided oversight of topographic LiDAR deliverables on Quantum Spatial's (as Photo Science) contract. Quantum Spatial was tasked to provide 4-band leaf-off, digital aerial imagery acquired using our DMC cameras. Additionally, Quantum Spatial has collected and processed over 7,000 mi^2 of airborne LiDAR as part of the program. Program deliverables include leaf-off natural color and near infrared digital orthophotos at 1 foot and 0.5 foot GSDs, numerous digital elevation products derived from LiDAR and selective planimetric and topographic mapping updates. Quantum Spatial's cloud based ortho QA tool, VOICE, has been customized and deployed to support collaborative QA review of the orthoimagery across state, and local agencies. To date, a total of 11,000 ortho image tiles have been delivered to the State at a first time acceptance rate of 97%.

North East LiDAR, U.S. Geologic Survey. LiDAR Technical Lead. Joel provided oversight of topographic LiDAR deliverables on Quantum Spatial's (as Photo Science) contract. Quantum Spatial (as Photo Science) collected and processed LiDAR data of a coastal zone spanning six

North Eastern states, **including Maine,** New Hampshire, Massachusetts, Connecticut, Rhode Island, and New York. This multi-task order approach by USGS and participating federal, state and local agencies resulted in LiDAR acquisition and processing of over 8,000 mi^2 including enhanced vertical accuracies, post spacing and tide-coordinated acquisition of selective areas. Quantum Spatial provided all aspects of the project including project management, data collection and processing, control surveys, product development, and quality control.

LiDAR NRCS New York, AMEC. LiDAR Technical Lead. Joel provided oversight of topographic LiDAR deliverables. As a subconsultant, Quantum Spatial (as Photo Science) provided the USDA's Natural Resources Conservation Service (NRCS) New York State office with high-resolution digital elevation model developed from LiDAR data for three Areas of Interest (AOI) in south central and western New York 1,032 mi^2. The south-central AOI is south of Syracuse in Tioga County (Dean Creek) totaling 57 mi^2. The western AOI's include portions of Genesee County totaling 335 mi^2 and all of Livingston County totaling 640 mi^2. Acquisition and processing of LiDAR data has been designed to adhere to USGS's NGP Base LiDAR Specification v13.

Coastal New York LiDAR, National Oceanic and Atmospheric Administration. LiDAR Technical Lead. Joel provided oversight of topographic LiDAR deliverables on Quantum Spatial's (as Photo Science) contract. Quantum Spatial was tasked to collect and deliver topographic elevation point data derived from multiple LiDAR measurements for areas of coastal New York including Long Island, eastern Westchester, and the tidal extend of the Hudson River. The data developed by Quantum Spatial is used for coastal management decision making.

Georgia Mountains Regional Commission Aerial Photography & LiDAR, Georgia Mountains Regional Commission (GMRC). LiDAR Technical Lead. Joel provided oversight of topographic LiDAR deliverables on Quantum Spatial's (as Photo Science) contract. Quantum Spatial contracted with GMRC in November 2014 to collect new 4-band digital imagery and LiDAR data for approximately 6,350 mi^2, consisting of 25 counties and jurisdictions in the state of Georgia. Michael is responsible for the management and supervision of all aspects of the project including acquisition, surveying, and production; client communication; progress reporting; maintaining project schedules; and monitoring budget.

Coastal Georgia Elevation Project (CGEP), National Oceanic and Atmospheric Administration. LiDAR Technical Lead. Joel provided oversight of topographic LiDAR deliverables on Quantum Spatial's (as Photo Science) contract. Quantum Spatial contracted with the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center to collect and deliver topographic elevation data derived from multiple return, light detection and ranging (LiDAR) measurements for approximately 4,500 mi^2 of southeast/coastal Georgia. These data are intended for use in coastal management decision making, including applications such as sea level rise and coastal flood mapping. The project was a joint effort between the Coastal Regional Commission of Georgia (Brunswick, GA), NOAA's Coastal Services Center (CSC), USGS, FEMA, the Georgia Department of Natural Resources, and multiple municipalities and local government entities. Quantum Spatial and its sub-contractor, provided LiDAR collection, processing, accuracy assessment, and delivery.

Clay Smith, PLS, CP

Project Assignment
Resource Manager, Quantum Spatial

Education
AD, Photogrammetry, Ferris State University, 1976
Training, InRoads 2, Intergraph, 2002
Training, InRoads 1, Intergraph, 2001

Registration
ASPRS Certified Photogrammetrist No. R939
Professional Land Surveyor: NC No. L-4078
Photogrammetric Surveyor No. SC
Land Surveyor Photogrammetrist VA No. 408000186

Years of Experience: 37

Years with Quantum Spatial: 37

Clay has over 35 years of experience providing quality geospatial services with Quantum Spatial (as Photo Science). Clay is an ASPRS Certified Photogrammetrist, a professional land surveyor, and ASPRS Certified Photogrammetrist. As a resource manager, Clay will be responsible for monitoring Quantum Spatial's resources – including personnel and equipment – to ensure that we continue to work at a steady capacity while accounting for auxiliary resources to respond to no-notice or rapid response geospatial projects such as emergency tasks. Clay is active in the American Society for Photogrammetry and Remote Sensing (ASPRS).

State of North Carolina LiDAR Program, State of North Carolina. Resource Manager. Clay's duties have include personnel assignment and equipment monitoring for risk reduction. In the spring of 2014, Quantum Spatial (as Photo Science) coordinated and collaborated with the State of North Carolina Emergency Management's (NCEM) Statewide Topographic Data Acquisition Program to collect and process 20 coastal North Carolina counties. This Phase 1 project was done in partnership and with funding from USGS. The LiDAR data was collected to assist in evaluation of storm damage and erosion of coastal systems from Hurricane Sandy. In 2015, Quantum Spatial was tasked to collect an additional 13 counties for the State. This was for Phase 3 of the statewide LiDAR which comprised of approximately 6,950 mi^2 of additional data collection. As with Phase 1, LiDAR data was collected at QL2 specifications. Data collection began in January 10, 2015 and continued through March 22, 2015.

Statewide LiDAR & Orthophotography, State of Kentucky. Resource Manager. Clay's duties have include personnel assignment and equipment monitoring for risk reduction. Quantum Spatial was tasked to provide 4-band leaf-off, digital aerial imagery acquired using our DMC cameras. Additionally, Quantum Spatial has collected and processed over 7,000 mi^2 of airborne LiDAR as part of the program. Program deliverables include leaf-off natural color and near infrared digital orthophotos at 1 ft and 0.5 ft GSDs, numerous digital elevation products derived from LiDAR and selective planimetric and topographic mapping updates. Quantum Spatial's cloud based ortho QA tool, VOICE, has been customized and deployed to support collaborative QA review of the orthoimagery across state, and local agencies. To date, a total of 11,000 ortho image tiles have been delivered to the State at a first time acceptance rate of 97%.

North East LiDAR, U.S. Geologic Survey. Resource Manager. Clay's duties have include personnel assignment and equipment monitoring for risk reduction. Quantum Spatial (as Photo

Science) collected and processed LiDAR data of a coastal zone spanning six North Eastern states, **including Maine**, New Hampshire, Massachusetts, Connecticut, Rhode Island, and New York. This multi-task order approach by USGS and participating federal, state and local agencies resulted in LiDAR acquisition and processing of over 8,000 mi^2including enhanced vertical accuracies, post spacing and tide-coordinated acquisition of selective areas. Quantum Spatial provided all aspects of the project including project management, data collection and processing, control surveys, product development, and quality control.

LiDAR NRCS New York, AMEC. LiDAR Technical Lead. Resource Manager. Clay's duties have include personnel assignment and equipment monitoring for risk reduction. As a subconsultant, Quantum Spatial (as Photo Science) provided the USDA's Natural Resources Conservation Service (NRCS) New York State office with high-resolution digital elevation model developed from LiDAR data for three Areas of Interest (AOI) in south central and western New York 1,032 mi^2. The south-central AOI is south of Syracuse in Tioga County (Dean Creek) totaling 57 mi^2. The western AOI's include portions of Genesee County totaling 335 mi^2 and all of Livingston County totaling 640 mi^2. Acquisition and processing of LiDAR data has been designed to adhere to USGS's NGP Base LiDAR Specification v13.

Coastal New York LiDAR, National Oceanic and Atmospheric Administration. LiDAR Resource Manager. Clay's duties have include personnel assignment and equipment monitoring for risk reduction. Quantum Spatial was tasked to collect and deliver topographic elevation point data derived from multiple LiDAR measurements for areas of coastal New York including Long Island, eastern Westchester, and the tidal extend of the Hudson River. The data developed by Quantum Spatial is used for coastal management decision making.

Georgia Mountains Regional Commission Aerial Photography & LiDAR, Georgia Mountains Regional Commission (GMRC). Resource Manager. Clay's duties have include personnel assignment and equipment monitoring for risk reduction. Quantum Spatial contracted with GMRC in November 2014 to collect new 4-band digital imagery and LiDAR data for approximately 6,350 mi^2, consisting of 25 counties and jurisdictions in the state of Georgia. Michael is responsible for the management and supervision of all aspects of the project including acquisition, surveying, and production; client communication; progress reporting; maintaining project schedules; and monitoring budget.

Brett Baker

Project Assignment
Flight Acquisition Manager, Quantum Spatial

Years of Experience: 31

Years with Quantum Spatial: 31

Brett manages the flight department for the Lexington, Kentucky office. His responsibilities include flight planning, logistics, image acquisition, coordination with field survey crews, and the overall quality of the imagery. He oversees the operations and maintenance of the aircraft and cameras, including all certifications. With over 34 years of industry experience, he has operated and maintained a wide range of equipment involving film processors, film printers, horizontal/vertical enlargers and aerial mapping cameras. Mr. Baker previously served as a project manager where his responsibilities included delivery of quality, communications with the client and internal staff and oversight of cost, schedule, procurement, risk, team resources, and the project scope.

3DEP BAA: Maine & Massachusetts QL1 & QL2 LiDAR, U.S. Geological Survey. Flight Operations Manager. Brett is responsible for flight planning, logistics, image acquisition, coordination with field survey crews, and the overall quality of the imagery. In the spring of 2015, Quantum Spatial commenced acquisition, process and delivery airborne topographic LiDAR data covering specified Areas of Interest (AOI) located in Massachusetts and Maine totaling approximately 5,967 mi^2. LiDAR data is being collected at an aggregate nominal pulse spacing (ANPS) of 0.35 meters with a point density of 8 ppsm (QL1) for an 815 mi^2 AOI in MA and 0.7 meters ANPS with a point density of 2 ppsm (QL2) for the remaining 2,270 mi^2 AOI in MA, as well as, a 2,882 mi^2 AOI in ME. A non-vegetated, bare earth vertical accuracy (NVA) of ≤19.6 cm at the 95% confidence level (10 cm RMSEz) will be achieved for all AOIs.

State of North Carolina LiDAR Program, State of North Carolina. Flight Operations Manager. Brett is responsible for flight planning, logistics, image acquisition, coordination with field survey crews, and the overall quality of the imagery. In the spring of 2014, Quantum Spatial (as Photo Science) coordinated and collaborated with the State of North Carolina Emergency Management's (NCEM) Statewide Topographic Data Acquisition Program to collect and process 20 coastal North Carolina counties. This Phase 1 project was done in partnership and with funding from USGS. The LiDAR data was collected to assist in evaluation of storm damage and erosion of coastal systems from Hurricane Sandy. In 2015, Quantum Spatial was tasked to collect an additional 13 counties for the State. This was for Phase 3 of the statewide LiDAR which comprised of approximately 6,950 mi^2 of additional data collection. As with Phase 1, LiDAR data was collected at QL2 specifications. Data collection began in January 10, 2015 and continued through March 22, 2015.

Statewide LiDAR & Orthophotography, State of Kentucky. Flight Operations Manager. Brett is responsible for flight planning, logistics, image acquisition, coordination with field survey crews, and the overall quality of the imagery. Quantum Spatial was tasked to provide 4-band leaf-off, digital aerial imagery acquired using our DMC cameras. Additionally, Quantum Spatial has collected and processed over 7,000 mi^2 of airborne LiDAR as part of the program. Program deliverables include leaf-off natural color and near infrared digital orthophotos at 1 foot and 0.5

foot GSDs, numerous digital elevation products derived from LiDAR and selective planimetric and topographic mapping updates. Quantum Spatial's cloud based ortho QA tool, VOICE, has been customized and deployed to support collaborative QA review of the orthoimagery across state, and local agencies. To date, a total of 11,000 orthoimagery tiles have been delivered to the State at a first time acceptance rate of 97%.

Georgia Mountains Regional Commission Aerial Photography & LiDAR, Georgia Mountains Regional Commission (GMRC). Flight Operations Manager. Brett is responsible for flight planning, logistics, image acquisition, coordination with field survey crews, and the overall quality of the imagery. Quantum Spatial contracted with GMRC in November 2014 to collect new 4-band digital imagery and LiDAR data for approximately 6,350 mi^2, consisting of 25 counties and jurisdictions in the state of Georgia. Michael is responsible for the management and supervision of all aspects of the project including acquisition, surveying, and production; client communication; progress reporting; maintaining project schedules; and monitoring budget.

National Agriculture Imagery Program, U.S. Department of Agriculture, Farm Service Agency. Flight Operations Manager. Brett is responsible for flight planning, logistics, image acquisition, coordination with field survey crews, and the overall quality of the imagery. The National Agriculture Imagery Program (NAIP) is comprised of digital aerial imagery acquired during leaf-on conditions with mature crops prior to harvest. In 2014, Quantum Spatial completed 11 statewide tasks for the USDA. In 2013, Quantum Spatial completed all image processing for 10 statewide task orders in a single facility. In 2012, Quantum Spatial completed all image processing for all eight statewide task awards in a single facility. Quantum Spatial has been supporting product development under APFO contract vehicles since 2002, and we have scaled our production environment to adjust for different throughput requirements. Brett has planned and executed missions to capture aerial imagery to meet 1 m and 2 m pixel resolution for over 33,000 line miles.

Steve Blask, PhD, GISP

Project Assignment
Geiger-mode LiDAR Acquisition Manager, Harris Corporation

Education
PhD
BA, Electrical Engineering

Registration
GISCI GIS Professional

Years of Experience: 28

Years with Harris: 21

Steve is Harris's chief scientist, guiding the overall design approach for Geiger mode and other LiDAR operations and image processing algorithm development. He has 28 years of experience in computer vision, computer graphics, image processing, and artificial intelligence, focusing on development of software systems for mobile robotics and unmanned vehicles, real-time machine vision for industrial robotics, tactical ISR payloads and ground processing, and space-based remote sensing. He has 24 publications and holds three patents in these areas. In the Purdue Robot Vision Lab, Steve developed geometric methods of classifying range data, low-level LiDAR range image processing, production systems for automatic recognition of hierarchical target models from noisy range images, methods and metrics for surface extraction from LiDAR images, and conducted automated target recognition (ATR) algorithm performance evaluation. Steve led the development of the embedded airborne processing and ground processing for the DARPA Jigsaw 3D Imaging LiDAR payload, and more recently led the team that developed the OCONUS and CONUS LiDAR ground processing elements supporting the NGA ALIRT Afghanistan (AA) 2010 mission. Steve holds a Top Secret/SCI Security Clearance. Steve will coordinate and work closely with Brett Baker, Quantum's flight operation manager on all Geiger-mode LiDAR acquisition.

Wide Area Mapping Geiger Mode LiDAR Operations, NGA. Technical Lead. Steve manages the NGA ALIRT ground processing and production system including system integration, operations, and production for wide-area Geiger mode LiDAR mapping that yields inch-level fidelity. Technical Lead for overall definition of system collections, operations, and data quality and accuracy. He led the team in the collection and production of more than 500,000 km2 of 1m and below LiDAR data coverage OCONUS.

Internal Research and Development, Harris Corporation. Technical Lead. Steve managed image processing and LiDAR research and development dealing in a diverse set of modalities including Electro Optical (panchromatic, multi-spectral, hyper-spectral), Radar/SAR, LADAR, LiDAR, and motion imagery. He developed an approach to enable wide area mapping collection with Geiger mode LiDAR.

DARPA, Technical Lead. Steve managed data processing/analysis on the DARPA Jigsaw Program (LiDAR data processing) and managed sensor integration and ground processing for the early experimental Geiger mode LiDAR system. He developed the initial system for wide-area collection Gieger mode LiDAR systems.

DARPA, DARPA Programs (Confidential). Technical Lead. Steve managed the development of algorithms and software for target position and orientation in LiDAR 3D point cloud data, including the Aided Target Recognition (AiTR) capability technology demonstrator and tool. He was the chief software engineer and lead for DARPA-IXO programs managing technical engineering efforts of Sarnoff and MIT/LL. He was the project and cost account lead for video motion imagery R&D and was a contributing member to the Motion Imagery Standard Board (MISB) and Working Groups. Steve was the principal investigator on the DARPA Airborne Video Surveillance – Precision Video Registration (AVS-PVR) program.

Ken Comeaux, CP, GISP

Project Assignment
Linear-mode LiDAR Acquisition Manager, Precision Aerial Reconnaissance (PAR)

Registration
ASPRS Certified Photogrammetrist No. 1485
GISCI GIS Professional No. 00060795

Years of Experience: 26

Years with PAR: 1

Mr. Comeaux is an ASPRS Certified Photogrammetrist and a GISCI Certified GIS Professional with 24 years of geospatial acquisition and processing experience. He has a wealth of experience working with airborne sensors, data processing, and in the planning of a variety of different types of photogrammetric surveys. Mr. Comeaux provides oversight and direction to PAR's data acquisition field staff and technical staff. Ken will work closely with Brett Baker, Quantum Flight Operations Manager to support linear mode LiDAR acquisition if additional resources are required.

USACE, New Orleans, LA / Mississippi River Corridor LiDAR Flight, Old River to Venice, LA. LiDAR Manager. The 2013 Mississippi River Corridor LiDAR Flights project includes the acquisition and processing of Light Detection and Ranging (LiDAR) elevation data along the Mississippi River corridor from Old River to Venice, La. This data will be used to support Channel Improvement. The project includes capture of airborne LiDAR data and the creation of digital elevation models derived from the LiDAR. The project area is approximately 499 mi^2. The purpose of the survey is to obtain measurements of the bare ground surface, as well as top surface feature elevation data for USACE analysis.

USACE Jacksonville District, Rio de la Plata and Puerto Nuevo, Topographic Surveys. LiDAR Manager. This task order consisted of airborne LiDAR survey in San Juan, Puerto Rico to support hydrologic modeling within the Rio de la Plata and Puerto Nuevo regions of Puerto Rico. The two project areas comprise approximately 404 square kilometers of land and adjacent water bodies. (156 mi^2), with a point density of approx. 15 ppsm. LiDAR relative accuracy is 5 cm line to line and an Absolute Accuracy of 10 cm RMSE on Bare Ground.

El Paso, Texas Streetcar Corridor Project. Engineering design support for a proposed street car system in El Paso, TX. The project included a topo survey conducted photogrammetrically with design-scale imagery acquisition and mapping. The project also included additional topo surveys by ground surveying methods, the tying in and mapping of all utilities by ground surveying methods.

USDA National Agricultural Imagery Program (NAIP), NGA LIDAR City. LiDAR Manager responsible for LiDAR data processing, GPS, airborne GPS/IMU and flight/sensor operations. Responsible for assessing project needs and constraints and accuracies to be met by ASPRS standards. Responsible for creating the project plan including data standards from SOW, flight planning, and photogrammetric control planning. Managed flight crews in the field.

Byron Freeman, LS

Project Assignment
Control Surveys Manager, Quantum Spatial

Education
Certificate, Surveying, Middle Georgia College, 2004

Registration
Land Surveyor: GA No. LS003184

Years of Experience: 19

Years with Quantum Spatial: 15

Byron has 19 years of experience in the Land Surveying industry. He currently manages survey projects in a variety of applications including large and small tract boundary surveys; engineering surveys for the design of roads, utilities, and site development; and field efforts on a variety of construction surveys. His background includes the use and familiarity with a variety of industry software including various CAD packages, survey reduction tools, highway design software, and Power line design software.

He has a great deal of field experience having held the positions of Rod man, Instrument man, Survey Party Chief, and field coordinator utilizing traditional survey tools and advanced methods including GPS. Byron has expertise in surveying (all types), CAD, GIS, and metadata documentation.

Georgia Mountains Regional Commission Aerial Photography & LiDAR, Georgia Mountains Regional Commission (GMRC). Survey Manager. Quantum Spatial contracted with GMRC to collect new 4-band digital imagery and LiDAR data for approximately 6,350 mi^2, consisting of 25 counties and jurisdictions in the state of Georgia. Michael is responsible for the management and supervision of all aspects of the project including acquisition, surveying, and production; client communication; progress reporting; maintaining project schedules; and monitoring budget.

Coastal Georgia Elevation Project (CGEP), National Oceanic and Atmospheric Administration. Survey Manager. Quantum Spatial contracted with the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center to collect and deliver topographic elevation data derived from multiple return, light detection and ranging (LiDAR) measurements for approximately 4,500 mi^2 of southeast/coastal Georgia. These data are intended for use in coastal management decision making, including applications such as sea level rise and coastal flood mapping. The project was a joint effort between the Coastal Regional Commission of Georgia (Brunswick, GA), NOAA's Coastal Services Center (CSC), USGS, FEMA, the Georgia Department of Natural Resources, and multiple municipalities and local government entities.

State of North Carolina LiDAR Program, State of North Carolina. Survey Manager. In the spring of 2014, Quantum Spatial (as Photo Science) coordinated and collaborated with the State of North Carolina Emergency Management’s (NCEM) Statewide Topographic Data Acquisition Program to collect and process 20 coastal North Carolina counties. This Phase 1 project was done in partnership and with funding from USGS. The LiDAR data was collected to assist in evaluation of storm damage and erosion of coastal systems from Hurricane Sandy. In 2015, Quantum Spatial was tasked to collect an additional 13 counties for the State. This was for Phase

3 of the statewide LiDAR, which comprised of approximately 6,950 mi^2 of additional data collection. As with Phase 1, LiDAR data was collected at QL2 specifications.

Great Smokey Mountain National Forest LiDAR, University of Georgia, 2011. Survey Manager. Quantum Spatial (as Photo Science) was contracted by the University of Georgia to obtain a LiDAR surface model of approximately 540 mi^2 of the Great Smokey Mountains National Forest in east Tennessee. This data was obtained in accordance with the most current USGS specifications for LiDAR data. Quantum Spatial utilized a LiDAR unit in conjunction with airborne GPS (ABGPS) and an Inertial Measurement Unit (IMU) to obtain the LiDAR data. In addition to this surface data, post processing of the data included the production and delivery of the following: Raw Point Cloud, a Classified Point Cloud, and a Bare Earth Surface (Raster DEM).

Imagery, Impervious, and Mobile LiDAR, Athens-Clarke County, Georgia. Survey Manager. Quantum Spatial contracted with the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center to collect digital aerial imagery, impervious surface data, and mobile LiDAR for Athens-Clarke County, Georgia. The project area for imagery included the entire county, approximately 121 mi^2. The imagery was flown at 9,600 ft above ground level to produce 0.5 ft pixel resolution imagery. The imagery was then rectified using photo-identifiable ground control collected as part of the task. Quantum Spatial collected 21 miles of roadway utilizing our Optech Lynx mobile mapping system (MMS). The areas collected were both residential and commercial, with one road segment in the downtown area of Athens. The LiDAR data collected was processed, calibrated, and cleaned to a LAS point cloud. The LiDAR data produced an elevation surface with a accuracy of >0.10 ft. This project required 4-band aerial imagery of the primary study area. In addition, Quantum Spatial utilized existing impervious data for updates including buildings, parking lots, driveways, and sidewalks identifiable from the photography. This data was provided in ArcGIS format in accordance with the Athens-Clarke County tile index and data schema. The final deliverables for this project were: 1"=100' scale color digital orthophotography countywide; Updated Impervious Surface data (ESRI Shapefile Format); Mobile LIDAR data LAS Format.

