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NOAA Appalachia

Shoreline Mapping Riverine Project: PA2401

Technical Data Report, NOAA Contract 1305M220DNCNL0064, Task Order 1305M224F0352

Prepared For:

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Cover Photo: A view looking southwest at the Tower Run Nature Viewing and Fishing area. The image was created from the lidar bare earth model overlaid by the above ground point cloud and orthoimagery.

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INTRODUCTION

This photo, taken by NV5 acquisition staff, shows a view of the Cheat River from the Jenkinsburg Bridge in West Virginia.

In July 2023, NV5 was contracted by National Oceanic and Atmospheric Administration (NOAA) to collect topobathymetric Light Detection and Ranging (lidar) data from September 2024 to October 2025 for the NOAA Appalachia site. The NOAA Appalachia area of interest encompasses several river sections along the Appalachian Mountains in Upstate New York, Pennsylvania, and West Virginia. In total, the NOAA Appalachia project extends approximately 275 square miles (1,135 river miles) including the Allegheny River (154 square miles, 578 river miles), Southwest Lake Ontario (17 square miles, 75 river miles), and the Monongahela River (103 square miles, 481 river miles). Traditional near-infrared (NIR) lidar was fully integrated with green wavelength lidar data (bathymetric returns) in order to provide a seamless topobathymetric lidar dataset. Data was collected to aid NOAA in modeling the topographic and geophysical properties of the study area to support accurate measurement and mapping of the national shoreline and to support riverine resource management.

This report accompanies the delivered topobathymetric lidar data and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset including lidar accuracy and density. Acquisition dates and acreage are shown in Table 1, a complete list of contracted deliverables provided to NOAA is shown in Table 3 with the coordinate reference system information for these deliverables shown in Table 2. The project extent is shown in Figure 1, and the project delivery areas are shown in Figure 1.

Table 1: Acquisition dates, acreage, and data types collected on the NOAA Appalachia site

Project Site	Contracted Acres	Contracted sq. miles	Buffered Acres	Buffered sq. miles	Aerial Acquisition Dates	Data Type
NOAA Appalachia	177,171	275	197,782	309	*9/7/2024 – 8/5/2025	Topobathymetric - Lidar

*See Figure 19 for more detailed flight dates for lidar acquisition

Deliverable Products

Table 2: Deliverable product coordinate reference system information

Product Type	Projection	Horizontal Datum	Vertical Datum	Units
Classified LAS	UTM Zone 17 North	NAD83(2011)	GRS80 (Ellipsoidal Height)	Meters
Classified LAS and Raster Model	UTM Zone 17 North	NAD83(2011)	NAVD88(GEOID18)	Meters

Table 3: Lidar products delivered for the NOAA Appalachia site

Product Type	File Type	Product Details
Points	LAS v.1.4 (*.las), Point Format 6	• 500m x 500m tiled All Classified Returns
Rasters	1.0-meter Cloud Optimized GeoTIFFs (*.tif)	• 5000m x 5000m tiled Void-Clipped Topobathymetric Bare Earth Digital Elevation Models (DEM) • 5000m x 5000m tiled Normalized Bathymetric Bottom Intensity Rasters
Vectors	Shapefiles (*.shp)	• Delivery Boundary • Lidar Tile Index • DEM Tile Index • Bathymetric Void Shape • Feedback Edits with Response • Water's Edge Breaklines • Time Intensive Area Shapes for D3 and D4 deliveries **
Flightline & Sensor Trajectories	ASCII Text File (*.txt)	• Chiroptera 4X • Chiroptera 5
Metadata	Extensible Markup Language (*.xml)	• LAS Metadata • Bare Earth DEM Metadata • Normalized Seabed Intensity Metadata • Project Boundary Metadata • Las Index Metadata • DEM Index Metadata • Breaklines Metadata • Bathymetric Void Metadata • Feedback Shapes Metadata • Time Intensive Areas Metadata
Reports	Adobe Acrobat (*.pdf)	• Field Data Collection Sheets • Ground Survey Report • Lidar Boresight and Calibration Reports • Lidar Technical Data Report

**NV5 delivered these lidar-derived products in addition to contracted deliverables in order to provide a more complete and versatile dataset to NOAA