John Allen, PLS

Project Assignment
Maine Land Surveyor,
James W. Sewall Company

Education
AS, Drafting Technology, Northern Maine Vocational Technical Institute,
Surveying core curriculum coursework, University of Maine, Orono and Wentworth Institute of Technology, Massachusetts

Registration
Professional Land Surveyor: ME No. 2311

Years of Experience: 23

Years with Sewall: 7

John Allen joined James W. Sewall Company in 2008. He has more than 23 years' experience in mapping, drafting and land surveying. His duties have included supervision of field crews and survey department, project management and business development. Mr. Allen has significant experience working with town and state regulating agencies, subdivision design, road layout, boundary work, and deed research. In addition, he is familiar with Maine State, Land Use Planning Commission, and Department of Environmental Protection regulations.

James W. Sewall Company. Senior Project Manager / Survey Lead. Responsible for project management and supervision of survey field crews for ground survey collection for:

- **USGS, North East LiDAR project,** States of Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut & New York. Project Manager for a coastal LiDAR project with Photo Science that included establishing and controlling approximately 350 quality control check points throughout the coastal project area.
- **USGS, New Hampshire Statewide LiDAR project.** Project Manager for a statewide LiDAR project with Photo Science that included establishing and controlling approximately 140 quality control check points throughout the entire State of New Hampshire.
- **MeDOT.** Responsible for establishing ground control to meet National Map Accuracy Standards for site in Machias, Maine to produce 50-scale planimetric maps with 1-foot contour intervals.

AMES A/E. Survey Supervisor. Responsible for supervision of survey field crews, project management, new equipment research, training & implementation, daily survey operations and business development.

Stevenson Sheppard, PLS

Project Assignment
Maine Land Surveyor,
Shyka, Sheppard & Garster Land Surveyors (SSG)

Education
BS, Surveying Engineering,
University of Maine, 1986

Registration
Professional Land Surveyor: ME No. 2086, PA No. SU75206

Years of Experience: 25

Years with SSG: 21

Mr. Sheppard is president and co-owner of Shyka, Sheppard & Garster Land Surveyors. He has over has over twenty-five years' experience in the practice of land surveying. He received a BS in Surveying Engineering from the University of Maine. His experience includes subdivision design and permitting, boundary analysis, topographic surveys, engineering surveys, hydrographic surveys, geodetic control surveys and GPS surveys for photogrammetric mapping and LiDAR.

His specific experience includes both managing and performing a wide variety of surveys throughout Maine and New England. His work has ranged from small boundary surveys in urban areas to acreage verifications for remote woodlands covering thousands of acres, to engineering surveys on a variety of commercial, residential, municipal and industrial sites, to geodetic and engineering surveys on right of way projects covering over a hundred miles.

A significant portion of his work has involved the use of GPS to extend high order, geodetic quality control into specific areas to facilitate mapping, design and construction activities. He has also managed and performed multiple GPS surveys to establish photo control points to support the Maine 5-year Statewide Orthophoto program and control and check point surveys for LiDAR surveys in Maine, including computations and preparation of final survey reports for the projects.

Mr. Sheppard is also a principal and vice-president of KAPPA Mapping, Inc., a full range photogrammetric services firm. KAPPA is certified in many states as a Disadvantaged Business Enterprise (DBE) and Woman Business Enterprise (WBE).

Adam Pike

Project Assignment
LiDAR Processing Manager, Quantum Spatial

Education
MS, Plant and Soil Science, University of Kentucky, 2008
BS, Plant and Soil Science, University of Kentucky, 2007
Training, Basic TerraScan and TerraModeler Part 1, GeoCue, 2008
Training, Basic TerraScan and TerraModeler Part 2, GeoCue, 2008
Training, Contour Production in TerraModeler, GeoCue, 2008
Training, TerraScan Classification Strategies, GeoCue, 2008

Years of Experience: 11

Years with Quantum Spatial: 7

Adam currently manages the firm's wide-area Topographic LiDAR processing projects. He performs post processing using the latest GeoCue and Optech software; as well as automated classification routines on the LAS files utilizing the Terra Solid Suite of products. Additionally, he processes all final deliverable data sets, such as Bare Earth DEMs, model key, contours, and related ASCII and LAS files using many in-house programs along with custom scripts created in ArcGIS. Feature extraction is currently being performed from LiDAR point clouds and calibrated images using Certainty 3D's TopoDOT.

Adam has expertise bathymetry, LiDAR data collection and processing, DEM/DTM development, CAD, GIS, and metadata documentation.

Sandy Supplemental NCR (VA-MD-DC) QL2 LiDAR, U.S. Geological Survey. LiDAR Processing Manager. Adam provides oversight of topographic LiDAR deliverables. Quantum Spatial is collecting and processing spring 2014, leaf off, airborne topographic LiDAR of the greater National Capital Region (NCR) covering portions of northern Virginia, Maryland and the District of Columbia totaling approximately 2,002 mi^2. The LiDAR data was collected at a planned density of 2.7 ppsm.

Statewide LiDAR & Orthophotography, State of Kentucky. LiDAR Processing Manager. Adam provides management and oversight of topographic LiDAR deliverables. Quantum Spatial was tasked to provide 4-band leaf-off, digital aerial imagery acquired using our DMC cameras. Additionally, Quantum Spatial has collected and processed over 7,000 mi^2 of airborne LiDAR as part of the program. Program deliverables include leaf-off natural color and near infrared digital orthophotos at 1 foot and 0.5 foot GSDs, numerous digital elevation products derived from LiDAR and selective planimetric and topographic mapping updates. Quantum Spatial’s cloud based ortho QA tool, VOICE, has been customized and deployed to support collaborative QA review of the orthoimagery across state, and local agencies. To date, a total of 11,000 ortho image tiles have been delivered to the State at a first time acceptance rate of 97%.

North East LiDAR, U.S. Geologic Survey. LiDAR Processing Manager. Adam provides management and oversight of topographic LiDAR deliverables. Quantum Spatial (as Photo Science) collected and processed LiDAR data of a coastal zone spanning six North Eastern states, **including Maine**, New Hampshire, Massachusetts, Connecticut, Rhode Island, and New York. This multi-task order approach by USGS and participating federal, state and local agencies resulted in LiDAR acquisition and processing of over 8,000 mi^2 including enhanced vertical accuracies, post spacing and tide-coordinated acquisition of selective areas. Quantum Spatial provided all aspects of the project including project management, data collection and processing, control surveys, product development, and quality control.

Mississippi River Delta – LiDAR & Digital Ortho, U.S. Army Corps of Engineers Vicksburg District, Districtwide. LiDAR Processing Manager for this multi-year IDT contract. Tasking included the collection of more than 10,000 mi^2 of aerial imaging and LiDAR data within the Mississippi River Delta stretching from Vicksburg, MS to Memphis, TN. Aerial imaging required the collection of 2,618 frames of DMC imaging to create orthoimagery at a 2 ft pixel resolution. A total of 19,691 flight line miles of LiDAR data was also collected at a swath width, scan angle, point spacing, and flight height capable of generating a 1 ft contour.

Coastal New York LiDAR, National Oceanic and Atmospheric Administration. LiDAR Processing Manager. Adam provides management and oversight of topographic LiDAR deliverables. Quantum Spatial was tasked to collect and deliver topographic elevation point data derived from multiple LiDAR measurements for areas of coastal New York including Long Island, eastern Westchester, and the tidal extend of the Hudson River. The data developed by Quantum Spatial is used for coastal management decision making.

Colorado QL2/3 LiDAR Flooding (S Platte River), U.S. Geological Survey. LiDAR Processing Manager. Adam provides management and oversight of topographic LiDAR deliverables. Quantum Spatial was tasked by USGS to acquire accurate, high resolution Light Detection and Ranging (LiDAR) data of the flood damaged areas of the South Platte watershed in Colorado covering approximately 4,616 mi^2 over the highest priority damage areas. Additionally, Quantum Spatial concurrently acquired and is processing LiDAR data and derivative terrain data products of the Denver Regional Council of Governments (DRCOG) area of interest, which totals approximately 3,600 mi^2, and added an additional 1,020 mi^2 of new area to the overall project.

Georgia Mountains Regional Commission Aerial Photography & LiDAR, Georgia Mountains Regional Commission (GMRC). LiDAR Processing Manager. Adam provides management and oversight of topographic LiDAR deliverables. Quantum Spatial contracted with GMRC in November 2014 to collect new 4-band digital imagery and LiDAR data for approximately 6,350 mi^2, consisting of 25 counties and jurisdictions in the state of Georgia. Michael is responsible for the management and supervision of all aspects of the project including acquisition, surveying, and production; client communication; progress reporting; maintaining project schedules; and monitoring budget.

Claire Kiedrowski, CP, PLS

Project Assignment
LiDAR Editing Support, KAPPA Mapping

Education
BS, Surveying Engineering, University of Maine, 1990
Graduate work, Analytical & Digital Photogrammetry, University of Maine, 1999

Registration
ASPRS Certified Photogrammetrist No. 1244
Photogrammetric Surveyor: SC No. 24160
Registered Professional Photogrammetrist: OR No. 80731
Professional Surveyor & Mapper: FL No. 6723
Surveyor Photogrammetrist: VA No. 0408000111

Years of Experience: 25

Years with KAPPA: 12

Claire has over twenty years' experience in the computer mapping industry. She is experienced in digital photogrammetry, image processing, orthophoto production, Digital Elevation Model generation, pipeline alignment mapping, database design, Geographic Information Systems, and surveying. Claire is skilled at managing projects from initial concept through delivery of the final product. Her success is a function of determining the most effective workflows, identifying appropriate technologies to meet the client's objectives, and working closely with staff and subcontractors.

Claire Kiedrowski, as KAPPA Project Manager, will be responsible for working with Quantum Spatial's Project Manager, delivery of all work products, ensuring that all Tasks meet or exceed specifications, and for all reporting requirements.

Claire is an active member in numerous organizations including:

- American Society of Photogrammetrists and Remote Sensing (ASPRS)
- Management Association for Private Photogrammetric Surveyors (MAPPS)
- Maine Society of Land Surveyors (MSLS), Associate Member
- Maine GIS Users Group (MEGUG)
- Industrial Advisory Committee for Surveying Technology Program,
- University of Maine

LiDAR Editing and Classification, U.S. Geological Survey. Project Manager. Coordinated LiDAR editing and manual classification activities. Beginning in 2010, KAPPA supported Quantum Spatial with LiDAR projects for the USGS including areas such as: San Luis Valley, CO, North Platte County, NE, Grand County, CO, Sage Grouse, MT, Calhoun County, TX, Hidalgo County, TX, Monroe County, WI, Arkansas Valley, CO, and Douglas & Logan Counties, IL. Our most recent LiDAR project was finalized in September, 2014.

Using LiDAR to Map Buildings for Sea-Level Rise Scenarios, Maine Geological Survey. Project Manager. Coordinated LiDAR processing activities and worked closely with end client (Maine Geological Survey) to develop suitable classification criteria; participated in developing methodology for classifying buildings from an existing dataset; reviewed deliverables and provided quality assurance, maintained client contact, helped develop GIS database and deliverables, including metadata. KAPPA's client was Lincoln County Maine.

Maine State Ortho Project – 5 Year Program (2012-2016). Project Manager. Coordinated quality control and assurance steps for orthophoto production activities, managed staff resources, maintained contact with client, evaluated final product before delivery. Ensured compliance with state specifications for orthophotography. Also led and participated in community outreach of program. KAPPA is a subconsultant to prime Woolpert.

Penobscot Narrows Bridge, Prospect ME. Project Manager. Coordinated activities for a high-profile project that consisted of planimetric and topographic mapping and color orthophotography Served as project manager by reviewing aerotriangulation (w/AGPS) results, coordinating QA/QC review for photogrammetric compilation, digital orthophoto and mosaic generation. Delivery of vector data complied with Maine DOT MicroStation specifications.

Nicole Cyr, CAPM

Project Assignment
LiDAR Editing Support, James W. Sewall Company

Education
AS, Horticulture Degree, University of Maine
Certified Project Management, University of Southern Maine
Surveying Coursework and Certified Soils and Plant Scientist, Southern Maine Technical College, South Portland, Maine
Forestry Coursework, SMTC and UM
Drafting Coursework, SMTC and UM
Photogrammetry Course, UM
Practical Project Management I & II, and Professional Adobe PhotoShop Users Certification Course I & II, University of New England
ArcView User, ESRI Training Course
Basic and Advanced GeoCue Production Workflow Management, Penn State CEU
eCognition Tools & Functionality, Trimble Training Course

Registration
Certified Project Manager, University of Southern Maine
Plant and Soils Certification, SMTC
Professional Adobe PhotoShop Users Certification Course I & II

Years of Experience: 25

Years with Sewall: 16

Nicole is responsible for overall remote sensing project management tasks and production as well as the processes and workflow of Sewall's photogrammetric team. During her sixteen years' experience, she has acquired expertise in all phases of ortho production and remote sensing. As Remote Sensing Production Manager, Nicole oversees Sewall's digital imaging and photogrammetric services, including all image processing tasks, personnel scheduling, digital photo printing, and scanning operations. She supervises the photogrammetric compilers and editors as well as the aerotriangulation process, continually develops new workflow processes, and oversees project scheduling and final QA/QC.

Her experience has given her the expertise to oversee the quality control and assurance of both the remote sensing and photogrammetric teams. As part of Sewall's quality-control process, Nicole oversees both QA/QC teams as they rigorously inspect and review every image, ensuring that the vector image co-registration meets project specifications and performs the final examination of all data. This same quality control process is performed with data conversion for all photogrammetric projects. Nicole also serves as Project Manager for a wide range of assignments involving municipalities, counties, forestry companies, and federal and private sector companies. Much of Nicole's project work incorporates oversight and/or management of all aerial photography capture, ABGPS/IMU processing, scanning, digital post processing, DTM or DEM development, orthoimage production and LiDAR post processing.

Ms. Cyr is experienced/proficient with orthorectification software programs including Applications Master, Inpho OrthoVista, PCI OrthoEngine, AutoMetric SoftPlotter, ERDAS Imagine, KDMS, TerraModel, MicroStation, GEOPak, ArcView, Adobe Photoshop, Photoshop CS2, LizardTech, ArcGis, ESRI ARC GIS suite, Global Mapper, DAT/EM, Vexcel, GeoCue Microstation and Inpho MatchAT.

James W. Sewall Company. Project/Production Manager

- **Maine DOT,** Dixfield, Maine. Performed scope of services that included aerial topographic and bathymetric LiDAR data acquisition and processing, ground control surveying, and topographic and hydrographic elevation model data production. (83895)
- **Gordon County, Georgia.** Gordon County is a 382 square mile area of rolling topography located within commuting distance of two large metropolitan areas. Sewall provided a new collection of 0.5-foot orthophotography, and a partner firm collected LiDAR for the entire area. Together, the Sewall Team delivered high quality digital orthophotography that clearly depicted drainage, road crowns, stream banks, and other areas of significant mapping importance utilizing LiDAR data, and generated LiDAR enforced 2-foot contour data. (75850)
- **Rabun County, Georgia.** Rabun County requested color orthophotography of their 404 square mile area from imagery captured during the leaf-off period in early 2013. Over 3500 aerial photos were captured via a high quality digital camera at 15cm GSD. A LiDAR elevation model was acquired, and processed data met the accuracy of 0.5-foot pixel resolution, USGS DEM quality. (83494)
- Sewall has generated and processed digital elevation models from LiDAR data collection for the following Counties in Georgia: Catoosa, Dade, White, Walker, Camden, Paulding, and Habersham.
- Sewall has classified buildings and elevation heights from LiDAR for several large confidential utility clients totaling thousands of pipeline miles.
- Sewall has generated the solar PV potential of rooftops using LiDAR and imagery for the following municipalities in Maine: Bangor, Bar Harbor, Boothbay Harbor, Camden, Isleboro and Rockland, to support the Maine Technology Institute (MTI) project http://webmap.sewall.com/solar/

Steve Wang, PhD, CP

Project Assignment
LiDAR Processing Support, Mira Solutions

Education
PhD, Photogrammetry/Remote Sensing, Oregon State University, 1991
MS, Remote Sensing/GIS/Photogrammetry, Oregon State University, 1988
BS, Computer Science and Engineering, Harbin Institute of Technology, 1982

Registration
ASPRS Certified Photogrammetrist No. 1034

Years of Experience: 23

Years with Mira Solutions: 16

Steve's primary functions involve management of the Company's production and research. This includes softcopy AT, DEM/DTM collection and processing, digital orthophotos, color mosaics, and contour and planimetric map production. He is the architect of Mira Solutions digital photogrammetry workstation systems. The system has separate modules for aerial triangulation, automated DEM collection, 3D stereo engine for DTM and planimetric data collections, digital orthophoto processing and automated color mosaic and color balancing. He has extensive experience with design, implementation, and operation of digital photogrammetric systems, digital image scanning systems, and image processing systems. He has strong experience with software development and management of digital orthophoto production.

With Vexcel Imaging, Steve was manager and senior programmer for photogrammetric products. He was responsible for the automated aerial triangulation system's (IDAS) product development involving programming and product management. He also managed the development of Vexcel Imaging's 2nd generation product, the Automatic Film Drive System II.

At HJW & Associates he was GIS/IP project manager and senior programmer for digital photogrammetry research and development. He was the primary developer for HJW's OrrthoView digital photogrammetric system and had responsibility for digital image processing and the quality control phases. Steve has managed other projects that used SPOT and TM imagery, aerial photography, video images, and GIS systems.

Multiple Mapping Projects, Digital Globe. Steve oversees production, QA/QC and any necessary research needed to complete mapping projects on time and within budget. Confer with the Project Managers concerning any internal issues or conflicts that affect schedule completion dates. Contacts: Jon Proctor. Tel: 303 684-1010

Multiple Mapping Projects, Quantum Spatial. Oversee production, QA/QC and any necessary research needed to complete mapping projects on time and within budget. Confer with the Project Managers concerning any internal issues or conflicts that affect schedule completion dates. Contact: Clay Smith. Tel: 859 277-8700

Nick Fusco, PLS, PSM

Project Assignment
Mobile LiDAR Acquisition Manager, Quantum Spatial

Education
BS, Civil Engineering, Penn State University, 1969

Registration
Professional Surveyor & Mapper: FL
Professional Land Surveyor: AL, AZ, LA, MD, MS, NJ, NM, NY, OH, PA, WV
Surveyor Photogrammetrist: VA

Years of Experience: 40

Years with Quantum Spatial: 13

Mr. Fusco is a Professional Surveyor with more than 40 years' experience in the surveying, mapping and photogrammetry field and is the Program Manager for Photo Science's Mobile Mapping clients. He is well versed in mapping issues ranging from aerial photography planning through advanced airborne applications involving photogrammetry, digital cameras, aerial LiDAR and mobile LiDAR acquisition and processing. Mr. Fusco is a current member of the Florida Board of Professional Surveyors and Mappers. Mr. Fusco's experience includes project management on numerous mobile mapping, LiDAR, aerial photography, mapping, and related services contracts.

Mobile Mapping, Point Cloud Processing; Interstate 86, Stuben County, New York. Acting as Program Manager under contract to provide Mobile Mapping and point cloud processing along the 6 mile section of this 4-lane highway, as well as geo-referenced digital images. Quantum Spatial (as Photo Science) collected all the mobile mapping data, post-processed the data for the Department of Transportation. The point cloud was calibrated to the control targets established on the shoulder of the roadway. A bare earth model was developed to determine the profile along the existing roadway. Digital images and an Image Viewer were provided of the entire project. The vertical RMSE relative accuracy on this project was 0.019-foot which the absolute accuracy was 0.043-foot. The horizontal RMSE relative accuracy was found to be 0.028-foot and the absolute was 0.043-foot.

Mobile Mapping, New Jersey Route 10, Roxbury, New Jersey. Nick was Project Manager under contract to BAE to provide Mobile Mapping along the 8 mile highway section. The limits were back of sidewalk to back of sidewalk. Additionally all "Jug Handle" intersections, controlled and uncontrolled intersections were to be completed a distance of 250-feet from the mainline Route 10. The project area was for the design of improvements along this four lane divided roadway. Quantum Spatial (as Photo Science) collected mobile LiDAR data and imagery from the Mobile Mapper's 4 cameras. The point cloud was calibrated to the control targets established on the shoulder of the roadway. Final RMSE for the project was: Horizontal 0.194 in the north and 0.157 in the east or 0.250-feet NSSDA. The Vertical RMSE was 0.06-feet

Mobile Mapping, Feature Extraction; Ellijay-Roundtop Transmission Line, Ellijay, Georgia. Nick was directly responsible under contract to the Georgia Transmission Corporation to provide Mobile Mapping and feature extraction along the 17 mile section of transmission line as well as digital images. Quantum Spatial (as Photo Science) collected all the mobile mapping data, post-processed and completed feature extraction creating a vector CADD deliverable showing all transmission lines, poles, transformers, appurtenances, roadway, guard rails and any other issues that would have an impact on design. The point cloud was calibrated to the control targets established on the shoulder of the roadway. A bare earth model was developed to determine the profile along the existing transmission line to be used for clearances.

Mobile Mapping, Feature Extraction; Interstate 84, Pike County, Pennsylvania. Mr. Fusco Nick on along the 6 mile section of this 4-lane highway, as well as geo-referenced digital images. Quantum Spatial (as Photo Science) collected all the mobile mapping data, post-processed and completed feature extraction creating a vector CADD deliverable showing overhead transmission lines, poles, overpass bridge clearances and all other issues that would have an impact on design. The point cloud was calibrated to the control targets established on the shoulder of the roadway. A bare earth model was developed to determine the profile along the existing roadway. Digital images and an Image Viewer were provide of the entire project for sign inventory and classification

Mobile Mapping, Feature Extraction, DEM development and contours, I-695, Baltimore, Maryland. Nick was the Program Manager contracted to provide Mobile Mapping this 1 mile section of this 4-lane highway and the mapping of another one mile of the overpass crossing the interstate. All mobile mapping data was processed for the mainline as well as overpasses to determine clearances. The point cloud was calibrated to the control targets established on the shoulder of the roadway and a pavement DEM was created to be able to create a TIN for contours. Bridge structure clearances and roadway slopes were developed as were areas of ponding.

Mobile Mapping for MES Wall Deformation; Route 322, Dauphin County, Pennsylvania. Nick was program Manager on this project to completed an initial mobile mapping survey of approximately 4,000 feet of MES wall along Route 322 west of Harrisburg, Pennsylvania. This wall was installed to vertically separate two roadways (Route 322 and Gap View Road). Of concern was the fact these walls had been built and there had never been any follow up to determine the stability of these walls. This survey was utilized to provide a base of data to go forward. The intent is to re-do this section of MES wall every 6 to 12 months to determine the overall stability of this wall.

State Route 15, Newton County, Mississippi. Quantum Spatial (as Photo Science) was under contract to the Mississippi DOT to provide Mobile Mapping along the 18 mile, 2-lane highway section. The Mobile mapping was performed on the hard surfaces, curb-to-curb and was supplemented by Aerial Photography, Aerial LiDAR, Photogrammetric Mapping and Digital Orthophotos. The limits were 1,000 feet each side of existing SR 15. The project area was for the widening of an existing two lane roadway. A combination of GPS and GLONASS in a true GNSS receiver was used to help mitigate the problems posed by dense vegetation for both the mobile mapping and the positioning of ground targets for the project. Final RMSEz for the Mobile Mapping was 0.034-feet.

Ryan Griffin

Project Assignment
Mobile LiDAR Processing Manager, Quantum Spatial

Education
BA, Geography, University of Kentucky, 2008

Years of Experience: 14

Years with Quantum Spatial: 7

Ryan joined Quantum Spatial in 2008 as a student intern where he worked as an Ortho Photography Technician. Upon completing his degree, Ryan transitioned into working as a LiDAR technician on a full-time basis. Ryan quickly moved into a quality control role within the LiDAR processing department and has since become heavily involved in all phases of the LiDAR production process. His current responsibilities include managing all technical aspects of LiDAR production on assigned projects, ensuring LiDAR deliverables are produced to specifications and all products are delivered to the client on-time. Ryan has expertise in LiDAR data collection and processing, DEM/DTM development, GIS, and metadata documentation.

Mobile Mapping, Feature Extraction; Florida Turnpike, Orange/Osceola Counties, Florida. LiDAR Processing Manager. Ryan provide oversight and management of the Mobile LiDAR processing for this project completed for The Wantman Group to provide Mobile Mapping along the 5 mile section of this 4-lane highway, as well as geo-referenced digital images. Quantum Spatial collected all the mobile mapping data and post-processed the data to be utilized in a design-build contract for the Florida Turnpike Enterprise. A bare earth model was developed to determine the profile along the existing roadway. Digital images and an Imager Viewer were provide of the entire project for sign inventory and classification. Completed: 2013.