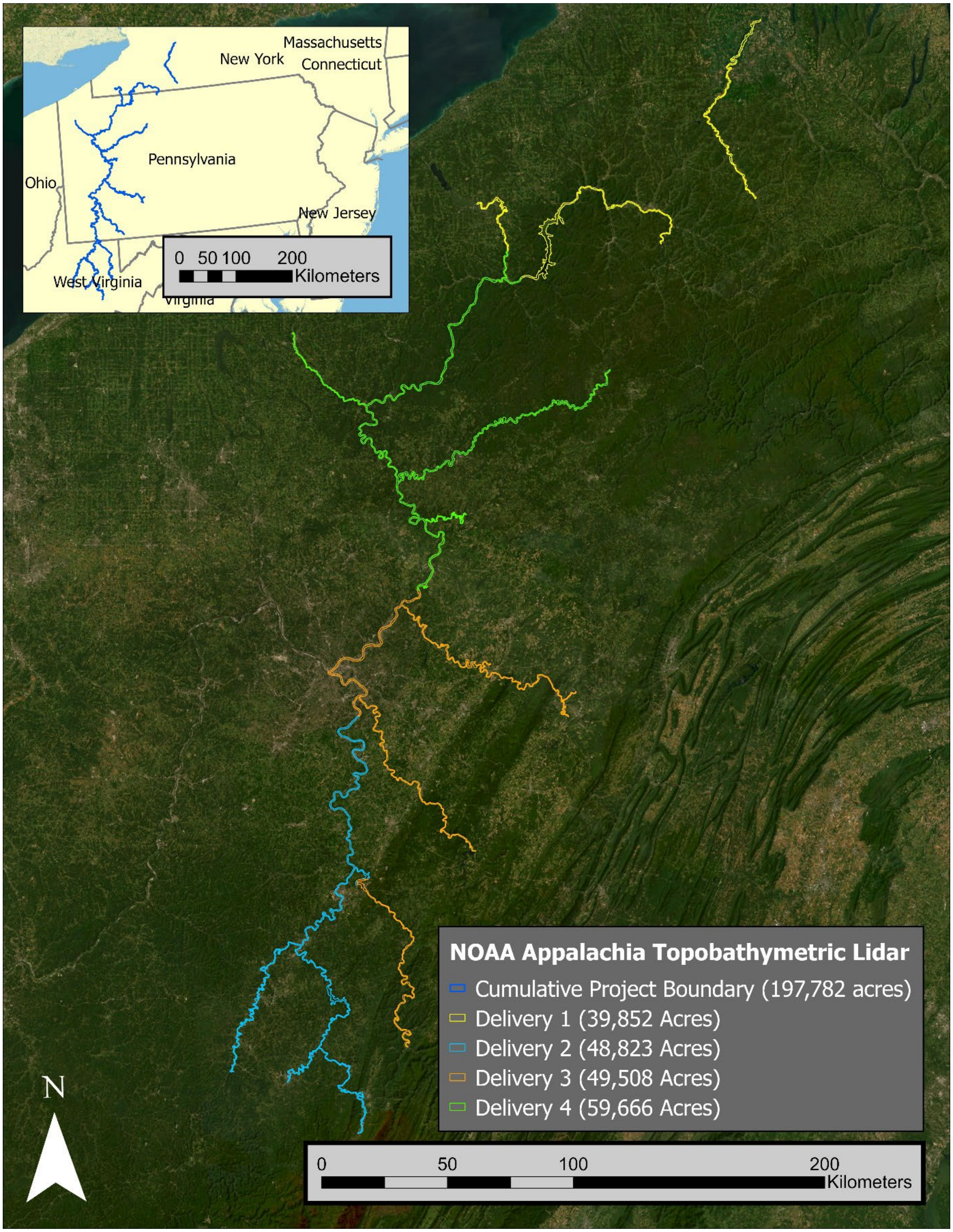


Figure 1: Location map of the NOAA Appalachia site

ACQUISITION

NV5's ground acquisition equipment set up on the bank of the Clarion River upriver from where Maple Creek flows into the Clarion River in the NOAA Appalachia lidar study area.

Logistics Planning

In preparation for data collection, NV5 reviewed the project area and developed a specialized flight plan to ensure complete coverage of the NOAA Appalachia lidar study area at the target combined point density of at least 3 points/m^2 for bathymetric areas and at least 4 points/m^2 for topographic areas. Acquisition parameters including orientation relative to terrain, flight altitude, pulse rate, scan angle, and ground speed were adapted to optimize flight paths and flight times while meeting all contract specifications. Figure 19 shows these optimized flight paths and dates.

Factors such as satellite constellation availability and weather windows must be considered during the planning stage. Any weather hazards or conditions affecting the flight were continuously monitored due to their potential impact on the daily success of airborne and ground operations. In addition, logistical considerations including private property access, potential air space restrictions, water clarity (Figure 3), and channel flow rates (Figure 4 through Figure 17), were reviewed.

Turbidity Measurements and Secchi Depth Readings

NV5's acquisition team considered several environmental conditions during the planning stage of the project to target the best possible windows for capturing bathymetric bottom returns. Water clarity was monitored daily using handheld Hach turbidity meters, Secchi disks, and semi-portable water quality data loggers operated by NV5 ground operations professionals. Readings were collected at 164 locations throughout the project site between September 11 and November 10, 2024. Turbidity observations were recorded three times to confirm measurements. Table 4 below provides turbidity and Secchi depth results per site on each day of data collection. A true Secchi depth reading is where the Secchi depth reaches extinction. However, all Secchi depth readings were noted to have reached the bottom surface. Some locations were also inaccessible for Secchi and/or turbidity measurements.

Table 4: 2024 water clarity observations for lidar flights

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
9/11	14:30	West Fork River Park, Weston, WV	West Fork River	39° 02' 14.51" N	80° 28' 10.62" W	5.67	6.10	6.44	*0.70
9/11	15:20	West Fork River Boat Ramp near Jackson's Mill, WV	West Fork River	39° 05' 44.70" N	80° 27' 56.97" W	9.06	8.88	7.74	*0.90
9/11	16:15	West Fork River Bridge	West Fork River	39° 09' 1.84" N	80° 26' 10.32" W	6.60	6.77	5.54	*0.40
9/12	14:10	West Fork River Boat Ramp near West Milford	West Fork River	39° 11' 54.57" N	80° 24' 21.59" W	5.50	5.57	6.82	*0.50
9/17	13:30	West Fork River near Laurel	West Fork River	39° 12' 22.88" N	80° 22' 45.82" W	8.49	8.47	10.10	*0.40
9/19	11:45	Clarksburg Bend	West Fork River	39° 16' 50.73" N	80° 21' 15.65" W	7.00	6.75	6.87	*0.48
9/19	14:45	Monongahela River Public Access	Monongahela River	39° 27' 38.63" N	80° 12' 58.36" W	2.72	2.58	2.05	*0.79
9/19	15:50	Spelter River Trail	West Fork River	39° 20' 16.54" N	80° 19' 16.76" W	5.52	4.89	5.28	*0.37
9/20	12:15	Shinnston Public River Access	West Fork Rive	39° 23' 55.65" N	80° 17' 52.78" W	2.95	2.46	3.10	*0.25
9/20	15:45	Worthington Public River Access	West Fork Rive	39° 27' 2.89" N	80° 15' 54.25" W	5.64	4.91	4.20	*0.52
9/21	11:45	West Fork River Trail – Everson Trailhead	West Fork Rive	39° 26' 57.95" N	80° 14' 38.44" W	2.88	2.12	2.28	*0.21
9/22	15:30	Tygart Valley River off E. Dailey Rd Bridge	Tygart Valley River	38° 47' 31.16" N	79° 53' 28.91" W	1.99	2.62	2.01	*0.45
9/23	13:15	Tygart Valley River near the end of Lough Ln	Tygart Valley River	38° 55' 46.80" N	79° 52' 48.24" W	13.10	12.30	11.80	*0.25
9/27	12:54	Palatine Park Fishing and Boating Access	Monongahela River	39° 29' 4.71" N	80° 08' 5.25" W	3.43	3.47	4.06	*1.20