Mobile Mapping, Feature Extraction; Interstate 390 and Interstate 86; Steuben County, New York. LiDAR Processing Manager. Ryan provided all Mobile LiDAR processing for the New York State Department of Transportation (NYSDOT) to complete Mobile Mapping along approximate 11.4 miles (including ramps) of Route I-86/17 and a portion of Route I-390, in the Kanona, Steuben County, New York area. Additionally Quantum Spatial was to complete mobile mapping on 9.1 miles (including ramps) of Route I-390 in Cohocton, Steuben County, New York area. Quantum Spatial collected all the mobile mapping data, post-processed and completed feature extraction creating a vector CADD deliverable showing overhead transmission lines, poles, overpass bridge clearances and all other issues that would have an impact on design. The point cloud was calibrated to the control targets established on the shoulder of the roadway. A bare earth model was developed to determine the profile along the existing roadway. Digital images and an Image Viewer were provide of the entire project for sign inventory and classification.

Mobile Mapping, Feature Extraction, DEM development and contours, Commerce Street Streetscape Project, San Antonio, Texas. LiDAR Processing Manager. Ryan provided mobile LiDAR processing for a portion of West Commerce Street beginning on the east with the intersection with St. Mary’s Street and traveling westerly to the intersection with Santa Rosa Street. The area is an urban street with heavy planimetric features along the route. The buildings are typically one to three story commercial structures with some high-rise buildings on the east end of the project. The roadway is one way westbound and is four lanes wide with one lane being restricted to bus traffic. There is also a parking area that serves as a service road on the south side of Commerce called Military Plaza.

Mobile Mapping, Feature Extraction; Interstate 84, Pennsylvania. LiDAR Processing Manager. Ryan provided LiDAR Processing for this project along the 6 mile section of this 4-lane highway, as well as geo-referenced digital images. Quantum Spatial collected all the mobile mapping data, post-processed and completed feature extraction creating a vector CADD deliverable showing overhead transmission lines, poles, overpass bridge clearances and all other issues that would have an impact on design. The point cloud was calibrated to the control targets established on the shoulder of the roadway. A bare earth model was developed to determine the profile along the existing roadway. Digital images and an Image Viewer were provide of the entire project for sign inventory and classification.

Mobile Mapping, Aerial Photography, Aerial LiDAR, Photogrammetric Mapping, Digital Orthophotos, State Route 100, Simpson County, Kentucky. LiDAR Processing Manager. Ryan provided LiDAR processing for Mobile Mapping LiDAR along the 1.3 mile highway section. In additional to the MMS mission, Aerial Photography, Aerial LiDAR, Photogrammetric Mapping, and Digital Orthophotos were completed. Quantum Spatial collected LiDAR data for SR 100 using our Optech Lynx V200 mobile mapping system. The sensor was used for the development of elevations on pavement surfaces for SR 100 for design purposes. The elevation surface was calibrated to the control targets established on the shoulder of the roadway.

Mobile Mapping, Feature Extraction, DEM development and contours, I-695, Baltimore, Maryland. LiDAR Processing Manager. Ryan process the LiDAR data collected during the mobile mapping phase of this project for this 1 mile section of this 4-lane highway and the mapping of another one mile of the overpass crossing the interstate. All mobile mapping data was processed for the mainline as well as overpasses to determine clearances. The point cloud was calibrated to the control targets established on the shoulder of the roadway and a pavement DEM was created to be able to create a TIN for contours. Bridge structure clearances and roadway slopes were developed as were areas of ponding.

Mobile Mapping, Feature Extraction; State Route 86, Corning, New York. Ryan was the LiDAR Processing Manager under contract to the New York State Department of Transportation (NYSDOT) to complete Mobile Mapping along approximate 6.5 miles of Route 86 in the City of Corning, Steuben County, New York. Quantum Spatial collected all the mobile mapping data, post-processed and completed feature extraction creating a vector CADD deliverable showing overhead transmission lines, poles, overpass bridge clearances and all other issues that would have an impact on design. The point cloud was calibrated to the control targets established on the shoulder of the roadway. A bare earth model was developed to determine the profile along the existing roadway. Digital images and an Image Viewer were provide of the entire project for sign inventory and classification.

Bryan Deslauriers, CP

Project Assignment
Feature Mapping Manager, Quantum Spatial

Education
BS, Earth Science, Geography, Frostburg State University, 2004

Registration
ASPRS Certified Photogrammetrist No. 1533
ASPRS Certified Photogrammetric Technologist No. 1421PT

Years of Experience: 10

Years with Quantum Spatial: 10

As a Certified Photogrammetrist, Bryan is well versed in national mapping policies and guidance standards. He has a diverse background in imagery analysis (traditional/digital aerial and satellite imagery), photogrammetry, aerotriangulation, and remote sensing for federal, state, local, and utility clients. Bryan is knowledgeable in the use of Microstation, ArcGIS, SOCET SET, and SoftPlotter feature extraction systems. Since joining Quantum Spatial, Bryan has worked on some of the firm's foremost federal programs such as the Geospatial Products and Services (GPSC) contract for USGS, Global Geospatial Intelligence (GGI) program for NGA, NOAA's Shoreline Mapping program, the USMC Real Property Inventory (RPI) program, and the FAA Airfield Obstruction Analysis Program. Bryan is an active member of the American Society for Photogrammetry and Remote Sensing and the Florida Surveying and Mapping Society. Bryan has expertise in compilation, CAD, GIS, and metadata documentation.

Mobile Mapping, Feature Extraction; Interstate 390 and Interstate 86; Steuben County, New York. Feature Mapping Manager. Bryan provide oversight and management of the feature extraction for this project for the New York State Department of Transportation (NYSDOT) to complete Mobile Mapping along approximate 11.4 miles (including ramps) of Route I-86/17 and a portion of Route I-390, in the Kanona, Steuben County, New York area. Additionally Quantum Spatial was to complete mobile mapping on 9.1 miles (including ramps) of Route I-390 in Cohocton, Steuben County, New York area. Quantum Spatial collected all the mobile mapping data, post-processed and completed feature extraction creating a vector CADD deliverable showing overhead transmission lines, poles, overpass bridge clearances and all other issues that would have an impact on design. The point cloud was calibrated to the control targets established on the shoulder of the roadway. A bare earth model was developed to determine the profile along the existing roadway. Digital images and an Image Viewer were provide of the entire project for sign inventory and classification.

Mobile Mapping, Feature Extraction; Interstate 84, Pennsylvania. Feature Mapping Manager. Bryan provide oversight and management of the feature extraction for this project along the 6 mile section of this 4-lane highway, as well as geo-referenced digital images. Quantum Spatial collected all the mobile mapping data, post-processed and completed feature extraction creating a vector CADD deliverable showing overhead transmission lines, poles, overpass bridge clearances and all other issues that would have an impact on design. The point cloud was calibrated to the control targets established on the shoulder of the roadway. A bare earth model was developed to determine the profile along the existing roadway. Digital images and an Image Viewer were provide of the entire project for sign inventory and classification.

Mischa Hey

Project Assignment
Forest Analytics Manager, Quantum Spatial

Education
MS, Wildlife and Fisheries Biology, University of Vermont, 2006
BS, Natural Resource Management, University of Massachusetts, 2000

Years of Experience: 21

Years with Quantum Spatial: 18

Mischa has broad experience and technical skills in remote sensing analysis, in particular the development of feature extraction techniques using combined LiDAR and spectral datasets, including leveraging hyperspectral imagery to delineate land cover characterization of interest. He has been instrumental in developing processing workflows for specialty deliverables in unique landscapes, including hydro-flattening, intensity normalization, and point feature coding. Mischa has also been active in developing object-based image analysis techniques and tools for point cloud QA tool known as “LAS Monkey” as well as vegetation feature extraction and attribution. Over his career, he has given numerous presentations on LiDAR approaches.

Landvest LiDAR, Landvest. Forest Analytics Manager. Mischa performed the biometric modeling component of this 2 ppsm LiDAR project. Quantum Spatial used regression models for inventory metrics and Nearest Neighbor imputation for overstory and understory vegegation typing.

Middle Fork East River, Idaho Department of Lands. Forest Analytics Manager. Mischa ran the segmentation and statistical modeling based on 8 ppsm LiDAR. Modeled volume, DBH, and species. Quantum Spatial (as Watershed Sciences) was contracted by the Idaho Department of Lands (IDL) to collect Light Detection and Ranging (LiDAR) data and digital imagery in the fall of 2012 for the Middle Fork East River site in Idaho. Data were collected to aid IDL in assessing the topographic and geophysical properties of the study area to support planning and development for forestry. One component of the project was for Quantum Spatial to develop predictive statistical models describing relationships between airborne remote sensing data and field-based forestry metrics

Panther Creek, Bureau of Land Management. Forest Analytics Manager. Mischa performed both the individual tree and stand segmentation and the forest inventory and species modeling from 8 ppsm LiDAR and 4-band imagery.

Geospatial Products and Services Contract 2, U.S. Geological Survey. Remote Sensing Manager. Mischa has been involved on numerous tasks on this contract including the Minute 319 Colorado River LiDAR, and the Glacier Peak LiDAR task orders issued to Quantum Spatial (as Photo Science) on this contract.

Wilfred Mercier, LFP

Project Assignment
Forest Analyst,
James W. Sewall Company

Education
MS, Forest Resources, University of Maine
BS, Forestry with a minor in Surveying, University of Maine

Registration
Maine Licensed Professional Forester No. LF3702

Years of Experience: 11

Years with Sewall: 3

Wilfred Mercier is a forest resources professional specializing in remote sensing and GIS. He joined James W. Sewall Company in January of 2011 as a photo interpreter and GIS technician and now serves as an analyst. Wil is currently responsible for providing GIS and analytic support for forest cover type and vegetation mapping projects as well as preparation of Sewall's CanopyData™ products. His background includes supervising summer forestry field crews, developing an agent-based model of small forest landowners, managing an international inventory database, compiling spatial databases and related metadata, developing custom code for geospatial problems, and processing digital images. In 2008, Wilfred received the Outstanding Masters Student Award from the University of Maine's College of Natural Sciences, Forestry, and Agriculture. He is experienced in many aspects of forestry fieldwork, including forest mensuration, harvest layout, planting, and pre-commercial thinning assessment.

James W. Sewall Company. Analyst. Responsible for GIS data processing, quality assessment, and geospatial analysis, as well as metadata and deliverables preparation, primarily for forestry and natural resources projects.

James W. Sewall Company. Photo Interpreter. Responsible for interpreting photos for forest cover type and vegetation mapping on projects serving the forestry market.

Cooperative Forestry Research Unit (CFRU), University of Maine. Interim Research and Communications Coordinator. Supervised summer field crews on silviculture growth and yield research projects for CFRU, which connects forest landowners and researchers in applied research to establish sustainable forest management practices and sound public policy. Updated the CRFU website, and organized and moderated the CFRU 2010 Fall Field Tour.

Sustainability Solutions Initiative, University of Maine, Orono. Staff Research Associate. Developed an agent-based model of small forest landowners, assisted in leading stakeholder focus groups, and managed employees conducting deed research.

School of Forest Resources, University of Maine, Orono. Staff Research Associate. Managed an international inventory database (Quebec, New Brunswick, Nova Scotia, Newfoundland, and Maine) and provided GIS mapping for inventory projects.

Maine Image Analysis Lab, University of Maine, Orono. Graduate Research Assistant. Responsible for compiling spatial databases, processing digital images, preparing project documentation and deliverables, and developing custom code for solving geospatial problems.

APPENDIX C
SAMPLE FOCUS REPORT

quantum SPATIAL

October 28, 2015

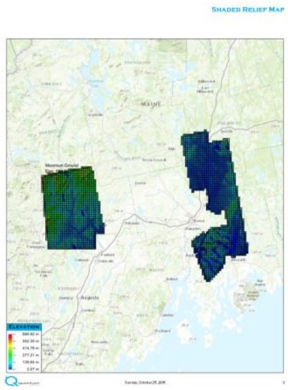
USGS Maine QL2 LiDAR Fall 2015 Delivery

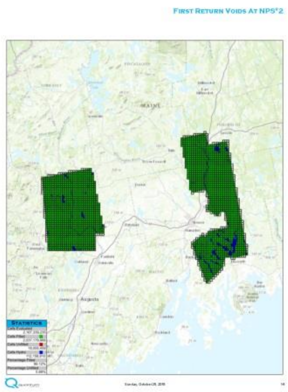
FOCUS

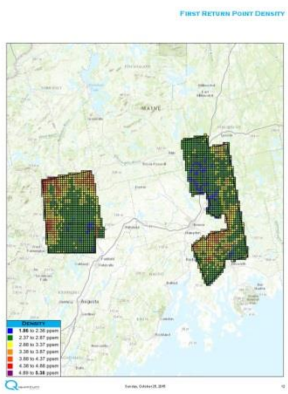
LiDAR Q/C
And Data
Exploitation
Report

PHOTO SCIENCE, INC.
A Quantum Spatial Company
523 Wellington Way, Suite 375
Lexington KY 40503

www.quantumspatial.com







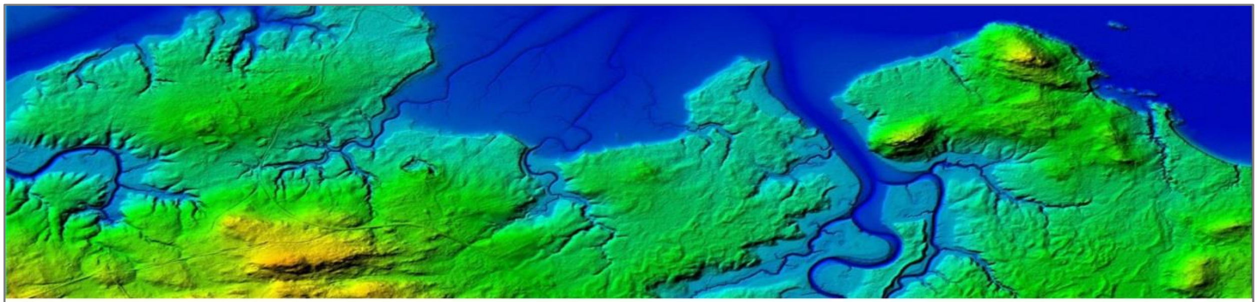
FOCUS™

POWERED BY QUANTUM SPATIAL

FOCUS is an acronym for Final Observed and Calculated User Statistics and serves as an important reporting and QC tool for LiDAR projects. As such, this report provides a comprehensive look and evaluation of LiDAR derived elevation products. The software tools that comprise FOCUS are an important part of our QC processes during the development of LiDAR elevation surfaces.

After writing the LAS and associated project files to the delivery media, we run these tools one more time on the actual deliverables to ensure that we are providing a quality product. The results of these final tests are contained in the following document and available for your general review of this dataset.

Appendix A of this document provides a thorough explanation of each of the tests summarized within this report. Appendix B provides a detailed glossary of common LiDAR terminology.



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quantum SPATIAL

SUMMARY

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281

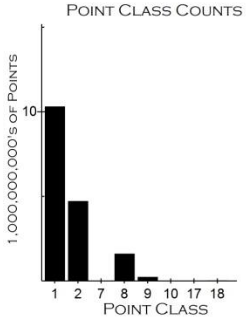
Project Information

LAS Version	1.4	2133 of 2133 Tiles
Point Data Format	6	2133 of 2133 Tiles
Projection	2011 UTM Zone 19	2133 of 2133 Tiles
Horizontal Datum	NAD83 2011	2133 of 2133 Tiles
Vertical Datum	NAVD88 meters	2133 of 2133 Tiles
Vertical Geoid	Geoid12A (Meter)|	2133 of 2133 Tiles
Minimum Ground	N 4,937,900.54 m E 521,143.63 m	Elev 2.07 m
Maximum Ground	N 4,991,239.61 m E 410,282.17 m	Elev 689.92 m
Planned NPS	0.7 meters	
Project Area	1,723.32 sq mi	
Tile Size	1,500 m x 1,500 m	
Start Of Acquisition	5/4/2015 1:59:57 PM UTC	
End Of Acquisition	5/9/2015 9:26:53 PM UTC	
Tile Boundary Test	Pass	

Point Classification Analysis

Classification	Point Count	Density*	Overlap
Class - All	30,531,850,324	6.37 ppsm	13,719,503,758
Class 1 - Unclassified	10,283,236,880	2.14 ppsm	8,954,833,436
Class 2 - Ground	4,691,717,012	0.98 ppsm	4,748,422,690
Class 7 - Low Points	204,240	0.00 ppsm	0
Class 8 - Model Key	1,583,737,170	0.33 ppsm	0
Class 9 - Water	209,246,367	0.00 ppsm	16,247,632
Class 10 - Ignored Ground	1,061,036	0.00 ppsm	0
Class 17 - Bridge	106,498	0.00 ppsm	0
Class 18 - High Noise	4,369,329	0.00 ppsm	0

*Results based only on points within AOI



Point Return Statistics

Return 1 Points	23,606,194,999
Return 2 Points	5,295,679,336
Return 3 Points	1,429,531,336
Return 4 Points	193,061,326
Return 5 Points	7,289,864
Return 6 Points	92,952
Return 7 Points	509
Return 10 Points	1
Return 8 Points	1

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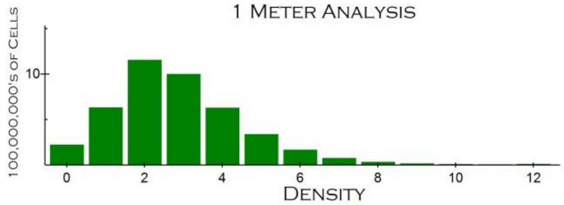
First Return Non-Overlap Density Analysis

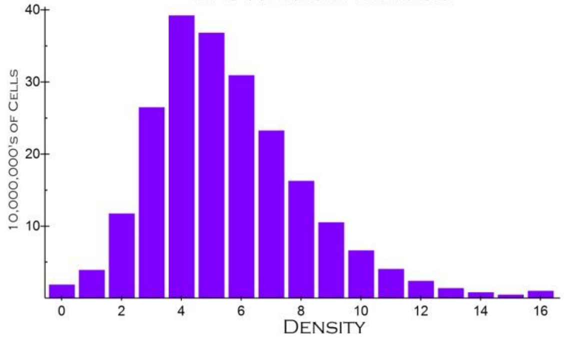
Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281

1 Meter Analysis



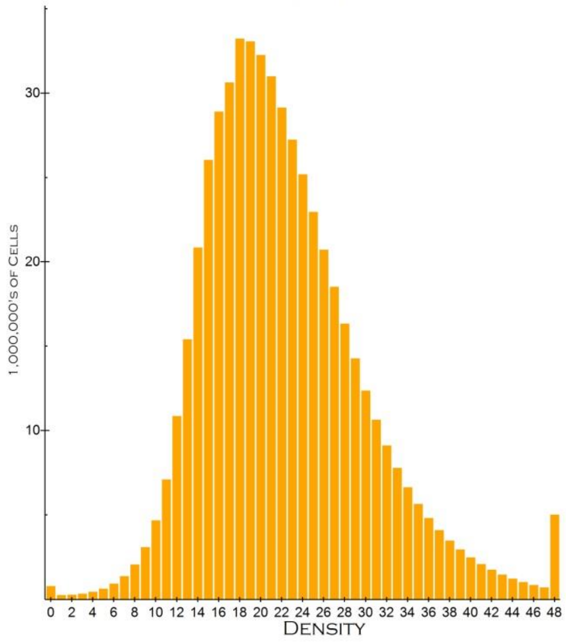
1 Meter Cell			
Average	2.85	Standard Dev.	1.80
Return Count	# of Cells	Return Count	# of Cells
0	218,923,779	7	71,002,405
1	628,071,651	8	29,203,510
2	1,151,290,203	9	11,861,164
3	996,432,614	10	5,207,715
4	625,017,492	11	2,548,908
5	334,617,126	12+	6,430,115
6	163,449,468		

NPS*2 Density Analysis



1.4 Meter Cell (NPS*2)			
Average	5.59	Standard Dev.	2.82
Return Count	# of Cells	Return Count	# of Cells
0	17,998,469	9	104,803,237
1	38,416,272	10	65,871,165
2	116,951,860	11	39,705,890
3	264,232,254	12	23,204,941
4	391,585,055	13	13,106,309
5	367,704,547	14	7,310,669
6	308,744,745	15	4,055,732
7	232,082,722	16+	9,343,079
8	162,222,289		

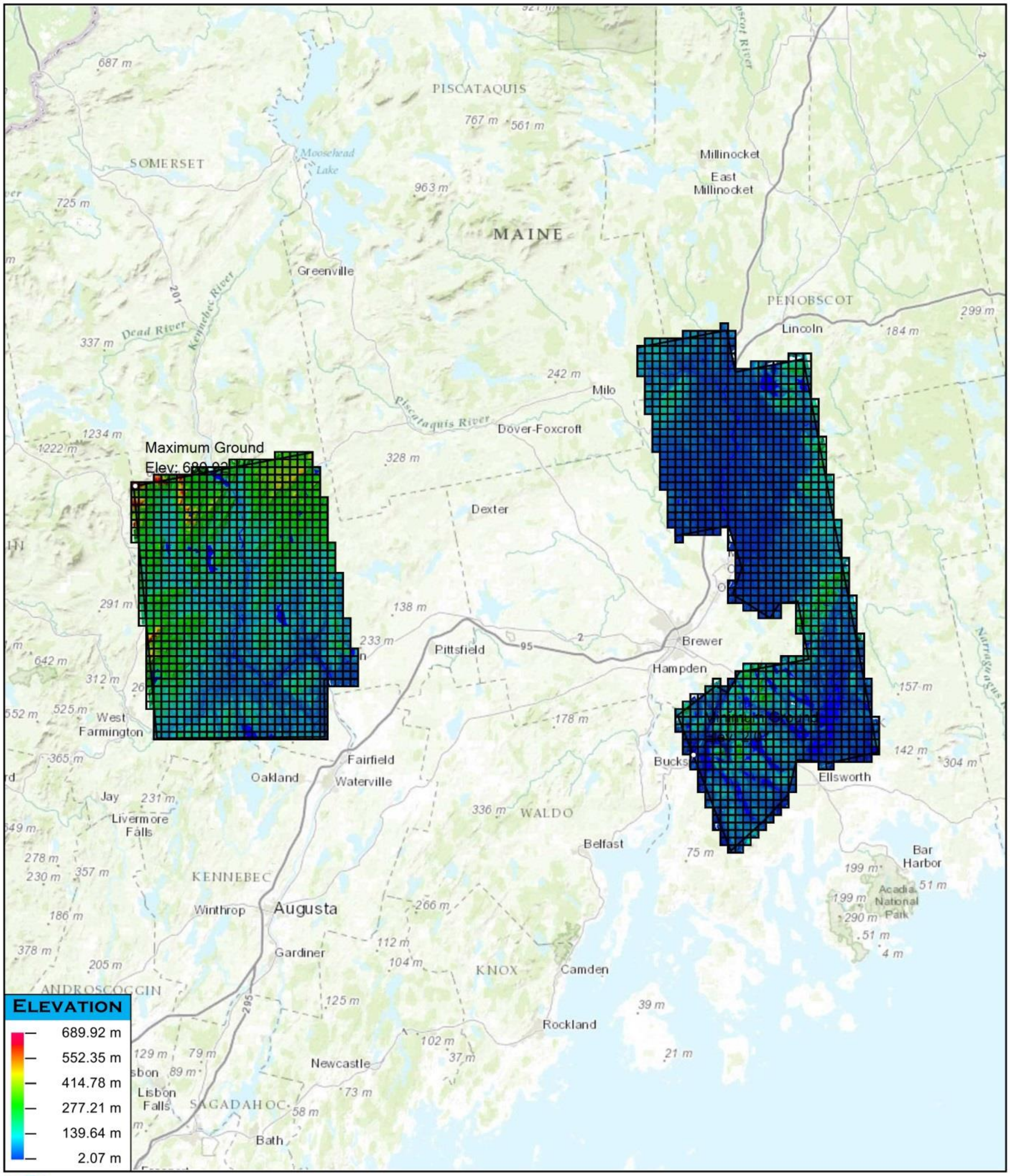
NPS*4 Density Analysis



2.8 Meter Cell (NPS*4)			
Average	22.34	Standard Dev.	8.67
Return Count	# of Cells	Return Count	# of Cells
0	769,448	25	22,938,387
1	235,347	26	20,698,608
2	254,928	27	18,483,669
3	315,241	28	16,304,966
4	431,421	29	14,243,148
5	613,359	30	12,334,015
6	913,969	31	10,610,692
7	1,355,652	32	9,085,209
8	2,048,116	33	7,758,183
9	3,060,154	34	6,610,498
10	4,647,387	35	5,623,261
11	7,067,920	36	4,787,713
12	10,829,772	37	4,068,523
13	15,373,907	38	3,451,090
14	20,824,982	39	2,921,702
15	26,018,512	40	2,468,076
16	28,880,280	41	2,074,994
17	30,603,281	42	1,741,471
18	33,204,022	43	1,453,914
19	33,039,590	44	1,209,640
20	32,234,346	45	1,003,111
21	30,966,884	46	831,247
22	29,116,676	47	691,051
23	27,218,319	48+	4,985,539
24	25,164,959		