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
9/27	17:12	Ices Ferry Bridge Fishing and Boating Access	Cheat Lake	39° 40' 4.15" N	79° 51' 33.67" W	2.23	2.82	2.56	*1.20
9/28	12:33	End of Route US-33 E, Norton, WV	Tygart Valley River	38° 56' 43.25" N	79° 57' 26.78" W	3.96	3.54	3.47	*1.32
9/28	14:16	1464 Camp Seefus Rd, Coalton, WV 26250	Tygart Valley River	38° 57' 34.79" N	79° 59' 26.58" W	3.92	3.89	4.02	*0.98
9/28	15:50	Fifth St Bridge, Junior, WV	Tygart Valley River	38° 58' 46.98" N	79° 57' 1.78" W	2.62	2.77	2.47	*1.32
9/29	13:50	Just South of Belington City Park	Tygart Valley River	39° 01' 2.93" N	79° 56' 31.55" W	3.24	2.97	2.92	*0.98
9/29	16:12	Blue and Gray Park Boat Ramp, Phillipi, WV	Tygart Valley River	39° 09' 10.17" N	80° 02' 36.72" W	1.57	1.50	1.79	*0.98
10/4	13:57	VFW Park Belington, WV	Tygart Valley River	39° 01' 54.36" N	79° 56' 23.78" W	3.21	3.13	3.49	*1.75
10/4	15:12	Tygart Valley River off Arrowhead Dr	Tygart Valley River	39° 01' 54.93'' N	79° 57' 27.68'' W	3.53	3.06	2.72	*1.75
10/4	17:07	Portageville Bridge	Tygart Valley River	42° 34' 17.70" N	78° 02' 26.00" W	13.40	14.60	15.20	*0.45
10/5	11:49	Duck Hollow Trail Head Parking Lot, Homestead, PA	Monongahela River	40° 24' 51.45" N	79° 54' 56.12" W	2.25	1.97	1.43	*1.75
10/5	12:46	Caneadea River Access	Genesse River	42° 22' 51.79" N	78° 09' 16.17" W	7.12	7.24	7.51	*1.23
10/5	12:57	Docking Area for Barges on the Monongahela River	Monongahela River	40°22'34 .34"N	79°50'25. 97"W	2.37	2.66	2.54	**N/A
10/5	14:32	Genesse River Wilds Transit Bridge	Genesse River	42° 17' 46.43" N	78° 04' 31.54" W	3.81	4.96	4.37	*1.12
10/5	15:09	Genesse Valley Wildlife Manegment Area	Genesse River	42° 30' 33.63" N	78° 02' 50.99" W	4.43	4.29	4.36	*0.73

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/5	16:28	579 Buckhannon River Rd, Volga, WV 26238	Buckhannon River	39° 04' 45.93" N	80° 07' 5.65" W	2.24	1.98	1.75	**N/A
10/5	17:50	30 E Pecks Run Rd Buckhannon, WV 26201	Buckhannon River	39° 03' 15.62" N	80° 06' 41.41" W	2.58	2.21	1.78	**N/A
10/5	18:25	Island Park Wellsville, NY	Genesse River	42° 06' 54.83" N	77° 56' 41.31" W	2.41	2.37	2.62	*0.98
10/6	11:01	Ocean Boat Launch Olean, NY 14760	Allegheny River	42° 04' 13.86" N	78° 25' 52.74" W	4.88	5.63	6.09	*0.21
10/6	11:42	467 River Rd, Buckhannon, WV 26201	Buckhannon River	39° 00' 20.26" N	80° 11' 16.22" W	1.78	1.99	2.10	*1.75
10/6	14:59	Junction Boat Launch Carrollton, NY	Allegheny River	42° 05' 6.40" N	78° 37' 56.29" W	3.49	3.82	3.96	*1.22
10/6	15:05	Post Mill, Buckhannon, WV 26201	Buckhannon River	39° 02' 2.03" N	80° 09' 22.65" W	1.49	1.39	1.51	*1.75
10/7	13:35	300 N River Rd, Philippi, WV 26416	Tygart Valley River	39° 12' 24.02" N	79° 59' 43.85" W	0.99	0.96	1.06	*1.75
10/7	17:24	Lower Pleasant Creek Rd, Philippi, WV 26416	Tygart Lake	39° 16' 2.97" N	80° 00' 36.41" W	4.79	4.70	4.24	**N/A
10/8	14:41	Main Street Bridge Jamestown, NY	Chadakoin River	42° 05' 36.34" N	79° 14' 43.05" W	7.26	6.30	8.33	*1.04
10/8	15:24	751 Maple Ave, Grafton, WV 26354	Tygart Valley River	39° 19' 32.45" N	80° 01' 10.97" W	1.75	1.89	1.96	*1.75
10/8	16:30	Confluence of Cassadaga Creek and Chadakoin River	Cassadaga Creek and Chadakoin River	42° 07' 54.38" N	79° 10' 48.33" W	16.50	18.10	17.70	*0.49
10/8	16:30	60 George Washington Hwy, Grafton, WV 26354	Tygart Valley River	39° 21' 13.65" N	80° 02' 35.00" W	2.05	2.54	2.20	*1.75
10/10	13:20	River Access Downstream of Bridge at Vandergrift Park	Kiskiminetas River	40° 36' 23.81" N	79° 33' 40.13" W	2.38	1.95	1.97	*1.00

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/10	15:20	River Access Downstream of Boat Launch at Roaring Run	Kiskiminetas River	40° 33' 50.15" N	79° 33' 38.49" W	2.40	2.25	2.22	*1.00
10/10	15:44	Floating Dock at Deer Creek Boat Ramp in Harmar Township Pittsburgh, PA 15238	Allegheny River	40° 32' 2.06" N	79° 50' 31.8" W	3.45	3.52	3.88	*1.20
10/11	10:45	Boat launch on north shore of Kiskiminetas River at Confluence of Allegheny & Kiskiminetas Rivers off South Railroad St. in Schenley, Pennsylvania 15682	Kiskiminetas River	40° 40' 46.62" N	79° 39' 57.57" W	2.08	1.91	1.98	2.08
10/11	12:10	Avonmore Canoe Launch	Kiskiminetas River	40° 31' 46.22" N	79° 28' 31.32" W	1.75	1.93	1.66	*1.00
10/11	12:50	Boat Launch Ramp at Onoville Marina Park 704 W Perimeter Rd, Steamburg, NY 14783	Allegheny River	42° 01' 39.27" N	78° 58' 0.48" W	11.30	14.00	13.70	0.91
10/11	13:35	Rosston Boat Ramp. Rosston Cir Ford City, PA 16226	Allegheny River	40° 44' 57.43" N	79° 33' 14.51" W	3.05	3.05	2.76	**N/A
10/11	13:35	Saltsburg Boat Launch	Kiskiminetas River	40° 29' 3.50" N	79° 27' 11.18" W	1.87	1.62	1.58	*1.00
10/11	14:25	Willow Bay Boat Ramp Bradford, PA 16701	Willow Bay	41° 59' 30.69" N	78° 56' 9.28" W	8.37	5.20	6.10	**N/A
10/11	15:01	Conemaugh Dam Kayak Launch	Conemaugh River	40° 27' 39.82" N	079° 22' 5.33" W	5.03	5.01	5.43	*1.00
10/11	16:20	Newport Rd Substation NE of Blairsville PA	Conemaugh River	40° 27' 23.49" N	79° 17' 51.06" W	3.11	3.09	3.42	*1.00

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/11	17:30	Webbs Ferry Boat Ramp Russell, PA 16345	Allegheny River	41° 59' 47.02" N	78° 57' 45.14" W	13.00	11.40	10.30	**N/A
10/11	18:00	Boat Launch Ramp at Onoville Marina Park. 704 W Perimeter Rd, Steamburg, NY 14783	Allegheny River	42° 01' 39.27" N	78° 58' 0.48" W	13.10	13.90	12.40	0.69
10/11	18:15	Friends Boat Launch. Allegany State Park, Salamanca, NY14779	Allegheny River	42° 03' 28.80" N	78° 52' 50.75" W	9.13	10.20	10.30	**N/A
10/12	12:20	Rosston Boat Launch	Allegheny River	40° 44' 57.45" N	79° 33' 16.25" W	6.62	6.25	6.02	1.00
10/12	13:16	Kittanning Boat Launch	Allegheny River	40° 48' 35.73" N	79° 31' 6.15" W	3.98	3.49	3.32	1.00
10/12	14:19	Templeton Boat Launch	Allegheny River	40° 55' 9.91" N	79° 27' 49.44" W	7.16	6.76	6.96	0.75
10/13	13:30	Valley Falls State Park	Tygart Valley River	39° 23' 10.95" N	80° 05' 9.44" W	2.05	2.24	2.02	*1.00
10/13	14:50	Tygart River Camp Towles Boat Access	Tygart Valley River	39° 22' 32.5" N	80° 02' 47.33" W	2.17	2.54	1.90	*1.00
10/14	11:50	Monongahela River off Hwy 74 NW of Catawba WV	Monongahela River	39° 32' 16.54" N	80° 04' 44.47" W	6.22	5.30	5.24	0.75
10/14	13:40	Tygart Valley River Behind Muriale’s Italian Kitchen, Fiarmont WV	Tygart Valley River	39° 27' 1.70" N	80° 10' 23.68" W	7.79	7.76	6.90	0.72
10/15	12:09	River Access Upstream of Foxburg Bridge on East Side of Allegheny River	Allegheny River	41° 08' 28.18" N	79° 40' 48.12" W	N/A	N/A	N/A	*0.98
10/15	15:49	River Access at Parker City Boat Launch	Allegheny River	41° 05' 44.13" N	79° 40' 48.66" W	N/A	N/A	N/A	*1.10

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/15	17:37	Private Staircase Down to Allegheny River	Allegheny River	41° 02' 54.73" N	79° 39' 38.01" W	N/A	N/A	N/A	*1.06
10/16	12:55	Boston Boat Launch near Boston Battlefield Park McKeesport, PA	Youghiogheny River	40° 18' 50.44" N	79° 50' 3.23" W	N/A	N/A	N/A	*1.50
10/16	14:13	Public River Access/Boat Launch near14 Sons of Sutersville Memorial Park Sutersville, PA	Youghiogheny River	40° 14' 14.84" N	79° 48' 25.27" W	N/A	N/A	N/A	*1.35
10/16	14:50	Public Boat Launch Buena Vista, PA near the Great Allegheny Passage - Buena Vista Trailhead	Youghiogheny River	40° 16' 38.11" N	79° 47' 47.34" W	N/A	N/A	N/A	*1.25
10/16	17:00	Overgrown Path Through Woods on the Buena Vista Pedestrian Trail	Youghiogheny River	40° 16' 47.66" N	79° 47' 46.66" W	N/A	N/A	N/A	*0.60
10/17	11:15	Conewango Creek Water Trail access on E bank, N side of highway 62 near 187 W Main St, Frewsburg, NY 14738	Conewango Creek	42° 03' 9.32" N	79° 10' 31.03" W	6.99	7.19	7.37	1.20
10/17	11:56	River Access Down Forested Slope Near Mckeesport Wastewater Treatment Plant and Dura Bond Pipe McKeesport, PA	Monongahela River	40° 21' 16.05" N	79° 52' 9.16" W	N/A	N/A	N/A	*1.40
10/17	12:53	Prickets Fork Boat Launch	Monongahela River	39° 31' 5.53" N	80° 05' 29.70" W	4.17	4.24	4.12	*0.69

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/17	12:58	Public River Access Near Railroad Bridge (P&LE Boro Bridge)	Youghiogheny River	40° 19' 28.47" N	79° 50' 32.48" W	N/A	N/A	N/A	*1.45
10/17	14:11	Monongahela River off Hwy 74 NW of Catawba WV	Monongahela River	39° 32' 16.54" N	80° 04' 44.47" W	3.75	3.57	3.38	*0.99
10/17	14:15	Hickory Bridge in Warren, PA 16365	Allegheny River	41° 50' 38.90" N	79° 09' 16.73" W	4.50	4.24	4.28	2.21
10/17	14:33	Fire Station/Gravel Hauling Site Ramp to River	Monongahela River	40° 20' 55.83" N	79° 53' 3.18" W	N/A	N/A	N/A	*1.05
10/17	16:08	Private Property/Docks	Monongahela River	40° 19' 12.26" N	79° 53' 53.2" W	N/A	N/A	N/A	*0.75
10/17	16:11	Little Falls Boat Launch/Trail Access	Monongahela River	39° 33' 29.0" N	79° 59' 59.08" W	3.84	3.75	3.76	*1.00
10/17	17:20	Kinzua Tailwaters Boat Ramp Powerhouse Dr, Warren, PA 16365	Allegheny River	41° 50' 31.17" N	79° 00' 46.82" W	3.58	3.28	3.60	*0.67
10/17	18:12	Castaway Keys Marina	Monongahela River	40° 14' 24.16" N	79° 56' 12.54" W	N/A	N/A	N/A	1.66
10/18	11:35	Kinzua Tailwaters Boat Ramp Powerhouse Dr, Warren, PA 16365	Allegheny River	41° 50' 31.22" N	79° 00' 46.61" W	4.29	4.76	4.58	*0.60
10/18	11:53	Public Boat Launch in Gallatin Sunnyside Park	Monongahela River	40° 11' 47.39" N	79° 53' 3.62" W	N/A	N/A	N/A	*1.05
10/18	12:00	Warren General Hospital Helipad on South Bank of Allegheny River Warren, PA 16365	Allegheny River	41° 50' 38.77" N	79° 09' 16.63" W	3.50	3.36	3.63	N/A