Shaded Relief Map

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



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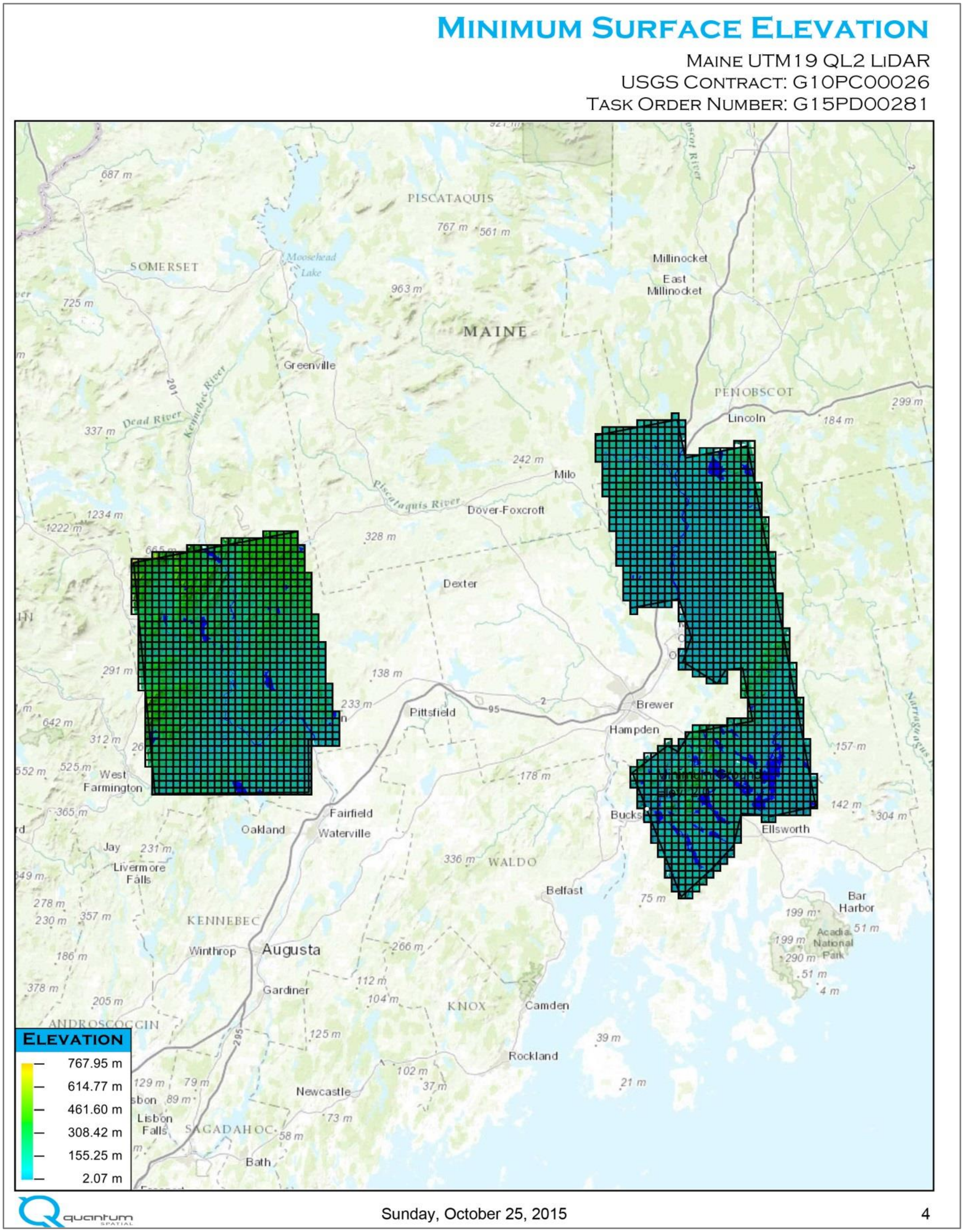
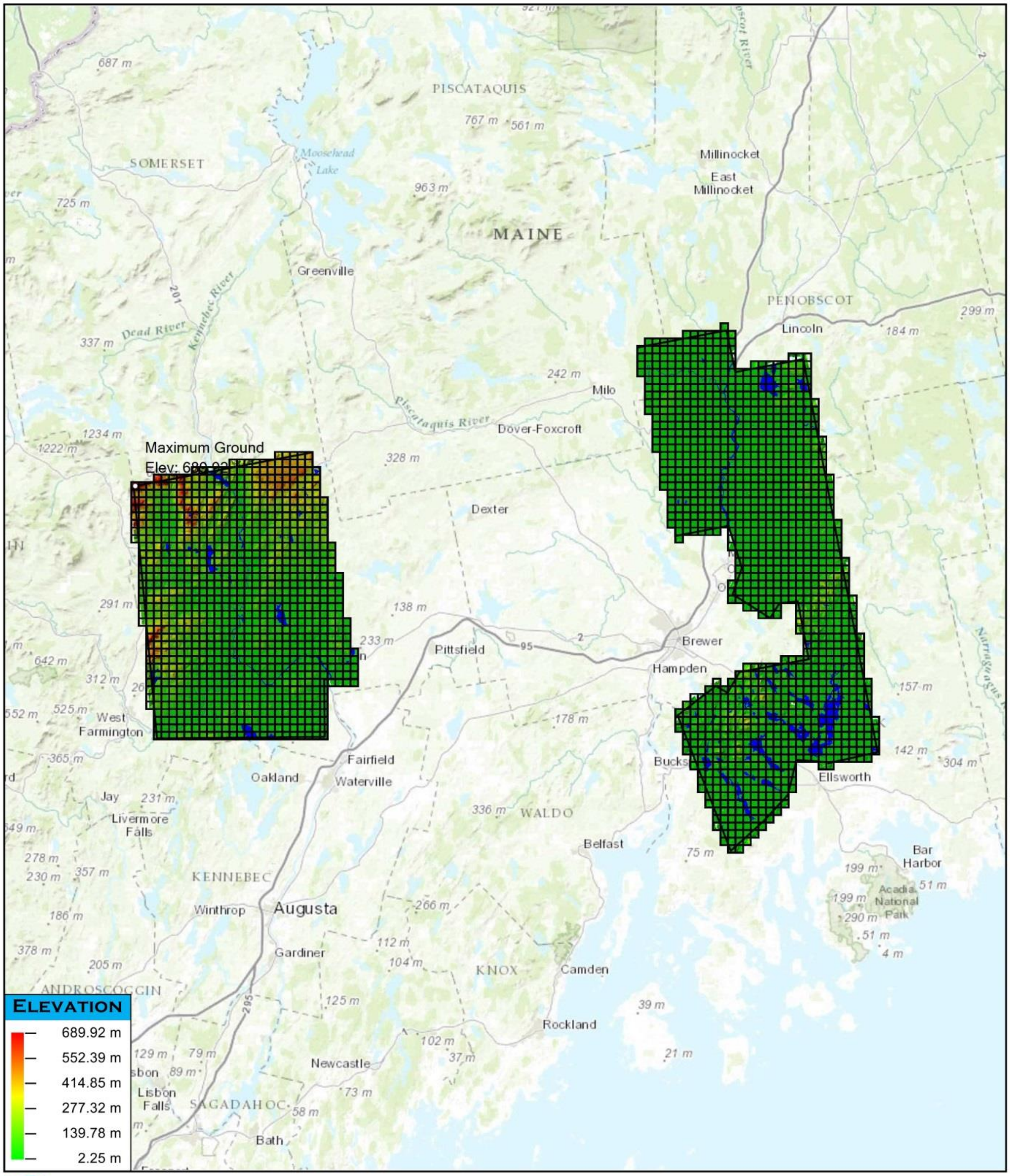


MINIMUM SURFACE ELEVATION
MAINE UTM19 QL2 LIDAR
USGS CONTRACT: G10PC00026
TASK ORDER NUMBER: G15PD00281
PISCATAQUIS
SOMERSET
MAINE
Moosehead Lake
Greenville
Millinocket
East Millinocket
PENOBSCOT
Lincoln
Milo
Dover-Foxcroft
Dexter
Pittsfield
Brewer
Hampden
Bucksport
Ellsworth
Belfast
WALDO
Bar Harbor
Acadia National Park
West Farmington
Oakland
Fairfield
Waterville
Jay
Livermore Falls
KENNEBEC
Winthrop
Augusta
Gardiner
KNOX
Camden
Rockland
ANDROSCOGGIN
Newcastle
Lisbon Falls
SAGADAHOC
Bath
Dead River
Kennebec River
Piscataquis River
ELEVATION
767.95 m
614.77 m
461.60 m
308.42 m
155.25 m
2.07 m
Sunday, October 25, 2015
4

Maximum Surface Elevation

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



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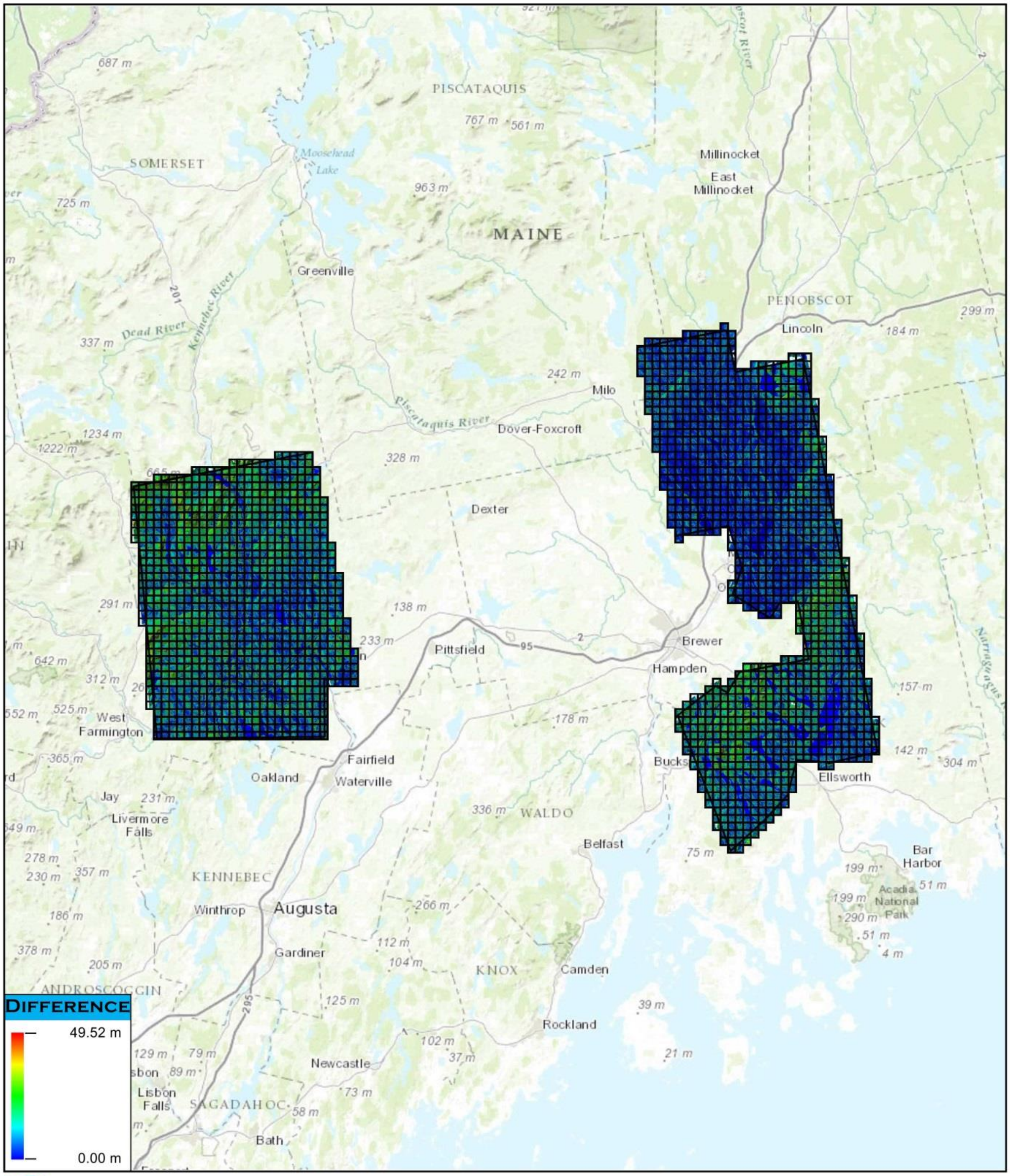
Relative Terrain Change

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



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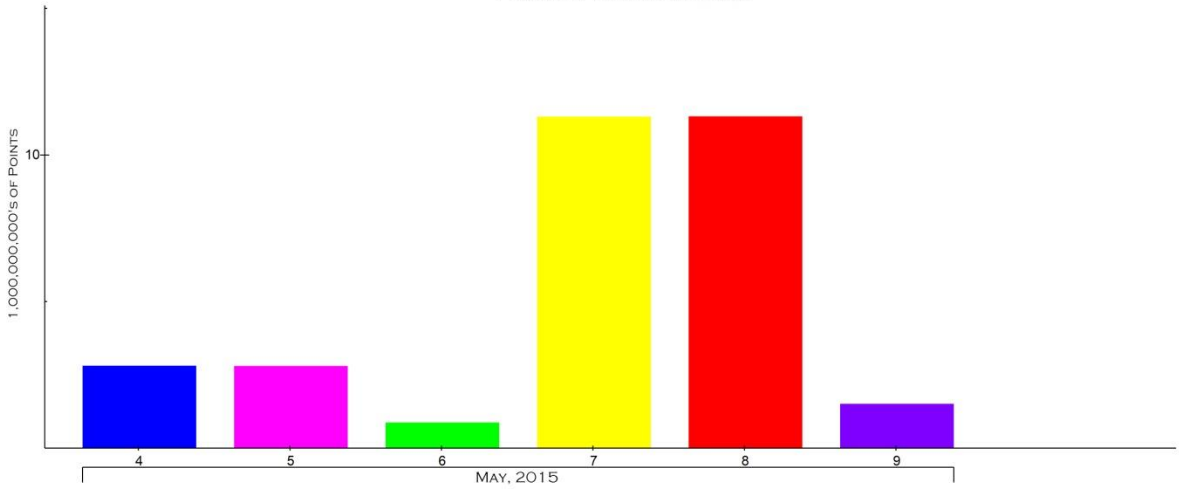
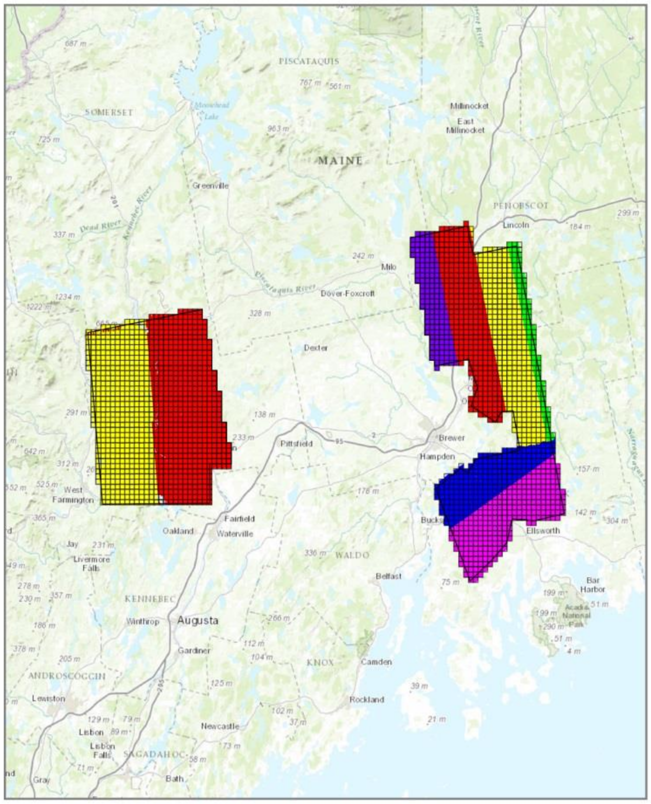
Collection Date Analysis

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281

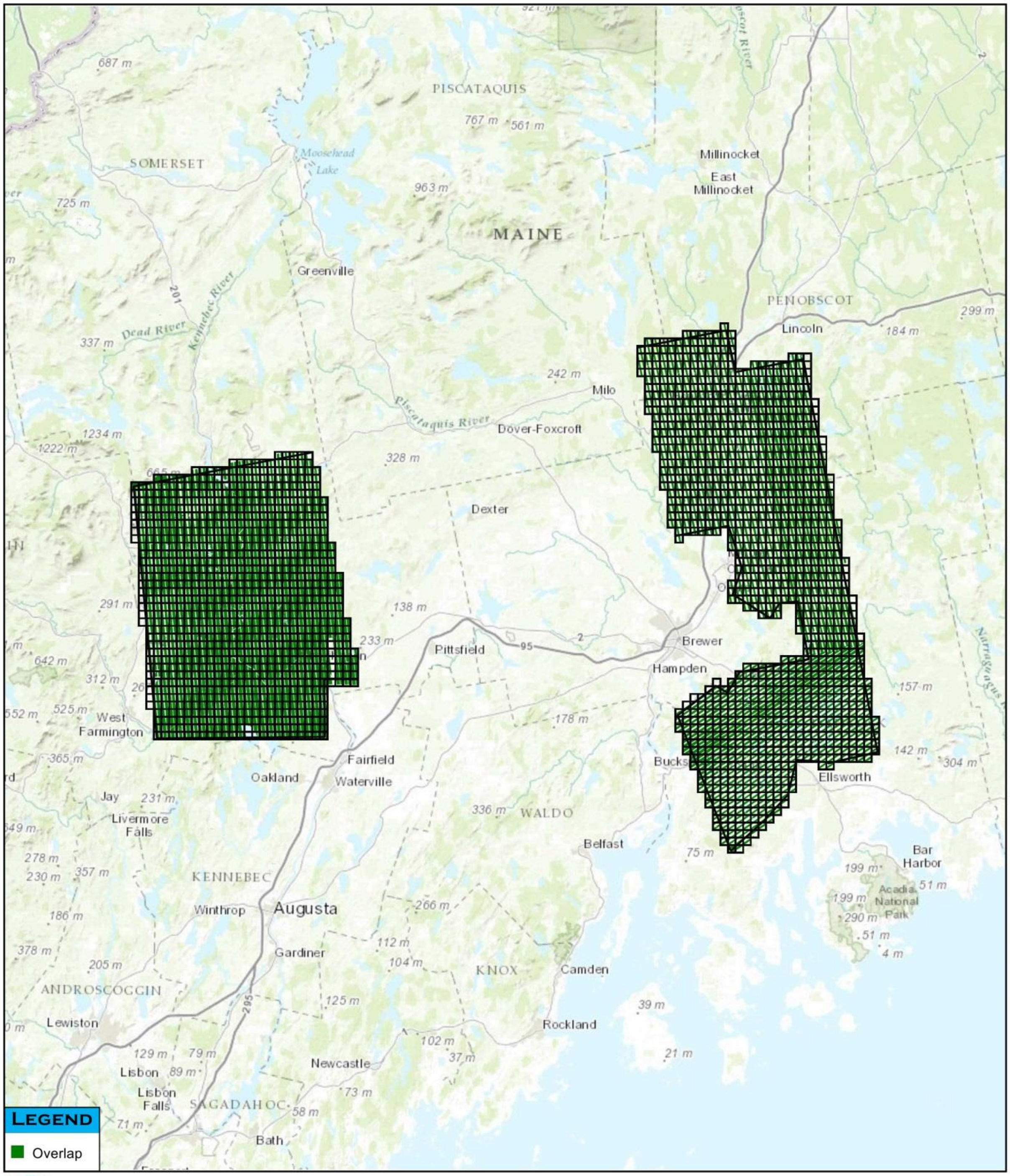


May, 2015			
Day	Key	# of Points	% of Overall
4		2,795,964,994	9.2%
5		2,788,555,994	9.1%
6		857,615,523	2.8%
7		11,292,761,949	37.0%
8		11,302,097,370	37.0%
9		1,494,854,494	4.9%



Overlap Map

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



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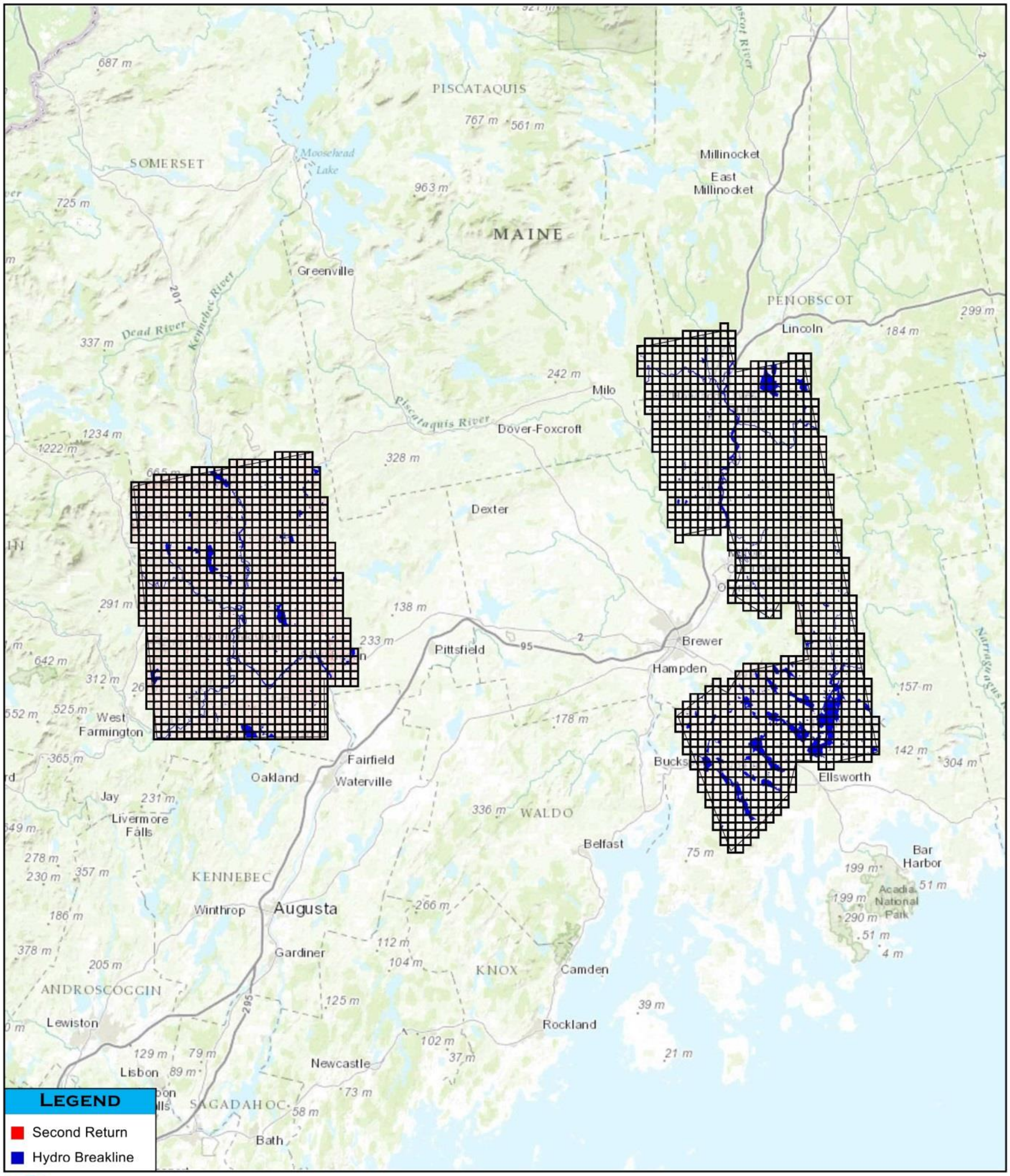
Second Return Locations