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/18	13:11	Uffington Monongahela River Access	Monongahela River	39° 35' 16.11" N	79° 58' 36.4" W	3.75	3.61	3.39	*1.10
10/18	13:50	Public Boat Ramp Near Magic City Park	Monongahela River	40° 08' 11.08" N	79° 53' 31.42" W	N/A	N/A	N/A	*1.55
10/18	15:56	Public Boat Ramp Near Coal Center Park.	Monongahela River	40° 04' 15.82" N	79° 53' 58.06" W	N/A	N/A	N/A	*1.40
10/18	17:20	Kinzua Tailwaters Boat Ramp Powerhouse Dr, Warren, PA 16365	Allegheny River	41° 50' 31.27" N	79° 00' 46.57" W	4.30	3.56	4.05	N/A
10/19	12:30	Kinzua Beach Mead Township, PA 16701 off of Route 59/Kinzua Road just east of Kinzua Beach Bridge	Allegheny River	41° 51' 15.21" N	78° 57' 23.06" W	4.98	5.57	5.19	N/A
10/19	13:40	Pollock Run Creek Outlet	Pollock Run Creek, Youghiogheny River	40° 13' 42.07" N	79° 47' 17.78" W	1.12	0.96	0.96	*0.75
10/19	15:38	Behind the West Newton Fire Department, Upriver of the	Youghiogheny River	40° 12' 39.70" N	79° 46' 7.33" W	1.16	0.62	0.90	*0.70
10/19	17:20	Kinzua Beach Mead Township, PA 16701 off of Route 59/Kinzua Road just east of Kinzua Beach Bridge	Allegheny River	41° 51' 14.07" N	78° 57' 23.06" W	10.30	8.28	8.41	N/A

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/20	11:20	Conewango Creek Water Trail access on E bank, N side of highway 62 near 187 W Main St, Frewsburg, NY 14738	Conewango Creek	42° 03’ 9.61” N	79° 10' 30.18" W	5.41	5.47	5.80	1.35
10/20	13:17	Public Boat Ramp at Kelley Park Blairsville, PA	Conemaugh River	40° 25' 52.54" N	79° 16' 12.18" W	2.75	2.61	2.63	*1.30
10/20	15:00	River Trail Access near Wyotech Park	Conemaugh River	40° 25' 10.85" N	79° 15' 26.89" W	1.72	1.70	1.78	*1.05
10/20	16:50	East bank of Conewango Creek At Russel Bridge. Cross streets Priest Holw Rd at Cider Mill Hill Rd Russell, PA 16345	Conewango Creek	41° 56' 16.70" N	79° 07' 57.65" W	6.02	5.91	5.16	*1.19
10/20	16:58	Near Bridge North of Shannon Run	Conemaugh River	40° 22' 42.20" N	079° 05' 33.12" W	3.41	3.51	3.46	*1.10
10/20	18:10	Boat Launch Down the Side of the Huff Road Bridge	Conemaugh River	40° 23' 7.36" N	79° 04' 26.03" W	4.42	3.84	4.52	*0.90
10/21	13:17	Turbidity Collected at Warren General Hospital Helipad on South Bank of Allegheny River, Secchi Collected at Hickory Bridge Warren, PA 16365	Allegheny River	41° 50' 38.77" N	79° 09' 16.63" W	3.39	4.76	5.42	1.00
10/21	13:45	Buckaloons Boat Ramp 181 National Forge Rd, Irvine, PA 16329	Allegheny River	41° 50' 19.94" N	79° 15' 22.74" W	3.33	3.43	3.87	N/A

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/21	15:00	Public Boat Launch/River Access Seward, PA	Conemaugh River	40° 24' 29.57" N	79° 01' 47.01" W	6.01	6.00	5.97	*0.40
10/21	16:25	Approximately 12km/7mi east of Tidioute, PA off of Althom Rd on the north bank of Alleghany River at Crosstreets Old River Rd at Mickey's Landing, Tidioute, PA 16351	Allegheny River	41° 45' 08.90"N	79° 18' 7.60"W	7.19	10.10	11.10	N/A
10/21	16:39	River Access on West Side of Route 711 Bridge on the North Bank	Conemaugh River	40° 25' 12.41" N	79° 01' 35.56" W	5.30	5.51	6.13	*0.45
10/21	17:00	Tidioute Boat Ramp at Riverside Park 21 King St, Tidioute, PA 16351	Allegheny River	41° 40' 53.40" N	79° 24' 39.03" W	3.51	3.32	3.53	N/A
10/21	18:08	Down Concrete Enbankment Just Upriver From the Inclined Plane Bridge Johnstown, PA	Stonycreek River	40° 19' 32.21" N	78° 55' 31.23" W	3.74	3.85	3.56	*0.50
10/22	10:58	Road Ramp to River Down the Concrete Embankment.	Conemaugh River	40° 20' 33.17" N	78° 55' 45.87" W	6.54	6.08	5.85	*0.65
10/22	11:25	Tidioute Boat Ramp at Riverside Park 21 King St, Tidioute, PA 16351	Allegheny River	41° 40' 53.46" N	79° 24' 38.88" W	3.31	3.11	3.09	*1.45

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/22	12:40	Turbidity Collected at West Hickory Boat Launch on the west bank of the Allegheny River off of Highways 62 West Hickory, PA 16370, Secchi collected mid-channel off of the West Hickory Bridge immediately adjacent to the boat launch	Allegheny River	41° 34' 10.30" N	79° 24' 15.01" W	2.25	2.11	1.99	*1.45
10/22	13:44	Oil City Boat Launch	Allegheny River	41° 25' 31.06" N	79° 43' 27.47" W	4.66	3.94	4.20	*1.00
10/22	15:22	Footpath From the Railroad Tracks.	Conemaugh River	40° 25' 51.45" N	79° 14' 0.22" W	2.82	2.29	2.39	*0.80
10/22	15:40	Turbidity Collected at West Hickory Boat Launch on the west bank of the Allegheny River off of Highways 62 West Hickory, PA 16370, Secchi Collected Mid-Channel Off of the West Hickory Bridge Immediately Adjacent to the Boat Launch	Allegheny River	41° 23' 30.85" N	79° 49' 14.95" W	2.15	2.38	2.32	*1.10
10/22	18:48	Boat Ramp Behind/Next to the Robinson Community Center	Conemaugh River	40° 23' 54.34" N	79° 08' 4.47" W	4.83	5.21	4.93	*0.85

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/23	11:50	North bank of Allegheny River. West side of storm drain outlet located directly south of the western baseball diamond fence at Franchot Park 201R W Green St, Olean, NY 14760	Allegheny River	42° 04' 15.80" N	78° 25' 57.60" W	5.34	4.36	3.96	*0.50
10/23	13:15	East bank of Genesee River at Caneadea River Access Park 8738 NY-19, Caneadea, NY	Genesee River	42° 22' 51.78"N	78° 9' 16.07"W	7.31	7.73	7.51	N/A
10/23	14:54	Cedar Creek Park Boat Ramp	Youghiogheny River	40° 10' 45.95" N	79° 46' 38.75" W	1.62	1.32	1.12	*0.95
10/23	17:04	Upstream of Smithton Bridge (Matthew Smelser Memorial Bridge)	Youghiogheny River	40° 09' 37.29" N	79° 45' 27.81" W	2.06	1.41	1.62	*1.00
10/24	13:33	Utica Boat Launch	French Creek	41° 26' 20.15" N	79° 57' 22.20" W	5.53	6.78	6.66	0.60
10/24	14:45	McKees River Trail	Monongahela River	40° 21' 16.72" N	79° 52' 8.17" W	2.68	3.20	2.32	1.45
10/24	15:11	Cochranton Landing	French Creek	41° 31' 6.96" N	80° 03' 14.43" W	10.40	10.90	10.60	0.69
10/24	15:35	Yough River Boat Ramp	Youghiogheny River	40° 10' 42.37" N	79° 46' 39.46" W	1.83	2.40	1.40	*0.60
10/24	16:30	Elizabeth Monongahela River Boat Access	Monongahela River	40° 16' 14.63" N	79° 53' 27.69" W	2.88	2.77	2.76	*1.55

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/24	16:50	Yough River Park	Youghiogheny River	40° 01' 16.63" N	79° 35' 50.96" W	1.91	2.12	1.90	*0.90
10/24	17:03	Joe Cat Launch	French Creek	41° 39' 8.28" N	80° 09' 33.41" W	4.43	3.99	4.03	*0.53
10/24	17:45	Yough River Boat Launch	Youghiogheny River	39° 51' 57.68" N	79° 29' 41.49" W	1.96	1.94	2.44	*0.90
10/24	18:10	Color Park	Monongahela River	40° 25' 53.06" N	79° 59' 42.50" W	3.43	3.19	3.27	1.16
10/25	8:55	Herman Mihalich Memorial River Launch	Monongahela River	40° 09' 41.12" N	79° 52' 12.26" W	2.51	2.55	2.56	*2.26
10/25	11:20	East Fredricktown Boat Ramp	Monongahela River	40° 00' 12.47" N	79° 59' 40.11" W	2.52	2.62	2.40	*1.25
10/25	12:33	Kennerdell Boat Launch	Allegheny River	41° 16' 2.97" N	79° 50' 39.66" W	2.79	2.92	2.85	*1.58
10/25	13:55	Rice's Landing Boat Ramp	Pumpkin Run Creek	39° 57' 1.22" N	80° 00' 0.16" W	1.61	1.89	1.99	2.41
10/25	15:15	Masontown Boat Ramp by Historic Masontown Iron Bridge	Monongahela River	39° 51' 7.69" N	79° 55' 35.53" W	3.65	6.63	4.43	3.23
10/25	15:29	Sandy Creek Rail Trail Bridge	Allegheny River	41° 19' 52.68" N	79° 46' 14.56" W	2.90	2.38	2.59	*1.12
10/25	17:52	Emlenton Boat Ramp	Allegheny River	41° 10' 32.34" N	79° 42' 32.85" W	2.03	2.48	2.36	*1.39
10/26	12:00	Great Allegheny Passage Trail at HWY 281	Youghiogheny River	39° 48' 26.15" N	79° 21' 50.38" W	3.07	3.14	2.85	0.82
10/26	12:24	Mill Creek Boat Launch	Clarion River	41° 14' 7.41" N	79° 19' 18.62" W	6.45	5.63	5.17	*1.34
10/26	14:30	Hall Memorial Park	Monongahela River	40° 12' 43.74" N	79° 57' 20.56" W	26.80	24.40	27.10	0.49
10/26	15:01	Cook Forest State Park Boat Launch	Clarion River	41° 19' 53.16" N	79° 12' 28.94" W	1.95	2.73	2.29	*0.94

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/26	15:45	California Union Street Wharf	Monongahela River	40° 04' 9.43" N	79° 53' 32.53" W	1.75	2.03	1.91	*1.07
10/26	16:53	Clarington Boat Launch	Clarion River	41° 20' 25.26" N	79° 08' 7.90" W	1.93	1.98	2.07	*1.14
10/27	11:00	Caperton Trail by Sherwin Williams	Monongahela River	39° 36' 54.69" N	79° 58' 15.40" W	2.56	2.58	2.57	*1.43
10/27	12:04	Clarion River Campground	Clarion River	41° 21' 13.32" N	79° 01' 27.71" W	1.76	2.52	2.15	*1.03
10/27	12:45	Van Voorhis Landing	Monongahela River	39° 41' 2.39" N	79° 57' 23.63" W	1.97	2.03	2.08	*1.37
10/27	14:00	Confluence of Monongahela and Cheat Rivers	Monongahela River, Cheat River	39° 44' 31.98" N	79° 54' 6.93" W	2.10	1.96	1.98	*1.46
10/27	14:48	Clarion River Bridge	Clarion River	41° 23' 3.38" N	78° 56' 10.03" W	1.93	2.02	2.29	*0.63
10/27	16:00	Cheat Lake Park by Boat Ramp	Cheat Lake	39° 42' 36.13" N	79° 50' 38.01" W	1.41	1.55	1.53	*1.77
10/27	17:00	Cheat Lake Ices Ferry	Cheat Lake	39° 40' 4.23" N	79° 51' 33.10" W	1.62	1.74	1.78	*1.34
10/27	17:25	Clarion-Little Toby Trailhead	Clarion River	41° 23' 49.31" N	78° 45' 11.09" W	2.57	2.05	2.21	*0.57
10/28	12:09	Old Brickyard River Access	Clarion River	41° 28' 44.56" N	78° 40' 22.85" W	2.89	2.52	2.70	*0.65
10/28	14:49	Gillis Run	Clarion River	41° 22' 28.01" N	78° 48' 45.99" W	2.67	2.17	2.67	*0.42
10/28	12:00	River West of Albright Power Plant Bridge	Cheat River	39° 29' 27.62" N	79° 38' 20.39" W	2.79	2.70	2.87	*1.95
10/28	13:45	Cheat River Trailhead by Preston	Cheat River	39° 25' 52.50" N	79° 41' 3.24" W	2.52	2.54	2.62	2.71
10/28	14:45	Rowlesburg City Park Cheat River Trail	Cheat River	39° 20' 58.57" N	79° 40' 16.32" W	0.75	0.85	1.35	*0.94
10/28	17:00	Saint George Cheat River Bridge River Access	Cheat River	39° 09' 53.79" N	79° 42' 21.38" W	1.70	1.76	1.51	*1.16