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



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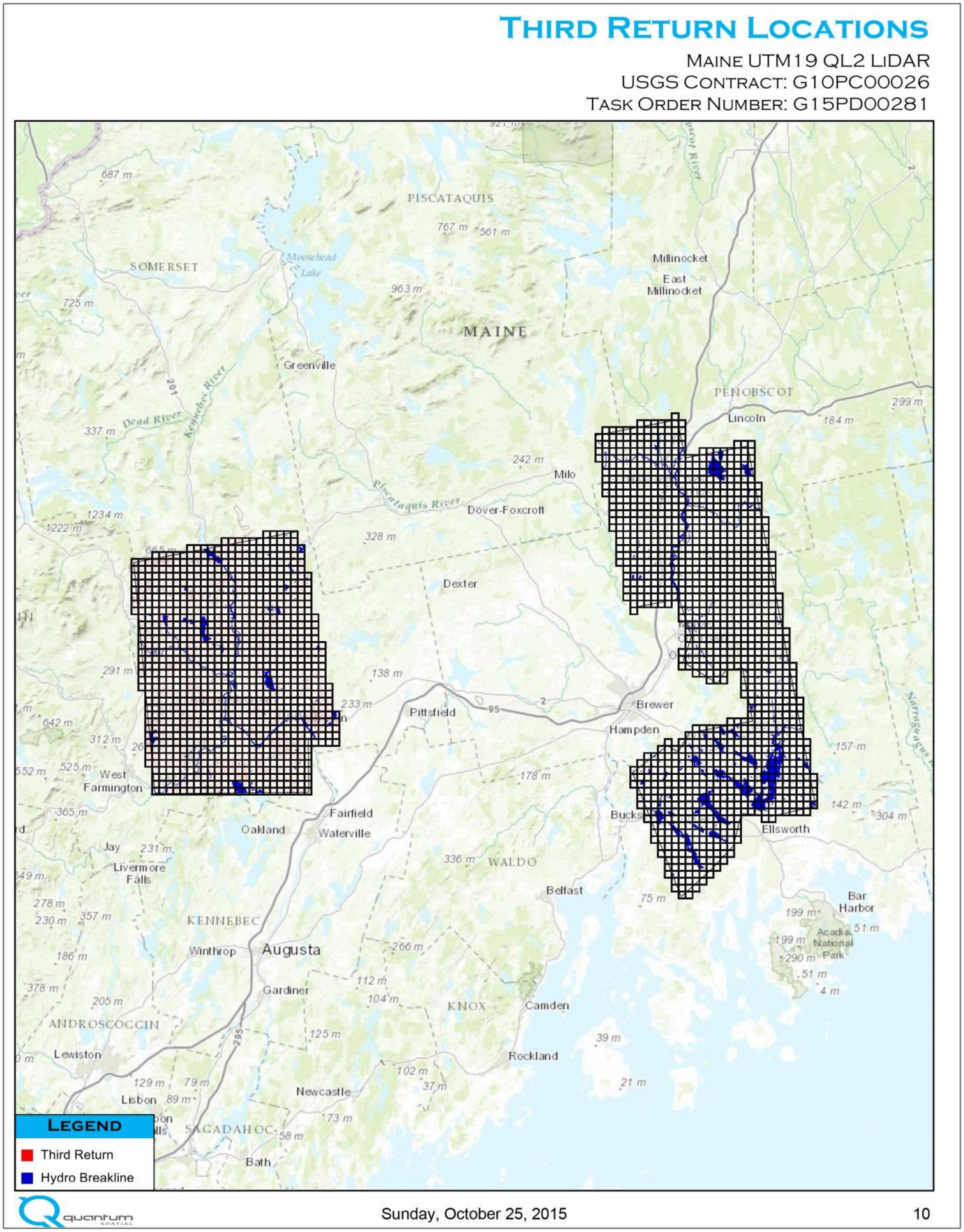
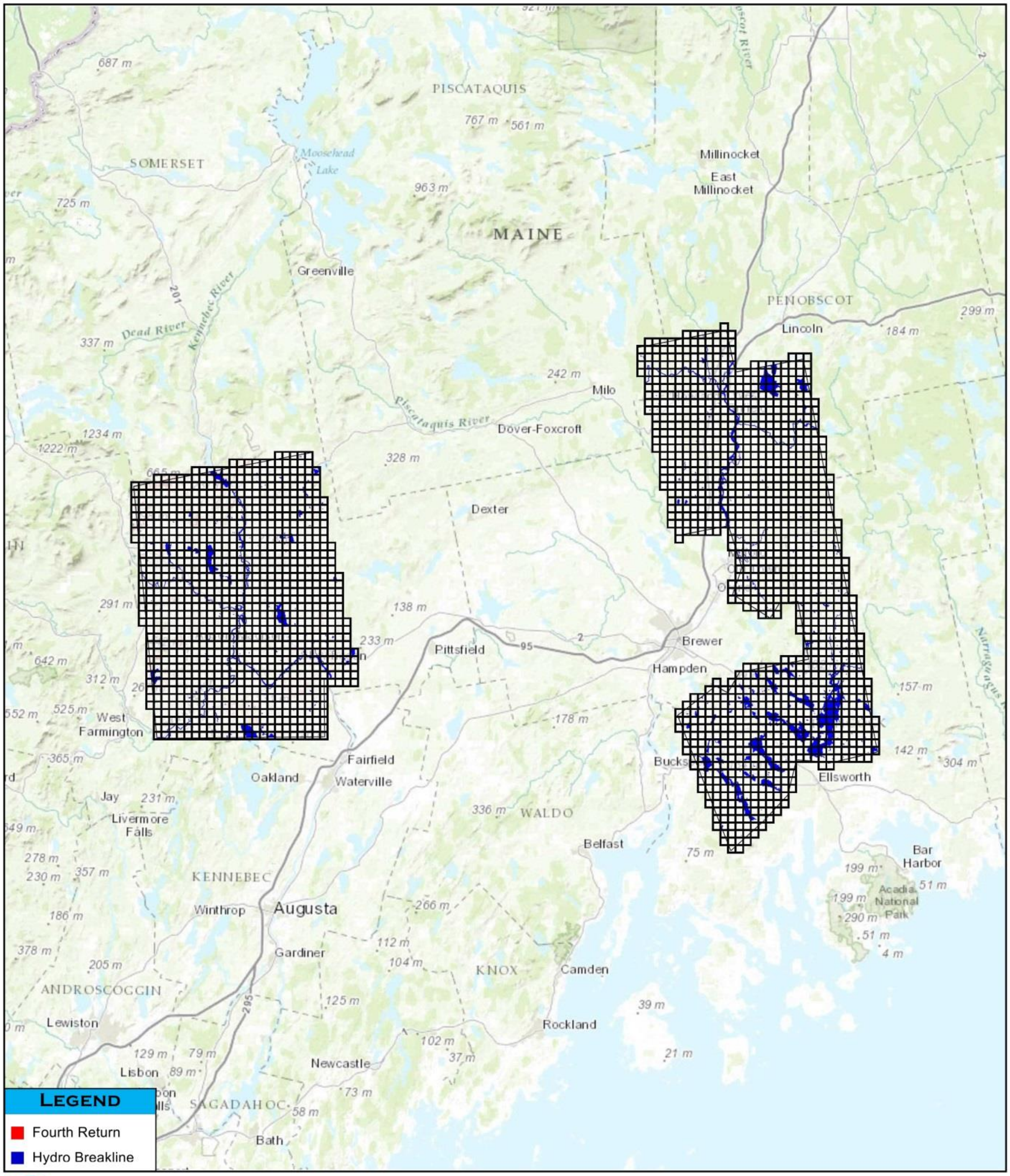

THIRD RETURN LOCATIONS
MAINE UTM19 QL2 LIDAR
USGS CONTRACT: G10PC00026
TASK ORDER NUMBER: G15PD00281
PISCATAQUIS
SOMERSET
MAINE
PENOBSCOT
KENNEBEC
WALDO
KNOX
ANDROSCOGGIN
SAGADAHOC
Millinocket
East Millinocket
Greenville
Lincoln
Milo
Dover-Foxcroft
Dexter
Pittsfield
Brewer
Hampden
Bucksport
Ellsworth
Bar Harbor
Acadia National Park
West Farmington
Oakland
Fairfield
Waterville
Jay
Livermore Falls
Belfast
Winthrop
Augusta
Gardiner
Camden
Rockland
Lewiston
Lisbon
Newcastle
Bath
Dead River
Kennebec River
Piscataquis River
Moosehead Lake
LEGEND
Third Return
Hydro Breakline
Sunday, October 25, 2015
10

Fourth Return Locations

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



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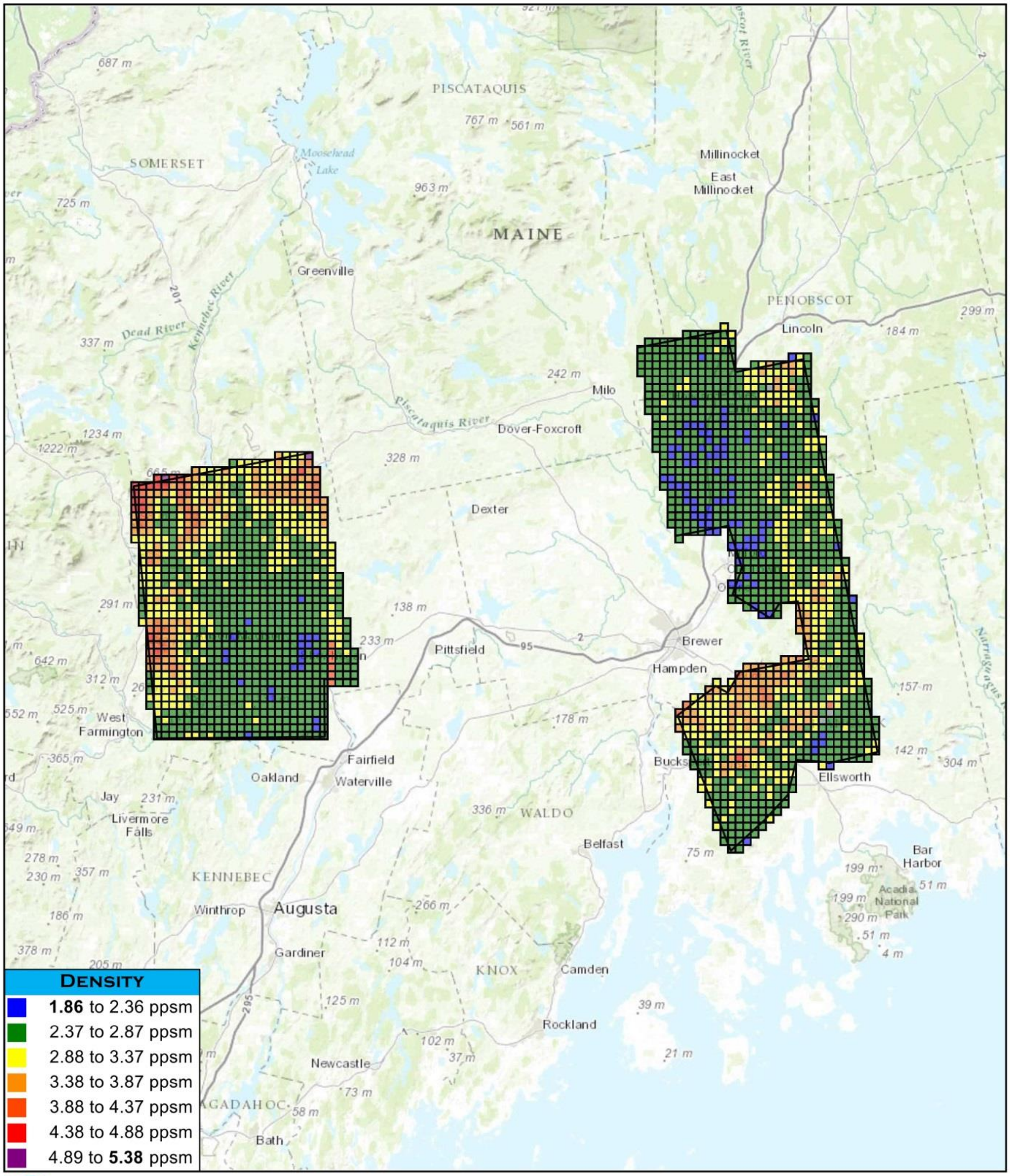
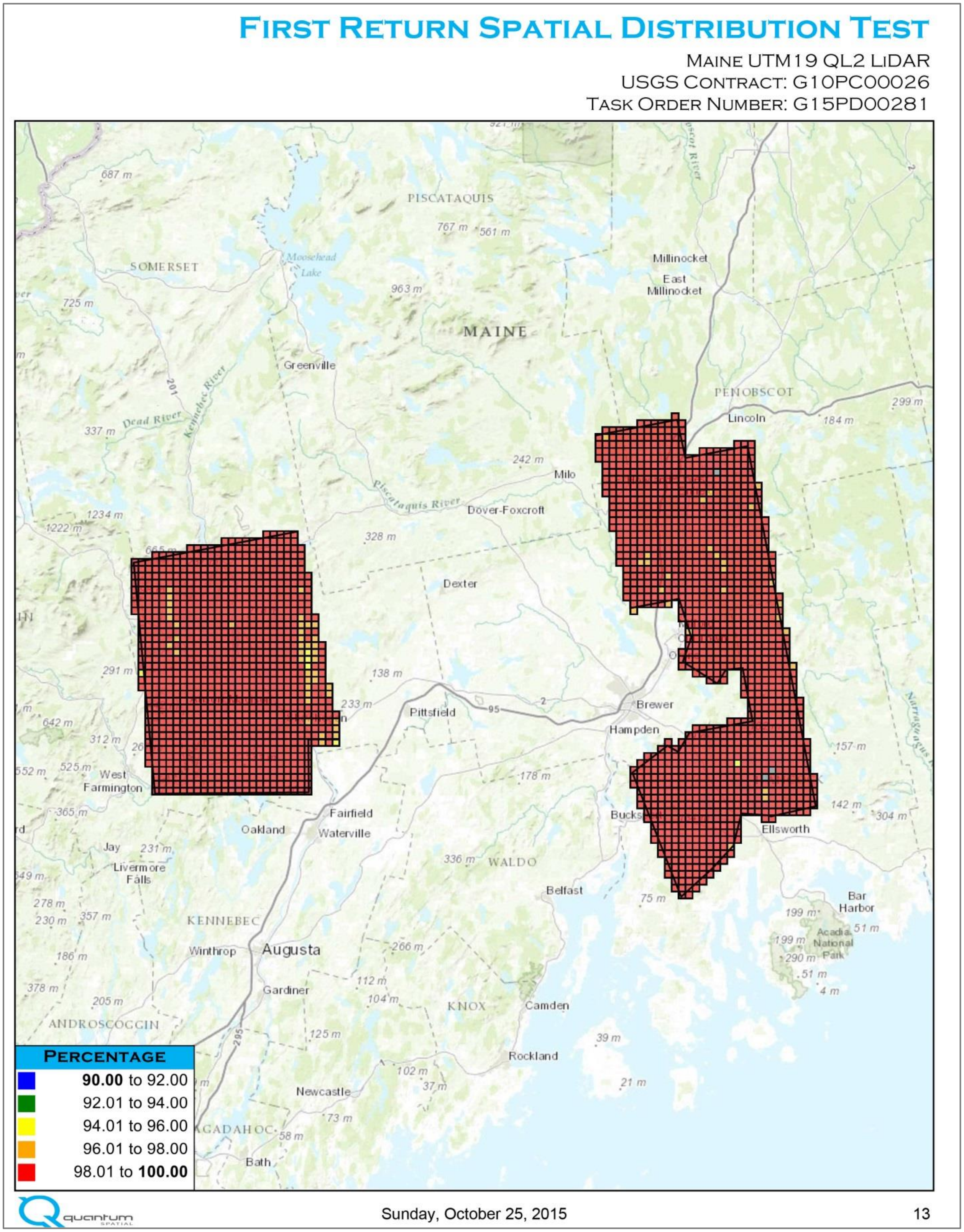
First Return Point Density

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281

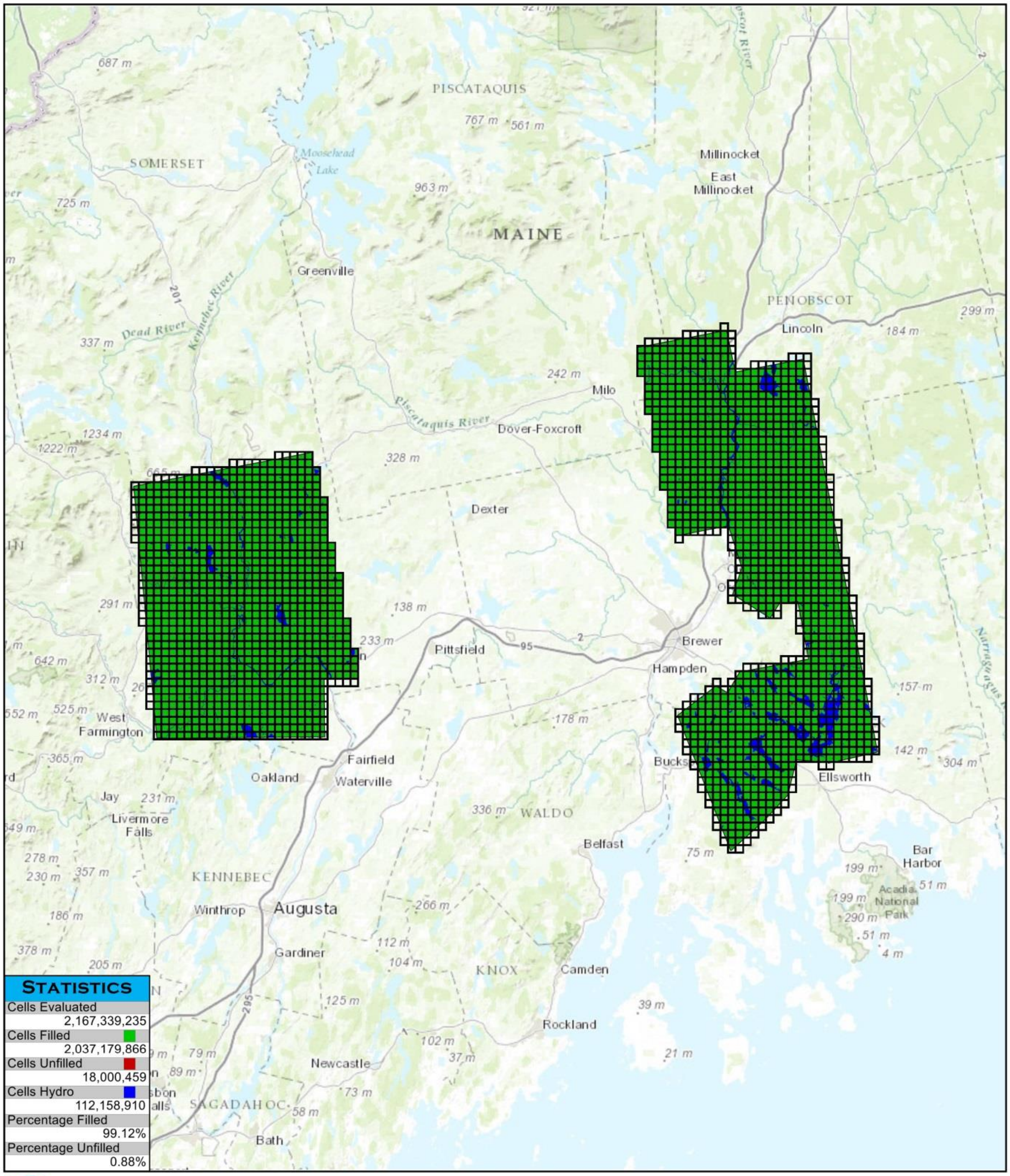


quantum SPATIAL Sunday, October 25, 2015 12


First Return Spatial Distribution Test
Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281
PISCATAQUIS
SOMERSET
MAINE
PENOBSCOT
KENNEBEC
WALDO
KNOX
ANDROSCOGGIN
Millinocket
East Millinocket
Greenville
Lincoln
Milo
Dover-Foxcroft
Dexter
Pittsfield
Brewer
Hampden
Bucksport
Ellsworth
Bar Harbor
Acadia National Park
Belfast
Camden
Rockland
Fairfield
Waterville
Oakland
West Farmington
Jay
Livermore Falls
Winthrop
Augusta
Gardiner
Newcastle
Bath
Moosehead Lake
Dead River
Kennebec River
Piscataquis River
Percentage
90.00 to 92.00
92.01 to 94.00
94.01 to 96.00
96.01 to 98.00
98.01 to 100.00
Sunday, October 25, 2015
13

First Return Voids At NPS*2

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



Statistics	
Cells Evaluated	2,167,339,235
Cells Filled	2,037,179,866
Cells Unfilled	18,000,459
Cells Hydro	112,158,910
Percentage Filled	99.12%
Percentage Unfilled	0.88%

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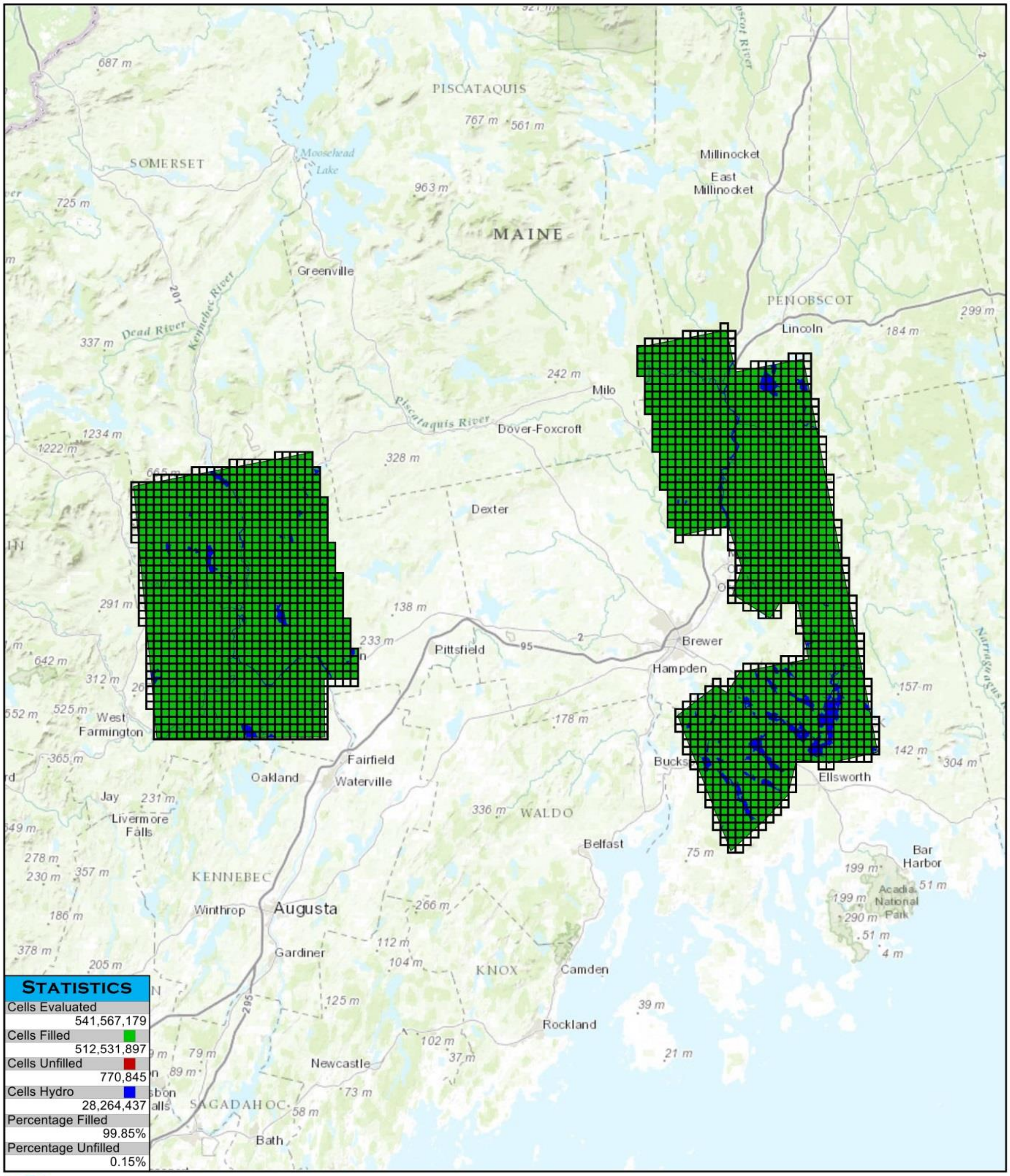
First Return Voids At NPS*4

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



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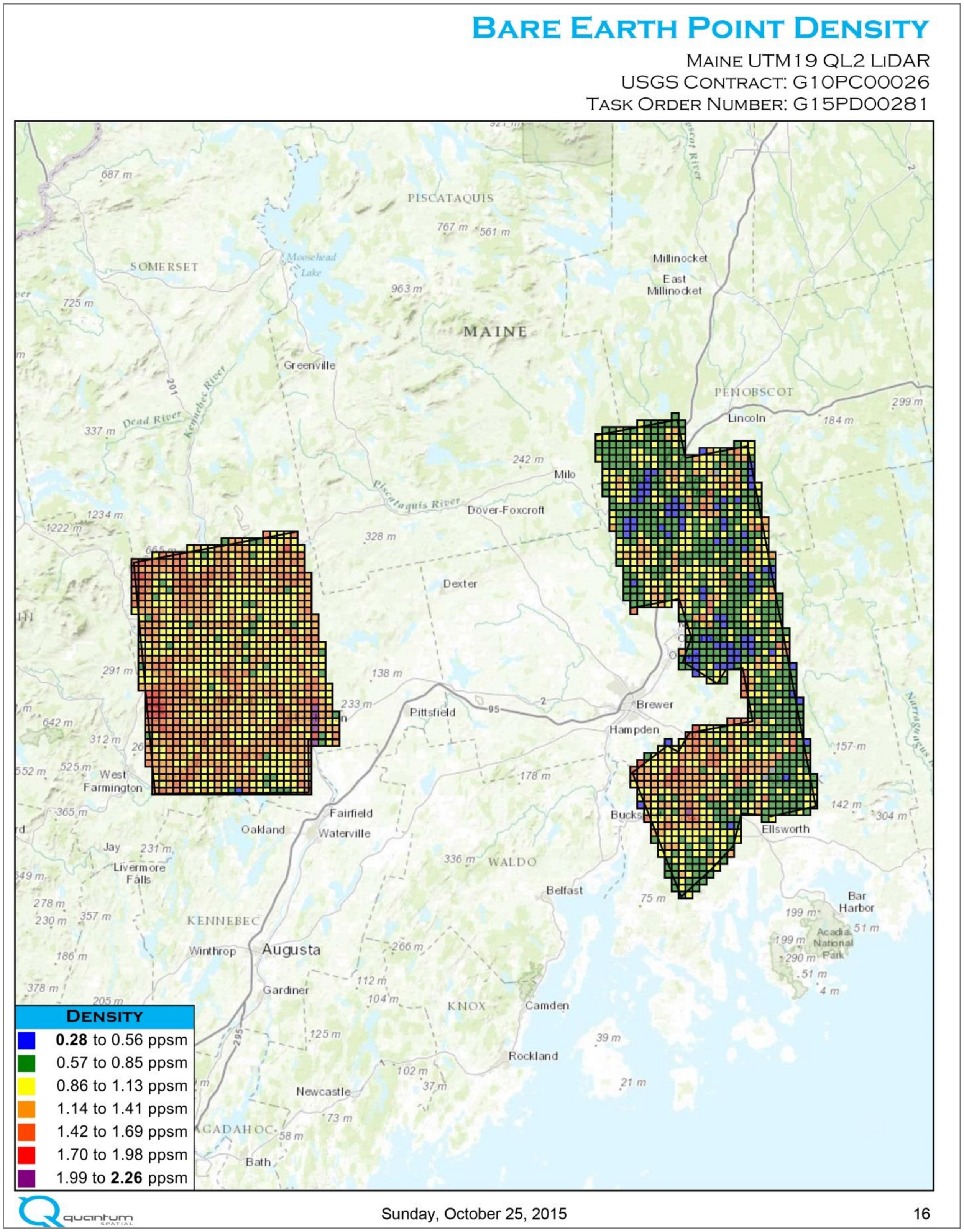
BARE EARTH POINT DENSITY
MAINE UTM19 QL2 LIDAR
USGS CONTRACT: G10PC00026
TASK ORDER NUMBER: G15PD00281
PISCATAQUIS
SOMERSET
MAINE
PENOBSCOT
KENNEBEC
WALDO
KNOX
Moosehead Lake
Greenville
Millinocket
East Millinocket
Lincoln
Milo
Dover-Foxcroft
Dexter
Pittsfield
Brewer
Hampden
Bucksport
Ellsworth
Bar Harbor
Acadia National Park
Belfast
Camden
Rockland
Newcastle
Bath
Gardiner
Augusta
Winthrop
Fairfield
Waterville
Oakland
West Farmington
Jay
Livermore Falls
Dead River
Kennebec River
Piscataquis River
DENSITY
0.28 to 0.56 ppsm
0.57 to 0.85 ppsm
0.86 to 1.13 ppsm
1.14 to 1.41 ppsm
1.42 to 1.69 ppsm
1.70 to 1.98 ppsm
1.99 to 2.26 ppsm
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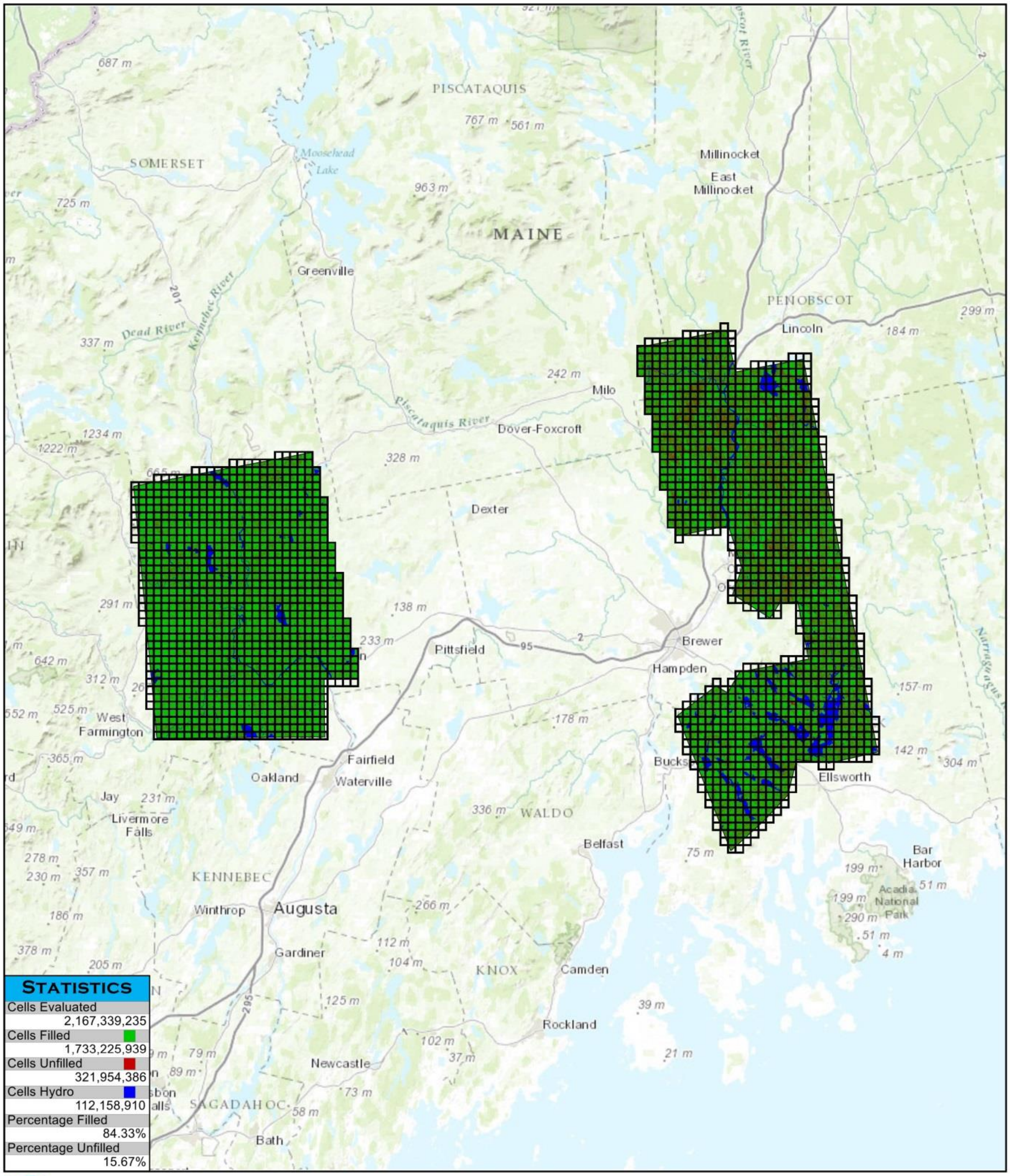
Bare Earth Voids At NPS*2

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



Statistics

Cells Evaluated	2,167,339,235
Cells Filled	1,733,225,939
Cells Unfilled	321,954,386
Cells Hydro	112,158,910
Percentage Filled	84.33%
Percentage Unfilled	15.67%

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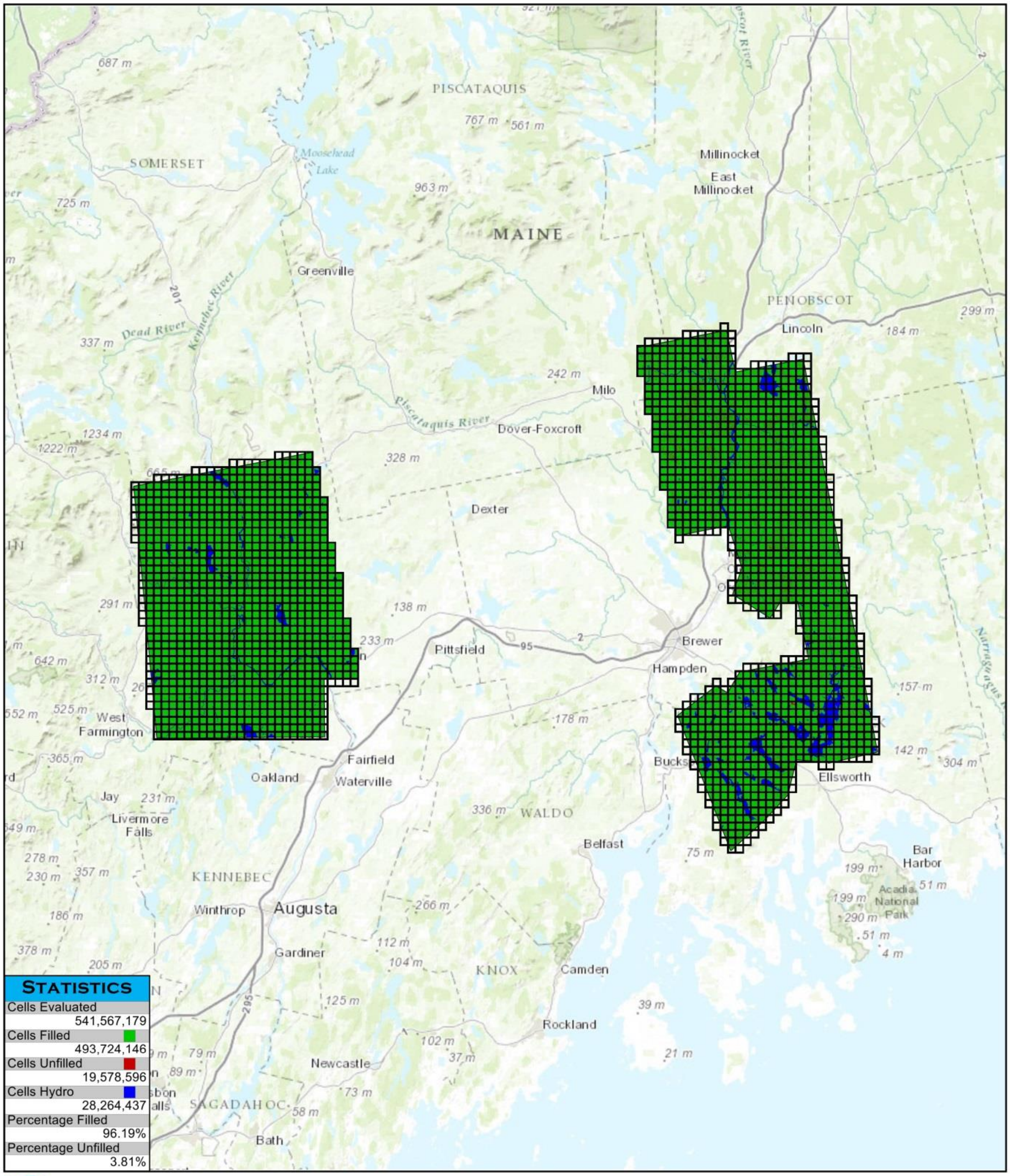
BARE EARTH VOIDS AT NPS*4

MAINE UTM19 QL2 LIDAR
USGS CONTRACT: G10PC00026
TASK ORDER NUMBER: G15PD00281



STATISTICS	
Cells Evaluated	541,567,179
Cells Filled	493,724,146
Cells Unfilled	19,578,596
Cells Hydro	28,264,437
Percentage Filled	96.19%
Percentage Unfilled	3.81%

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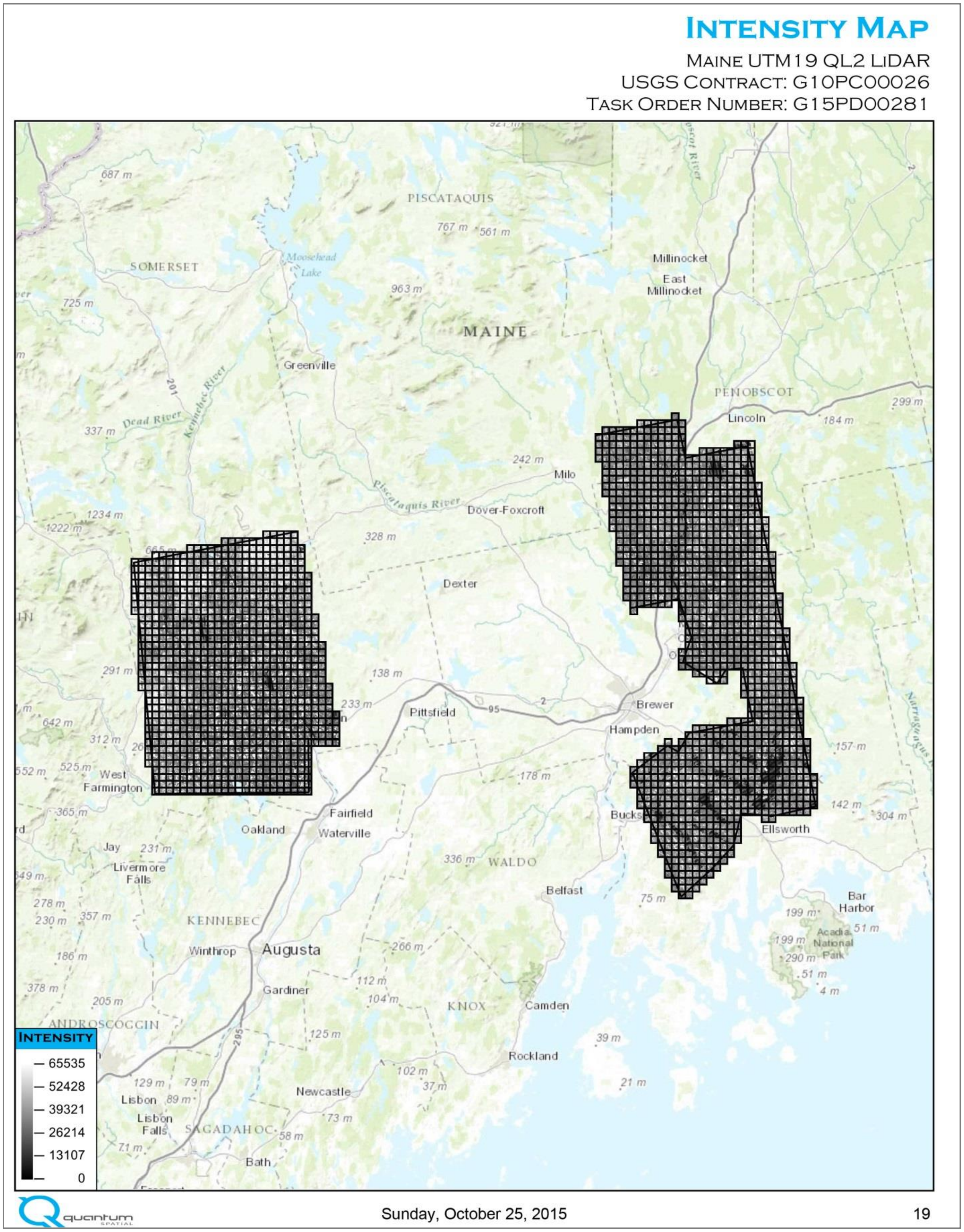
INTENSITY MAP
MAINE UTM19 QL2 LIDAR
USGS CONTRACT: G10PC00026
TASK ORDER NUMBER: G15PD00281
PISCATAQUIS
SOMERSET
MAINE
PENOBSCOT
KENNEBEC
WALDO
KNOX
ANDROSCOGGIN
SAGADAHOC
Moosehead Lake
Greenville
Millinocket
East Millinocket
Lincoln
Milo
Dover-Foxcroft
Dexter
Pittsfield
Brewer
Hampden
Bucksport
Ellsworth
Bar Harbor
Acadia National Park
Belfast
Camden
Rockland
Fairfield
Waterville
Oakland
West Farmington
Jay
Livermore Falls
Winthrop
Augusta
Gardiner
Lisbon
Lisbon Falls
Newcastle
Bath
Dead River
Kennebec River
Piscataquis River
INTENSITY
65535
52428
39321
26214
13107
0
Sunday, October 25, 2015
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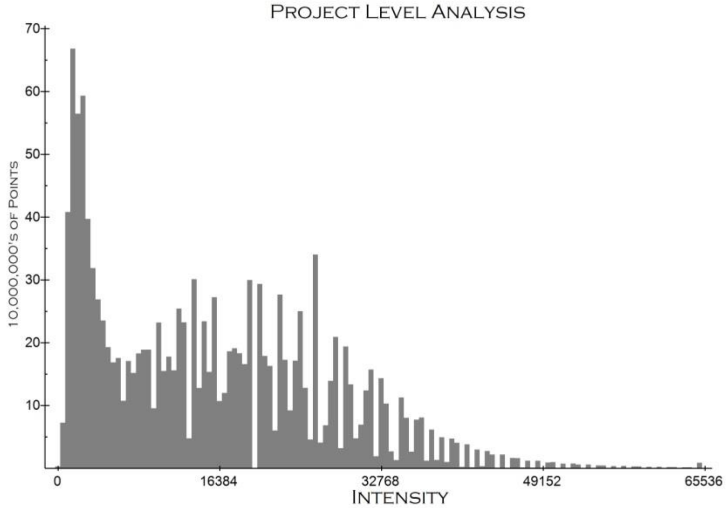
Intensity Analysis

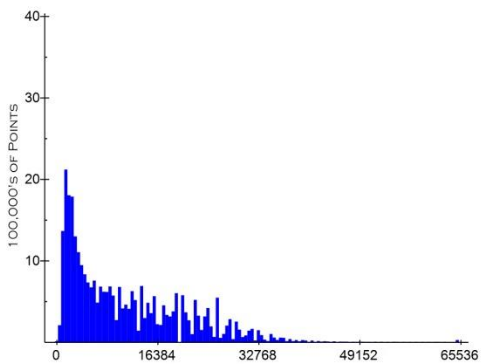
Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281

Statistics	
Project Mean Intensity	15,727.1
Lowest Mean Intensity	9,981.5
Highest Mean Intensity	27,283.9

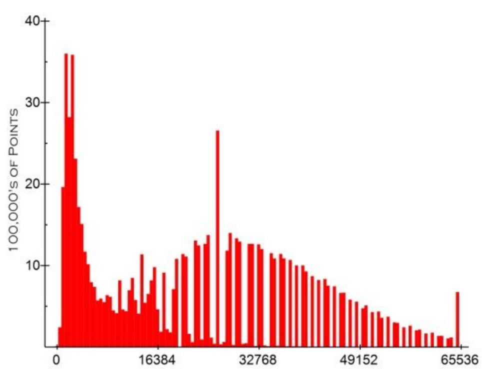
Project Level Analysis

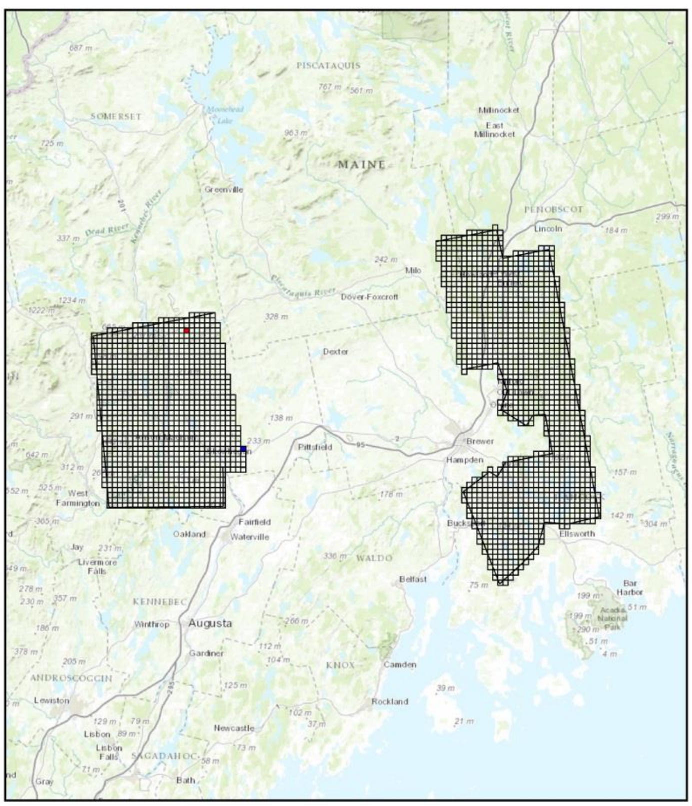


Lowest Mean Intensity



Highest Mean Intensity





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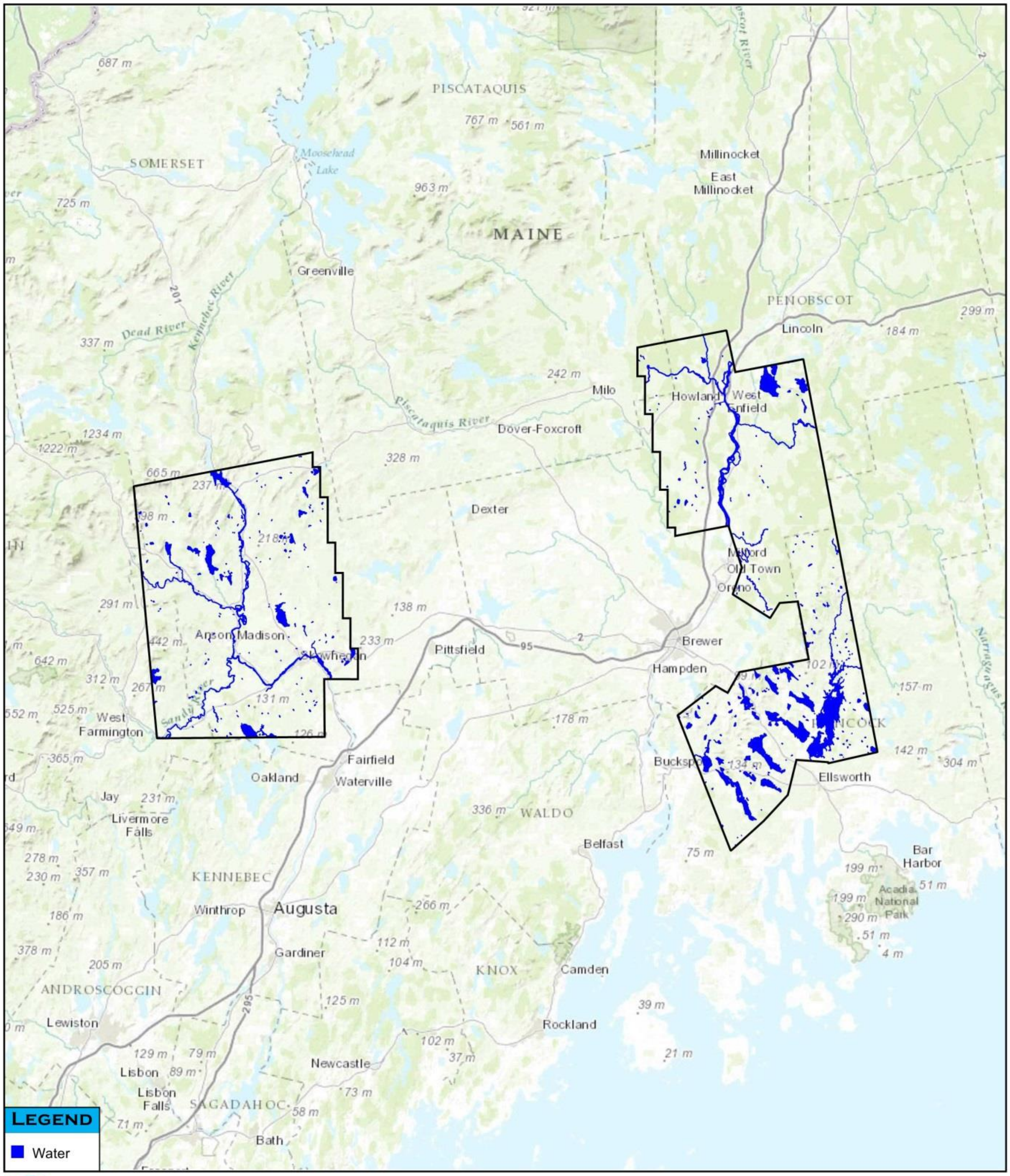
Breakline Map