Date	Time (UTC - 4h)	Location	Creek, Lake, or River	Latitude	Longitude	Turbidity Read 1 (NTU)	Turbidity Read 2 (NTU)	Turbidity Read 3 (NTU)	*Secchi Depth (m)
10/29	9:45	CJs Pizzeria Cheat River Access	Cheat River	39° 06' 1.00" N	79° 40' 26.57" W	1.04	0.81	1.00	*1.31
10/29	11:00	Callensburg Bridge	Clarion River	41° 07' 49.02" N	79° 33' 14.76" W	2.03	2.20	2.19	*0.72
10/29	11:30	Cheat River Holly Meadows Access	Cheat River	39° 07' 17.35" N	79° 40' 30.15" W	0.67	0.77	0.78	*0.94
10/29	13:12	Lawsonham Bridge	Redbank Creek	40° 59' 43.24" N	79° 29' 9.20" W	1.64	1.52	1.99	*1.12
10/29	14:46	St. Charles Road Bridge	Redbank Creek	40° 59' 40.09" N	79° 23' 33.47" W	3.18	4.49	6.86	*1.03
10/29	16:30	Riverview Lounge	Cheat River	39° 19' 12.95" N	79° 40' 57.93" W	2.69	2.46	2.36	*1.28
10/29	17:01	Brady Bend Boat Ramp	Allegheny River	40° 59' 28.23" N	79° 36' 47.34" W	2.38	2.89	3.01	*1.17
10/30	12:13	Cosmus Boat Launch	Allegheny River	40° 56' 48.43" N	79° 32' 42.63" W	3.04	3.15	3.20	*1.92
10/30	13:09	Dawson Park	Youghiogheny River	40° 02' 44.04" N	79° 39' 29.49" W	1.18	1.47	1.39	*1.01
10/30	15:10	Private Property near Great Allegheny Passage Picnic Area	Youghiogheny River	40° 13' 51.39" N	79° 48' 3.80" W	0.76	0.91	0.88	*0.98
10/30	16:18	Piney Creek Bridge	Clarion River	41° 10' 19.59" N	79° 28' 10.71" W	5.59	5.58	5.67	*1.42
10/31	13:30	Jenkinsburg (Bull Run) Bridge on Cheat River, WV	Cheat River	39° 35' 46.78" N	79° 44' 54.23" W	0.83	1.08	1.15	*1.68
11/10	13:50	River Access NE Side of Canoe Ripple Rd Bridge Knox, PA	Clarion River	41° 09' 46.31" N	79° 32' 13.51" W	1.66	1.57	1.50	*0.40
11/10	15:40	Toby Boat Launch	Clarion River	41° 13' 26.59" N	79° 23' 13.65" W	8.60	5.61	10.50	*0.85

** Measurement is depth to the bottom surface due to observational depth limitations*
***Inaccessible because of steep banks or shallow water with easily disturbed sediment*

Figure 3: These photos taken by NV5 acquisition staff display water clarity conditions in six different locations within the NOAA Appalachia site.

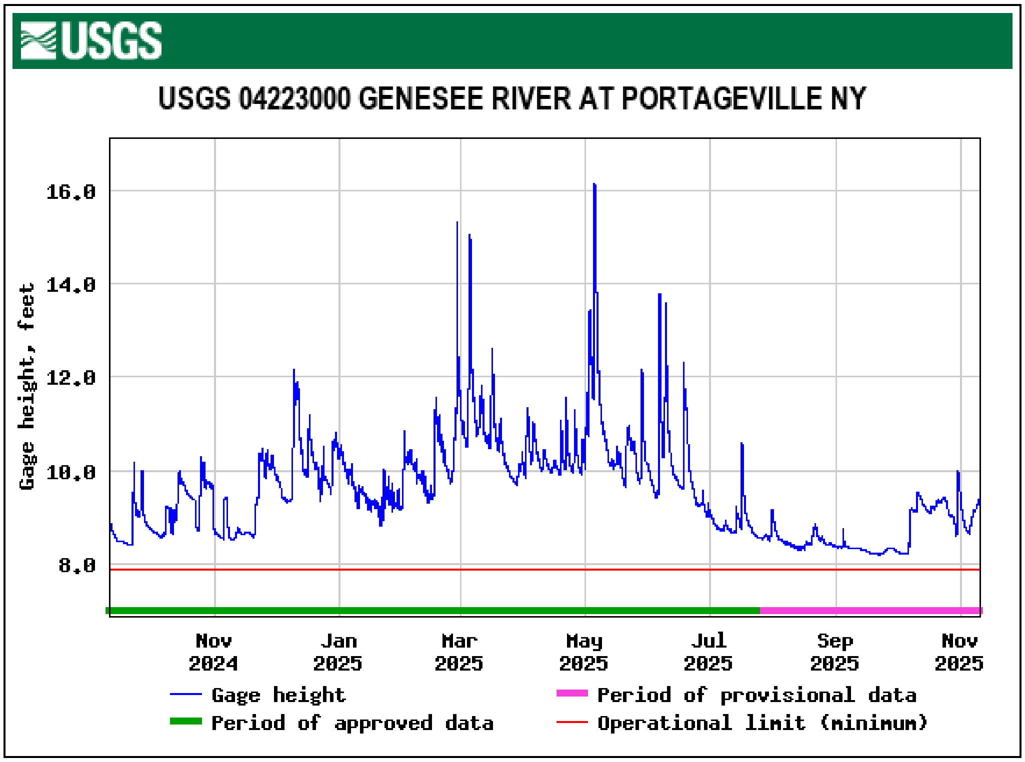


Figure 4: USGS Station 04223000 gage height along the Genesee River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