Maine UTM19 QL2 LiDAR
USGS Contract: G10PC00026
Task Order Number: G15PD00281



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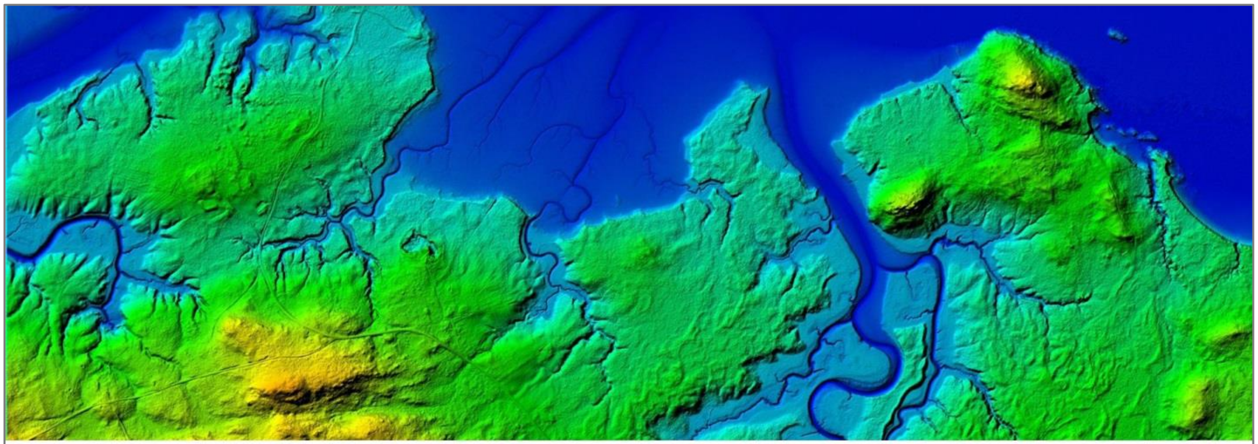
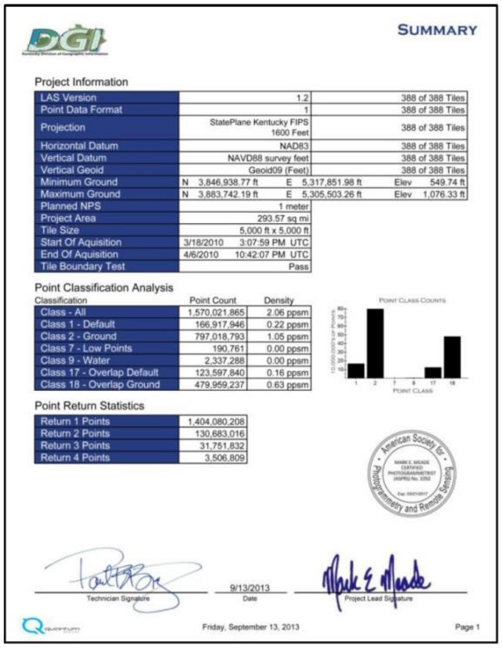


Appendix A – Explanation of Reporting

The following section provides a summary of all the reporting provided within FOCUS™. While most of the reports should be intuitive, it will be very useful to read through the background information for each of these reports to gain a full understanding of the comprehensive nature of this important tool.

Project Summary

Each of the LAS headers is carefully reviewed and a summary of this information is provided at the beginning of the report. This summary includes information for the LAS versioning, point data format, units, projection, geoid model, datums, etc. This provides a quick overall view of the project. You would normally expect that all tiles would have identical versions, point data formats, units, geoid models, projections, and datums. There are times, however, when the projection information could be different for varying groups of tiles. This might occur, for example, when a large project splits two state plane or UTM coordinate zones. Regardless, these statistics provide a quick sanity check of



DGI

SUMMARY

Project Information

LAS Version	1.2	388 of 388 Tiles
Point Data Format	1	388 of 388 Tiles
Projection	StatePlane Kentucky FIPS 1600 Feet	388 of 388 Tiles
Horizontal Datum	NAD83	388 of 388 Tiles
Vertical Datum	NAVD88 survey feet	388 of 388 Tiles
Vertical Geoid	Geoid09 (Feet)	388 of 388 Tiles
Minimum Ground	N 3,846,938.77 ft E 5,317,851.98 ft	Elev 549.74 ft
Maximum Ground	N 3,883,742.19 ft E 5,305,503.26 ft	Elev 1,076.33 ft
Planned NPS	1 meter	
Project Area	293.57 sq mi	
Tile Size	5,000 ft x 5,000 ft	
Start Of Aquisition	3/18/2010 3:07:59 PM UTC	
End Of Aquisition	4/6/2010 10:42:07 PM UTC	
Tile Boundary Test	Pass	

Point Classification Analysis

Classification	Point Count	Density
Class - All	1,570,021,865	2.06 ppsm
Class 1 - Default	166,917,946	0.22 ppsm
Class 2 - Ground	797,018,793	1.05 ppsm
Class 7 - Low Points	190,761	0.00 ppsm
Class 9 - Water	2,337,288	0.00 ppsm
Class 17 - Overlap Default	123,597,840	0.16 ppsm
Class 18 - Overlap Ground	479,959,237	0.63 ppsm

Point Class Counts

Point Class

Point Return Statistics

Return 1 Points	1,404,080,208
Return 2 Points	130,683,016
Return 3 Points	31,751,832
Return 4 Points	3,506,809

American Society for Photogrammetry and Remote Sensing

Technician Signature — 9/13/2013 Date — Project Lead Signature

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all tiles in the delivery. A quick test is also performed to verify that all points within a tile fit within the exact boundary of the tile. This is shown as the tile boundary test and is presented in terms of a pass/fail. If any points for an individual tile are found outside of the logical tile boundary, an exception log is created that includes the tile name and the horizontal location and vertical position of all exceptions within that tile.

The summary also provides detailed information for the classification for all LiDAR returns, including a histogram that summarizes this analysis. This provides a very good check on the accuracy of the point classification and would serve to highlight missing or invalid classes. For example, if a single point was incorrectly identified as Class 29 (with no expectation of such a class in the project specifications), it will show up in this summary. Finally the summary page provides a detailed look at the number of 1st, 2nd, 3rd, and 4th returns in the acquisition. This can be very useful to idenitify a sensor malfunction that results in the failure to record multiple returns, or possibly an acquisition with unusually high or low numbers for multiple returns.

First Return Density Analysis

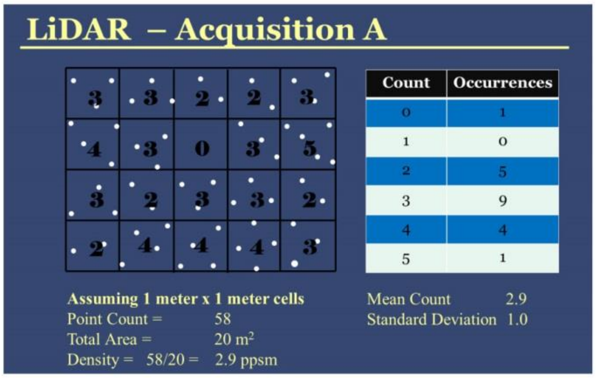
Our first return density analysis takes the review of the spatial distribution of the LiDAR returns to a level never achieved before. The ideal acquisition (at least for most projects) would be a perfectly uniform and square grid of laser returns that are spaced evenly throughout the entire project with equal along- and cross-track dimensions. This "ideal" condition is not perfectly achievable in the real world due to turbulence, cross winds (that result in aircraft crab), varying terrain elevations, the scan characteristics of the various LiDAR sensors, changing wind speeds, and many other factors.

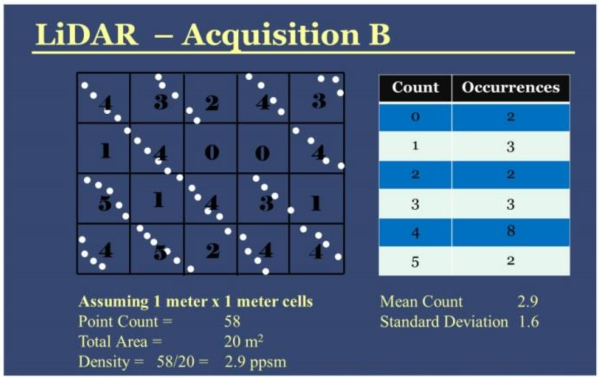
The most simplistic way of reporting the nominal point density is to derive a count of the number of first returns within the overall project and divide that total by the overall project area. While this is technically a correct way to determine the average or nominal point density, it doesn't really tell the whole story.

Instead of this more simplistic analysis, we use a series of three grids to better analyze the density of first return points and to perform tests analagous to the spatial distribution and void tests as defined by the US Geological Survey (USGS) LiDAR Base Specification Version 1.0[1]. The first analysis uses a grid overlaid on the entire project area with a cell size of 1 meter by 1 meter. Once the grid is overlaid, we simply look into

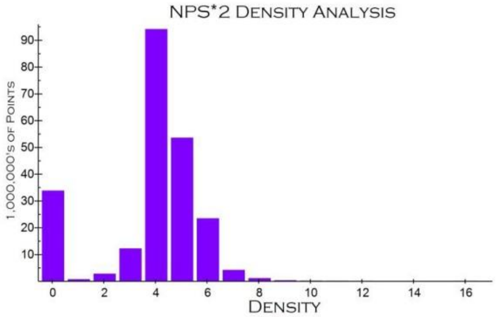
[1] Heidemann, Hans Karl, 2012, Lidar base specification version 1.0, U.S. Geological Survey Techniques and Methods, book 11, chap. B4, 63p.

each cell and count the number of first returns within each cell. We then develop a histogram of the results and determine the average and standard deviation for the overall project. We then repeat this same test two more times with a grid of cells measuring the project's Nominal Post Spacing (NPS) x 2, and the NPS x 4. The NPS x 2 was chosen as this is the basis of a clustering, or spatial distribution test within the USGS LiDAR specifications. The NPS x 4 was chosen as this is the basis of a void test for these same specifications.



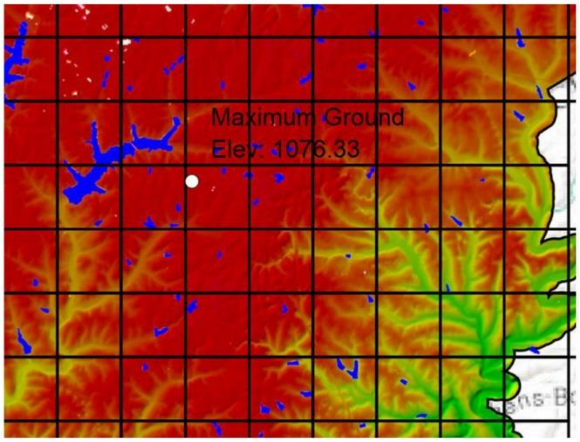


The two graphics at right illustrate this point. It should be apparent that the flight direction is in a northeast – southwest direction. In Acquisition A, the along- and cross-track point spacing is fairly consistent, indicating an effective flight plan. In Acquistion B, the cross track point spacing is much tighter (nominally about a 4 to 1 ratio) than the along track spacing, which would be undersirable for most LiDAR projects. Note that the nominal point density is exactly the same for both at 2.9 ppsm. The standard deviation, however, is considerably higher for Acquisition B.



2 Meter Cell (NPS*2)			
Average	3.85	Standard Dev.	1.90
Return Count	# of Cells	Return Count	# of Cells
0	33,759,123	9	266,273
1	663,996	10	98,439
2	2,688,201	11	45,350
3	12,158,911	12	29,267
4	94,065,088	13	15,167
5	53,516,159	14	9,656
6	23,379,551	15	5,986
7	4,117,316	16+	32,597
8	1,030,492		

Shaded Relief Map



Our shaded relief map is generated from each of the actual tiles on the delivery media. It is useful to get an overall view of the project area along with the terrain captured by the LiDAR acquisition. The shaded relief is draped over the tile layout and project boundary (when available). This graphic provides a quick visual check for missing or corrupt tiles (missing or corrupt tiles will not be shaded and therefore appear as a void area within the graphic), and can also illustrate large data gaps within individual tiles. The location of the minimum and maximum points within the ground class are also located on this graphic.

Minimum Surface Elevation

This graphic depicts the minimum elevation within the ground class for each of the tiles in the delivery. The ground class is defined as Class 2 and when present, Class 8 (present when the model key class is part of the project requirements). In producing this graphic, each tile is subdivided into 50 rows and 50 columns and the minimum elevation within each of these sub grids is rendered. This graphic is very useful for making a quick determination of unusually low points or other elevation anomalies.

Maximum Surface Elevation

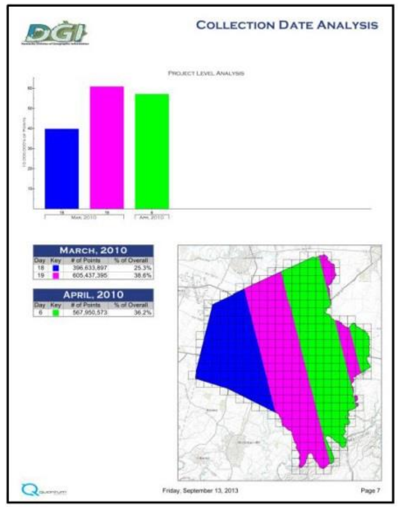
This graphic depicts the maximum elevation within the ground class for each of the tiles in the delivery. As with the minimum elevation graphic described above, the ground class is defined as Class 2 and Class 8, when present. As with the minimum elevation graphic detailed above, when producing this graphic each tile is further subdivided into 50 rows and 50 columns and the maximum elevation within each of these sub grids is rendered. This graphic is very useful for making a quick determination of unusually high points or other elevation anomalies.

Relative Terrain Change

The relative terrain change graphic is representative of the amount of elevation change within each of the sub grids (50 rows by 50 columns for each tile) within the project area. This elevation difference between the maximum and minimum ground surface elevations discussed above is determined and rendered within the graphic. Relatively flat areas will exhibit very little difference between the minimum and maximum surface elevations. Conversely, steep areas will exhibit fairly substantial differences between these surface elevations.

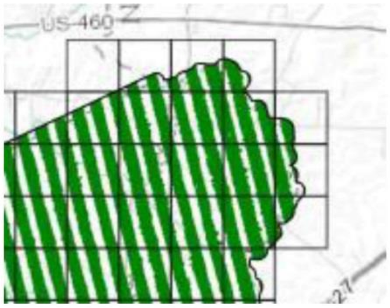
Collection Date Analysis

This graphic provides useful information relating to the way the LiDAR point cloud data was acquired. The graphic is rendered by collection date based on UTC time. Multiple acquisition dates will be rendered with multiple colors. A statistical summary is also provided, which illustrates the LiDAR returns by flight date as a percentage of the overall number of returns within the project. This graphic is developed strictly from the GPS time tags in the LAS file structure, and as such provides an accurate representation of the final composition of the acquisition dates that would discard all lines that might have been reflown due to issues in the acquisition.



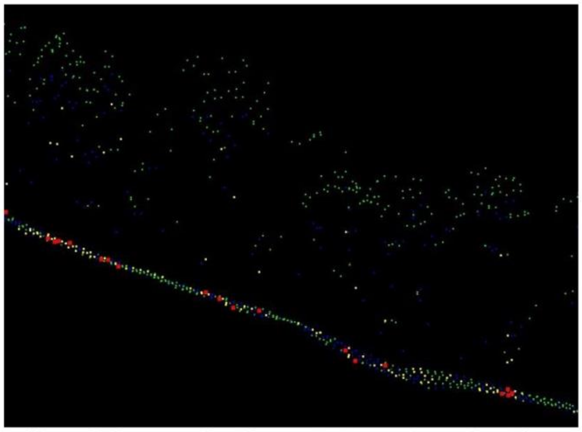
Overlap Map

The overlap map provides a graphic illustration of the side overlap between adjacent parallel flight lines. For this graphic, all points within the side overlap zone are rendered in green, and are overlaid on a location map of the project area. The ideal situation is to have perfectly parallel overlap zones that are also very consistent in width. There a number of factors, however, that can have significant effects on the consistency of the overlap



throughout parallel flight lines. Significant changes in terrain elevations, turbulence that can affect the roll of the aircraft during acquisition, the pilot's ability to follow pre-planned flight paths at consistent altitudes, and sensor performance will all result in variation within this overlap.

Second, Third, and Fourth Return Locations

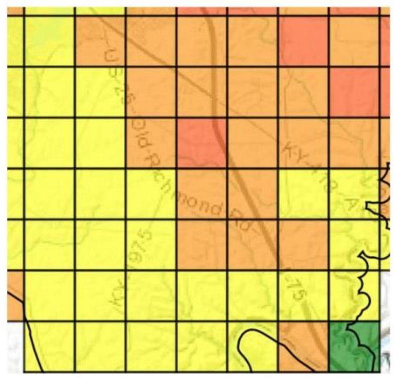


Similar to the graphic above, we provide detailed information for the location of all second, third, and fourth returns within the project area. These graphics are somewhat different, however, as they are derived from the relative density of these returns within a grid of 50 rows and 50 columns within each tile. Basically we derived a count of the number of second, third, and fourth returns within each of these cells and then render the project area based on these densities. Cells with a very low density of these multiple returns will appear transparent. Cells with high densities will be rendered as darker colors.

Note that the graphic for the fourth returns will be a subset of the other two graphics as you can't have a fourth return without a second and third. Similar logic applies to the third return graphic related to the second return graphic. The analysis of the third and fourth return locations will typically provide a very good idea of the presence of relatively tall vegetation. This is because today's high end discrete return LiDAR sensors have a minimum pulse discrimination distance ranging from about 0.75 to 3 meters. This means that the sensor cannot record a second return within this discrimination range from the first return (and the same argument applies to the third from the second, and fourth from the third). Therefore you won't get any fourth returns unless the distance from the first to the fourth is nominally three times the pulse discrimination distance, or more. In the case of a sensor with a discrimination of 1.5 meters, the first return must be at least 4.5 meters (or about 15 feet) higher than the fourth.

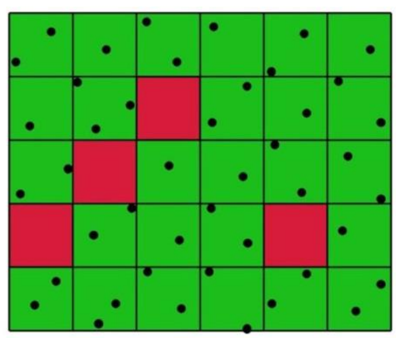
The graphic on the previous page illustrates multiple returns in tall trees. In this case the trees are about 110 feet in height. The green returns are first, blue second, yellow third, and red fourth (last) returns.

First Return Density Map



This graphic depicts the point density of first returns for each of the tiles in the delivery. This density is determined by dividing the total number of returns within a tile, using classes 1-6, 8-10, and 13-15, by the area of the tile. This value is expressed in the units of points per square meter (ppsm) regardless of the units selected (feet or meters) for the project. Multiple returns from a single outgoing pulse are not considered in this determination. This density will be negatively affected by water or other very low reflective surfaces (e.g., fresh asphalt). If the project boundary splits any tile, the calculation takes place only within the project boundary. Translucent colors are used in this graphic so that you can see the project map behind the rendering. This can be useful in evaluating tiles with lower first return point densities that might be affected by water bodies that are often visible in the background project map.

First Return Spatial Distribution Test



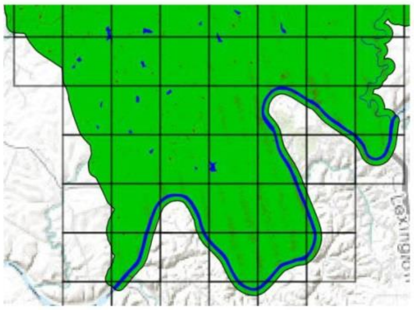
This graphic provides the results of a spatial distribution, or clustering, test as required by the USGS LiDAR Base Specification. A uniform grid is overlaid on the LiDAR returns (first returns). This is a square grid with linear dimensions along the sides of the grid equal to the NPS x 2.0. For example, a project with a NPS of 0.7 meters would result in a grid of 1.4 meters on each side. Each grid cell within the project boundary is examined to determine if there are any returns that fall within that grid cell as indicated in the graphic at right. If at least one return falls within a cell then that cell is counted as a populated cell. If not, that cell is counted as one void of returns. If hydro breaklines were collected for the project then any cell that either touches a hydro breakline, or falls entirely within a hydro breakline is removed from the test.

The USGS specification requires at least 90% of the tested cells to contain at least one return. The results of this test are presented graphically by tile with the percentage of "filled" cells rendered for each tile. The legend provides the color scheme for this rendering.

The results of this test will be skewed (negatively) by projects that either do not contain hydro breaklines, or projects with a considerable number of small water bodies that fall below the threshold for breakline collection (e.g., small ponds or narrow streams).

First Return Voids at NPS x 2 and NPS x 4

These two graphics and legends provide additional information from the spatial distribution test discussed in the section before this one. The only difference between these two tests is the cell size of the grid overlaid on the first return points. One is based on the NPS x 2, while the second is based on the NPS x 4. The latter is considered to be "voids" within the data.

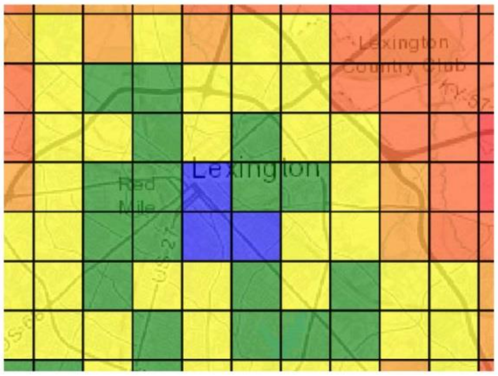


The USGS specification defines data voids within a single swath as unacceptable, except when caused by water bodies, areas of low near infra-red reflectivity such as asphalt or composition roofing, or where filled in by another swath. It is extremely rare for this void test to result in no voids within a dataset, but the location of the voids are almost always found in small streams or ponds that are less than the collection requirements for hydro bodies, or in fresh asphalt surfaces.

All individual unfilled cells are illustrated within this graphic by the color red overlaid on a green background. The hydro breaklines are shown in blue. This provides a very clear understanding of the location, density, and grouping of any void areas. The legend provides very clear information on the number of cells evaluated; the subset of the evaluated that are filled, unfilled, or located within hydro breaklines; and the percentage of the evaluated cells that are filled and unfilled.

Bare Earth Density

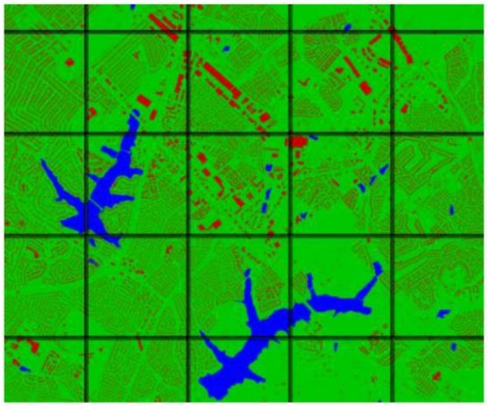
This graphic depicts the point density for each of the bare earth returns on a tile-by-tile basis in the delivery. We define bare earth as Class 2 (ground) and Class 8 (model key), if applicable. This density is determined by dividing the total number of bare earth ground returns within a tile by the area of the tile. Points classified as overlap are excluded from the density calculation.



Again, this value is always expressed in the units of ppsm. This density will also be affected by water or other very low reflective surfaces. This density can be reduced significantly by buildings, dense vegetation, bridge decks, etc. as these points are removed from the bare earth surface. Again, if the project boundary splits any tile, the calculation takes place only within the boundary. The graphic above illustrates a lower bare earth density in the urban downtown area in blue, followed by a slightly higher density in residential areas shown in green, with the highest densities surrounding these developed areas that are representative of wide open areas and horse farms.

Bare Earth Voids at NPS x 2 and NPS x 4

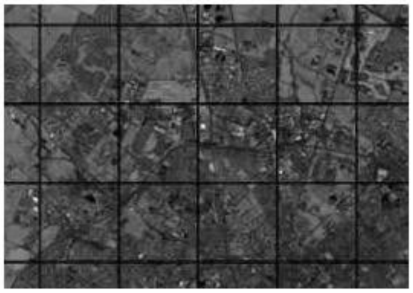
Our graphics for the bare earth voids are identical to the tests that we perform on the first return LiDAR surface with the one significant exception that these tests are performed only on the bare earth class (Class 2, and Class 8 when model key is included in the project). Some of our clients think of this as a test of the effectiveness of the laser's penetration in vegetation, and it serves as valuable tool in this respect. But this test is also significantly affected by the built environment (e.g., homes, commercial buildings, bridges, etc.) that are always removed from the bare earth class.



We perform these tests by overlaying a square grid over the project area with the dimensions along each side of the cell fixed at the NPS times two and times four. As an example, for a project designed for a NPS of 1.0 meters we would use cells of 2.0 x 2.0 meters, and 4.0 x 4.0 meters in this evaluation. We simply overlay these cells on the LiDAR surface and look to see if there is a bare earth return within each cell. If there is at least one, we render that cell green and add it to the list of populated cells. If there are no bare earth returns within the cell, then we render that cell as red and add it to the list of unpopulated cells. We then provide the rendered project area and complete summary statistics of this analysis. Note that any areas that fall within hydro breaklines are rendered as blue and are excluded from the statistical analysis.

Intensity Map

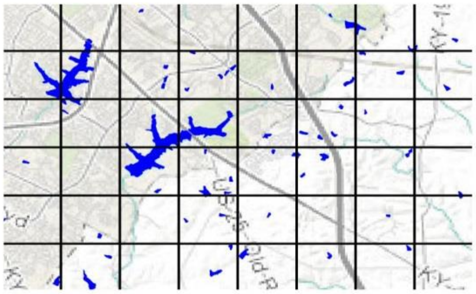
Our intensity graphic is generated from each of the actual tiles on the delivery media. It is useful to get an overall view of the project area along with the intensity captured by the LiDAR acquisition. The intensity plot is draped over the tile layout and project boundary (when available). This graphic can display potential problems with the recorded intensity values found in the LAS files.



Intensity Analysis

Today's LiDAR units record the reflectance of the surfaces illuminated by the sensor's laser. This measure of reflectance is referred to as the intensity of the return. This intensity is mainly a function of the characteristics of the surface (for example, concrete has a significantly higher reflectance as compared to asphalt), but it is also affected by the incidence angle that the laser beam makes with the footprint surface, the path length of the beam, the sensor's laser optics and receiver characteristics, and atmospheric attenuation. Most LiDAR units capture this intensity as an 8-bit value, which provides 256 relative values ranging from 0 to 255. We provide an overall project histogram of the first return intensities, and highlight the individual tiles with the highest and lowest mean intensities. Note that the actual intensity characteristics can vary significantly based on the project area and the sensor used for the acquisition.

Breakline Map



This graphic depicts the location of all hydro breaklines collected for the project. The area within closed breaklines around ponds and lakes, and double line drains for large streams are rendered in blue and overlaid on a screened project background map for quick orientation.

Calibration

The accuracy of LiDAR point clouds are affected by systematic errors or scaling. The accuracy is also affected by variable errors result from GNSS conditions that might include baseline length, number of satellites tracked, values of positional dilution of precision (PDOP), etc. During the initial processing of LiDAR data, geospatial firms typically spend a considerable amount of effort to remove both systematic and variable errors that allow the development of a homogenous elevation surface for the entire project area.

This results in quality data fitting well from flight line to flight line, and from mission to mission. This homogenous surface is then typically fit to ground through the use of calibration points located throughout the project area. This graphic depicts the results of the final calibration of this surface. All calibration points are shown as solid circles centered about their horizontal position, are scaled by the amount of relative error at each of the points (larger circles represent larger errors), and color coded by the direction of the error (whether the LiDAR surface is either higher or lower than the ground calibration point). The graphic is extremely useful to analyze the distribution of the calibration points within the project area as well as looking for systematic errors that might remain in the LiDAR surface after calibration. The statistical analysis of this final calibration is included in tabular form with this graphic.

Drive Contents

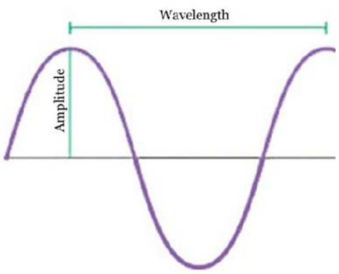
This illustration provides a quick look at the directory structure and location of all electronic files on the delivery media. All contents under the FOCUS directory are written onto the delivery media during the final checks and provide all results of these tests, including this document.

Appendix B – Glossary of LiDAR Terminology

Absolute Accuracy – The degree to which a point within the LiDAR point cloud conforms to its correct location on the earth within an accepted coordinate system. See also *Relative Accuracy*.

Accuracy –The term accuracy is often used inconsistently when describing a LiDAR elevation surface. Under NSSDA, however, the term accuracy is defined as the 95% confidence interval, which would be equivalent to the interval in which you would expect to see 95% of the errors within a LiDAR dataset. For example, if the "accuracy" of a dataset is stated as 25 cm, you should expect that 95% of random points sampled from the dataset would fall within 25 cm of their correct position.

Amplitude – In LiDAR, the amplitude represents the maximum distance of the alternating NIR wave, measured from the position of equilibrium to either the crest or trough of the wave.



Attenuation – Attenuation refers to the loss of signal strength as the signal travels through a medium. Attenuation can be thought of as the opposite of amplification.

Bare Earth Surface – A bare earth surface is a terrain surface that is free from vegetation, buildings, vehicles, bridges, and other man-made features. A bare earth surface is meant to be an accurate representation of natural ground.

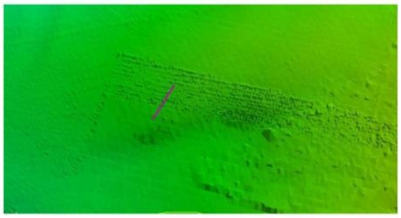
Beam Divergence – The energy emitted by the laser within a LiDAR sensor leaves the sensor as a very narrow beam of light, but increases in diameter along the path to the ground. The angle at which the beam increases is known as the beam divergence. This divergence is typically measured in the units of millirads. It is common for today's sensors to have a beam divergence ranging somewhere between 0.1 and 1.0 millirads. At 0.4 millirads, the diameter of the beam 1,000 meters away from the sensor would be 40 cm.

Breakline – A breakline is a line that defines areas of discontinuity, or sharp breaks in the natural ground surface. Breaklines are often placed at toes of slope, along ridgelines, and at the edges of water in lakes, ponds, streams, and the coast.

Class – See *Feature Class*.

Consolidated Vertical Accuracy (CVA) – The CVA for a LiDAR elevation surface is defined as the accuracy of that surface in all land cover combinations. Technically it is the consolidation of the FVA and SVA. See also *Fundamental Vertical Accuracy* and *Supplemental Vertical Accuracy*.

Corn Rows – Corn rows in a LiDAR elevation surface typically represent a sensor problem during acquisition that results from positive and negative elevation biases in adjacent passes (normally in opposite scan directions) of the scanning mirror. Because of the biases, these errors present the appearance of a plowed field, or rows of corn as shown in the graphic at right.



Digital Elevation Model (DEM) – a DEM is a digital representation of the earth's surface. See also *Digital Surface Model* and *Digital Terrain Model*.

Digital Surface Model (DSM) – A DSM is most often used to describe a first return LiDAR surface that would typically include all natural and man-made features (e.g., trees, brush, buildings, etc.) that lie above the natural ground surface. See also *Digital Elevation Model* and *Digital Terrain Model*.

Digital Terrain Model (DTM) – A DTM is most often used to describe a digital representation of the earth's surface that includes both mass points and breaklines. See also *Digital Elevation Model* and *Digital Surface Model*.

Discrete Returns – LiDAR sensors are known as discrete return sensors when they are set to record individual returns at precisely referenced points in time and 3D space. Most of today's top-of-the-line LiDAR sensors can measure and record 4 discrete returns per outgoing laser pulse. Typically these returns are recorded as first, second, third, and last (as opposed to fourth) returns. This is significantly different from full waveform technology discussed below.

Echo – See *Return*.

Enhanced Nominal Ocular Hazard Distance (eNOHD) – The eNOHD is quite similar to the NOHD, in that it represents a safe distance for laser operation. But the significant difference here is that this distance is reduced from the NOHD by the assumption that someone on the ground is using binoculars to view the aerial platform during acquisition, which would effectively increase the potential damaging effects of the sensor's laser. This is also termed binocular eyesafe range. See also *Nominal Ocular Hazard Distance*.

Feature Class – A feature class is homogenous collection of LiDAR returns that represent a specific type of feature imaged with LiDAR. Common feature classes within a typical LAS file structure include Class 1 – Default, or non-ground, Class 2 – Bare Earth, Class 8 – Model Key, and Class 9 – Water.

FEMA Land Cover Classes – FEMA defined standard land cover categories for testing within a LiDAR surface in their *Appendix A: Guidance for Aerial Mapping and Surveying*, which was published in April 2003. These classes include: 1) Bare earth and low grass, 2) High grass, weeds, and crops, 3) Brush lands and low trees, 4) Forested, fully covered by trees, 5) Urban areas, 6) Sawgrass, and 7) Mangrove.

Field of View (FOV) – The field of view refers to the angular measure of the scan pattern of the mirror that directs the laser's energy from the sensor to the ground. The FOV is measured perpendicular to the flight of the aircraft. The angular measure of the complete scan on both sides of nadir is known as the full angle FOV. The angular measure of the scan from nadir to the left or right side is known as the half angle FOV. The FOV for today's LiDAR sensors are typically selectable during flight planning and many sensors have a maximum full angle FOV of about 75 degrees.

Frequency – For cyclic processes like the propagation of a laser beam from a LiDAR sensor, the frequency is defined as the number of cycles per unit time. The frequency is most often provided in terms of cycles per second, which represents the unit of frequency in Hertz (Hz).

Full Waveform – LiDAR sensors that record a near-continuous digital representation of the returned laser signal are known as full waveform. This is significantly different from the discrete returns discussed above.

Fundamental Vertical Accuracy (FVA) – The FVA for a LiDAR elevation surface is defined as the accuracy of that surface in open terrain where the LiDAR surface is thought to be most reliable. See also *Supplemental Vertical Accuracy* and *Consolidated Vertical Accuracy*.

Galvanometer – A galvanometer is a sensitive ammeter that is used within a LiDAR sensor to accurately measure the swing angle of the scanning mirror as a function of time.

Hertz (Hz) – A unit of measure equal to the number of cycles per second. A rate of 100 Hz would be equal to 100 cycles per second.

Illuminated Footprint – The illuminated footprint is a measure of the theoretical diameter of the laser beam as it is reflected off a surface that is perpendicular to the path of the beam at the planned flying height. It is a function of both the beam divergence and the planned flying height above ground. Common illuminated footprints for today's sensor range from a few decimeters, to a meter or more in diameter. You can think of this simply as the area of the ground illuminated by the non-visible laser beam emitted from the LiDAR sensor.

Inertial Measurement Unit (IMU) – See Inertial Navigation System.

Inertial Navigation System (INS) – An INS is used to accurately measure the three-dimensional rotation of a LiDAR sensor at all times during flight. The INS uses a combination of accelerometers to measure motion, and gyroscopes to measure rotation within an Inertial Measurement Unit (IMU). When combined with GPS positioning, the INS can provide the very accuracy position, orientation, and velocity of the sensor at all times. The typical sampling rate of today's INSs is 200 Hz, which provides updates 200 times per second during flight.

Intensity – Today's LiDAR units record the reflectance of the surfaces illuminated by the sensor's laser. This measure of reflectance is referred to as the intensity of the return. This intensity is mainly a function of the characteristics of the surface (for example, concrete has a significantly higher reflectance as compared to asphalt), but it is also affected by the incidence angle that the laser beam makes with the footprint surface, the path length of the beam, the sensor's laser optics and receiver characteristics, and atmospheric attenuation.

Kilohertz (kHz) – A kilohertz is a unit of electromagnetic wave frequency equal to 1,000 Hertz. In LiDAR technology, the frequency of laser pulses emitted for ground measurement is commonly referred to in the units of kilohertz. For example, a LiDAR sensor might be pulsed at 100 kHz for data acquisition, and this would be equivalent to 100,000 measurements per second of flight.

Land Cover Classes – See FEMA Land Cover Classes.

LAS – LAS refers to the binary data file that is used to store LiDAR point data records. An LAS file is hardware independent and is recognized by most LiDAR software platforms in the market today. The LAS structure was developed and is maintained by the ASPRS LiDAR Committee.

Laser Repetition Rate – The laser repetition rate is defined as the number of emitted pulses per second from the laser within a LiDAR sensor. This is typically specified in the units of kHz, with today's top-of-the-line sensor operating in the general maximum range of 150 to 500 kHz. This is also known as the pulse repetition frequency (PRF).

LiDAR – LiDAR is an acronym for Light Detection and Ranging. LiDAR technology provides an efficient means of measuring three-dimensional points on the ground along with the amount of energy reflected from the LiDAR sensor's laser. A LiDAR sensor is a complex combination of a number of electrical systems including a laser, scanning optics, a photodetector and receiver optics, and a position and orientation system.

Minimum Discrimination Distance – This distance is the minimum separation of reflections along the path of the laser beam that can be resolved by the LiDAR sensor. This can be thought of as a "dead zone" along the path such that once one return is logged by the sensor, the detection of another return is not possible until the laser travels this defined distance along its path. This is a function of the electronics of a discrete return sensor and the disadvantages of this are removed with a full waveform sensor. This is also known as the vertical discrimination distance, with typical measurements ranging from sub-meter to 3.5 meters or more with today's LiDAR sensors.

Multiple Returns – Multiple returns in LiDAR refer to the sensor's ability to record multiple discrete returns along the laser's path. This is very useful for penetrating overhanging trees, or seeing the ground below the tops of electrical conductors or utility poles. This is based on the theory that a portion of the laser's energy will be reflected from above ground features, but the remainder of the energy will continue on its path to the ground. More energy might be reflected off a branch or additional vegetation during this path and therefore recorded as a second or third return. Ideally enough energy will make it to the ground surface where it will be reflected and recorded as a last return. Most sensors today have the ability to record up to four returns for each outgoing laser pulse.

Multiple Pulse in Air (MPiA) – MPiA technology refers to LiDAR sensors that have the ability to fire the next laser pulse prior to receiving the reflection of the previous return. The name is derived from the sensor's ability to have multiple pulses in the air at one time, yet accurately equate the right reflected return with the correct outgoing pulse. MPiA technology has the significant advantage of increased point density as compared to a single pulse system, or allowing higher flights at any given point density, which results in a wider swath width and decreased acquisition times.

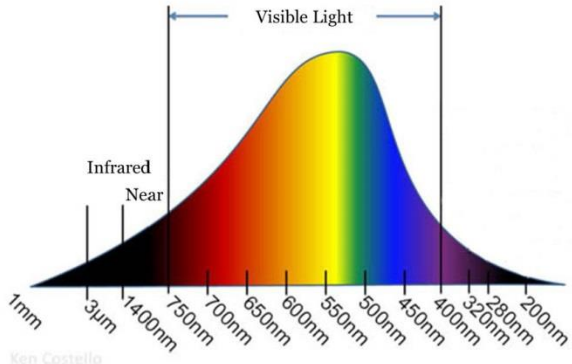
Nadir – In LiDAR, the direction pointing straight down from the bottom of the aircraft.

Nanometer – A unit of length in the metric system equal to one billionth of a meter.

Nanosecond – A unit of time equal to one billionth of a second. At the nominal speed of light of 299,792,458 meters per second, the laser beam in LiDAR will travel about 30 cm in one nanosecond.

National Standard for Spatial Data Accuracy (NSSDA) – The NSSDA implements a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy.[2] It represents the most popular accuracy standard for use in testing and reporting the accuracy for today's LiDAR projects.

Near Infrared (NIR) – Most terrestrial LiDAR sensors today use a solid-state Nd:YAG (neodymium-doped yttrium aluminum garnet, if you really have to know) laser that produces non-visible light in the near infrared region of the electromagnetic spectrum at 1,064 nanometers (nm). The visible spectrum corresponds to wavelengths ranging from 400 (violet) to just over 700 nm (red), and that portion of the spectrum just beyond red is known as the near-infrared region, extending from 700 nm to 1 millimeter (mm).



[2] Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy published by the Subcommittee for Base Cartographic Data, Federal Geographic Data Committee.

Nominal Ocular Hazard Distance (NOHD) – The NOHD is the distance from the LiDAR sensor at which point the laser's energy falls below the maximum permissible exposure (MPE) limit, or in other words, the distance at which the laser beam from the LiDAR sensor will not result in damage to the eyes. It might also be termed the eyesafe distance. See also *Enhanced Nominal Ocular Hazard Distance.*

Nominal Point Spacing (NPS) – The NPS is the nominal linear dimension between the centers of consecutive laser points on the ground. The NPS is typically presented in the units of meters for LiDAR, even when the units selected for the project are not metric units. The NPS is mathematically related to the point density by the following equation:

NPS = Square Root (1 / Density)

A project with a 0.7 meter nominal point spacing would be equivalent to a density of 2 ppsm.

Photon – A photon is a particle without mass that travels with a certain energy and momentum. The near infrared rays in a LiDAR beam are comprised of individual photons, which travel through space at 186,282 miles per second.

Point Cloud – A LiDAR point cloud is a collection of three-dimensional points, the relative intensity of the returns for these points, and metadata associated with their acquisition.

Point Data Format – The point data format is an ID within the LAS file structure that corresponds to the point data record format.

Point Density – The nominal point density refers to the number of laser returns within a given unit area. This density is almost always quoted in the units of points per square meter (ppsm), which is representative of the number of returns typically found in a square cell measuring one meter by one meter. The point density is mathematically related to the nominal point spacing by the following equation:

Density = 1 / NPS^2

A project with a nominal point density of 4 ppsm would be equivalent to a nominal point spacing of 0.5 meters.

Points per Square Meter (ppsm) – The density of laser returns within a LiDAR project are almost always quoted in terms of the nominal number of returns within a square cell measuring one meter by one meter, with this number presented as the density in the units of ppsm.

Pulse Repetition Frequency (PRF) – See *Laser Repetition Rate.*

Pulse Width – The pulse width is the measure of time that the laser diode is energized during the generation of an individual laser pulse. This width is typically measured in the units of nanoseconds. At the speed of light, one nanosecond in pulse width is about 30 centimeters in length.

Reflectance – The reflectance of the typical 1,064 nm NIR laser beam used in LiDAR can vary substantially with typical reflectivities ranging from 5% for new asphalt, 20% for asphalt shingles, 30% for concrete, 50% for mixed forest, and 70 to 90% for snow. See also *Intensity*.

Relative Accuracy – The relative accuracy is a measure of the theoretical uncertainty in the location of one point within the LiDAR point cloud to the points surrounding it. The USGS LiDAR specifications call for a relative accuracy within a single swath of 7 cm, stated in terms of an RMSE, and a relative accuracy of 10 cm when comparing one swath to another adjacent swath, again in terms of an RMSE. See also *Absolute Accuracy*.

Refractive Index – The ratio of the speed of light in a vacuum to the speed at which light travels in a material is known as the refractive index (n) of the material. The refractive index for air for visible light is about 1.0003. The refractive index for water at 20 degrees C is 1.33 and this index is very important to topo bathy LiDAR sensors used in bathymetric applications.

Return – A LiDAR return refers simply to the measurable reflection of the laser signal from an object on or near the ground that is provided in 3D space. This is also known as an echo.

Root Mean Square Error (RMSE) – The RMSE is a statistical value equal to the square root of the average (mean) of the squares of the individual errors within a test. Individual errors in LiDAR refer to the difference between a known position on the ground (horizontal position or elevation) and the position represented within the LiDAR surface. In terms of the horizontal position, the value is often referred to as $RMSE_{XY}$ or $RMSE_R$. In terms of elevation, the value is most often referred to as RMSEz.

Scan Rate – The rate at which a scanning device (in the case of LiDAR the scanning mirror) samples the field of view of the sensor. This typically provided in the units of cycles per second, or Hertz.

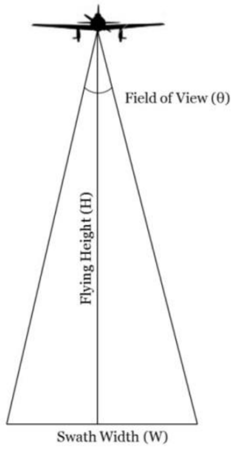
Signal to Noise Ratio (SNR) – The SNR in LiDAR represents the ratio of desired signal level to the background noise in an acquisition, with higher values generally more desirable. The SNR is a unitless number.

Smoothed Best Estimate of Trajectory (SBET) – The estimated trajectory, or sensor path, in three dimensional space as a function of time during LiDAR acquisition. The SBET is normally determined from post processing the AGPS and inertial navigation information captured during the LiDAR acquisition.

Speed of Light – The speed of light in a vacuum is equal to 299,792,458 meters per second, or about 186,282 miles per second. This speed is independent of temperature, but it does vary with the density of the medium through which the light is passing. See also *Refractive Index*.

Supplemental Vertical Accuracy (SVA) – The SVA for a LiDAR elevation surface is defined as the accuracy of that surface in land cover combinations other than open areas. See also *Fundamental Vertical Accuracy* and *Consolidated Vertical Accuracy*.

Swath Width – The swath width in LiDAR is the width of ground coverage acquired in a single pass of the LiDAR sensor. The nominal swath width is simply a function of the field of view of the sensor and the flying height above terrain and can be determined with simple trigonometry from the graphic on the previous page. The equation is W = 2 x H x tan (theta / 2).



Wavelength – The wavelength of LiDAR is the distance over which the wave from the laser repeats itself. This could be measured from one crest of the wave to the next, or from one trough to the next as these distances will be equal. The number of times this wave repeats itself over a unit of time is known as the frequency.