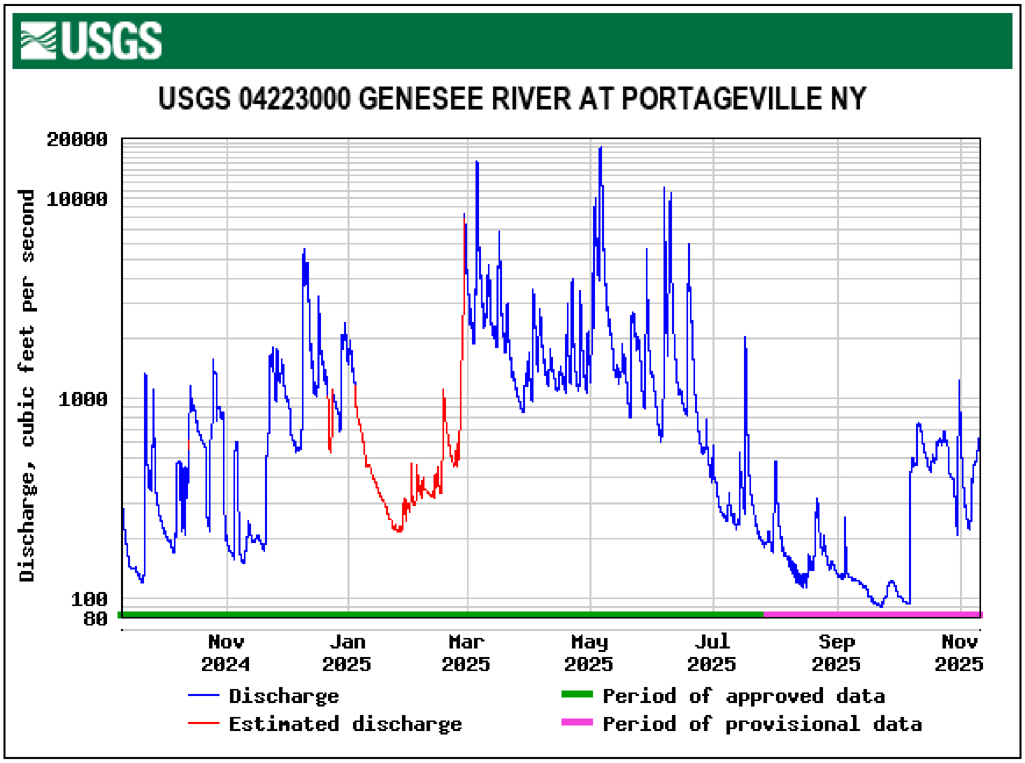


Figure 5: USGS Station 04223000 flow rates along the Genesee River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

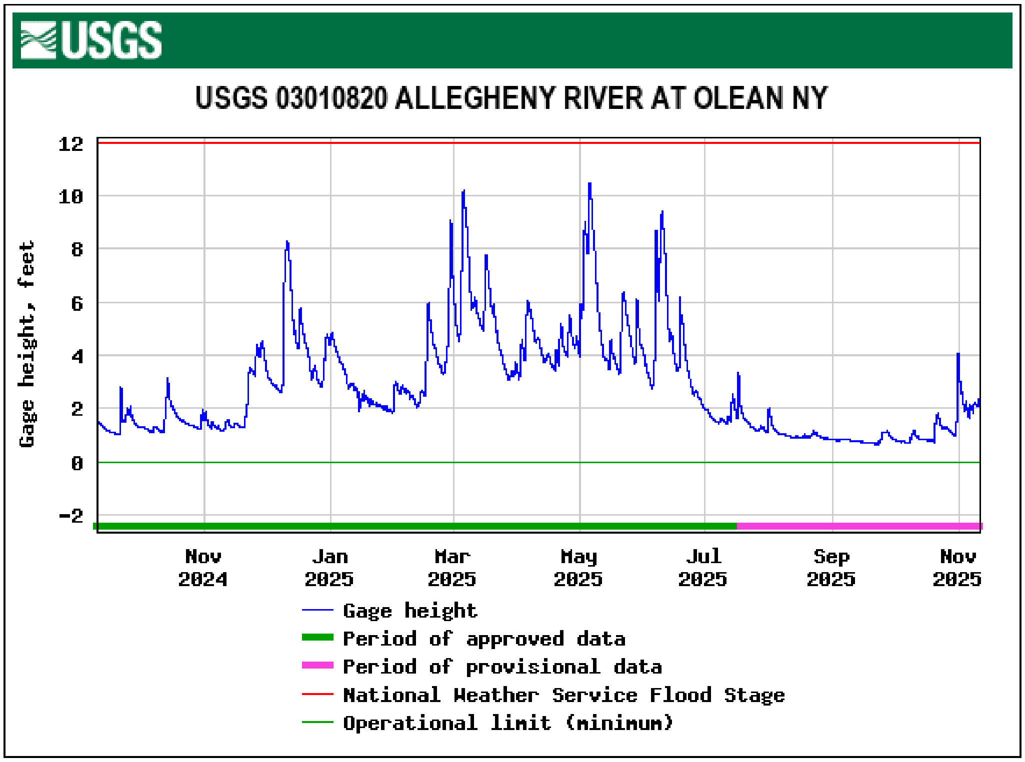


Figure 6: USGS Station 03010820 gage height along the Allegheny River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

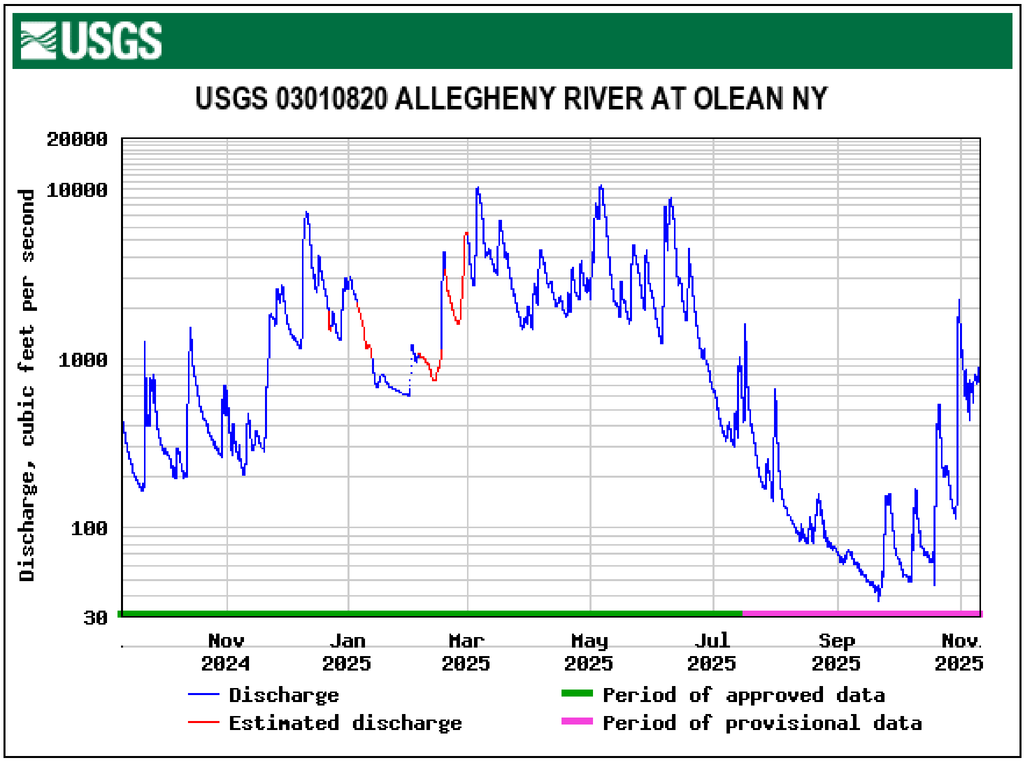


Figure 7: USGS Station 03010820 flow rates along the Allegheny River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

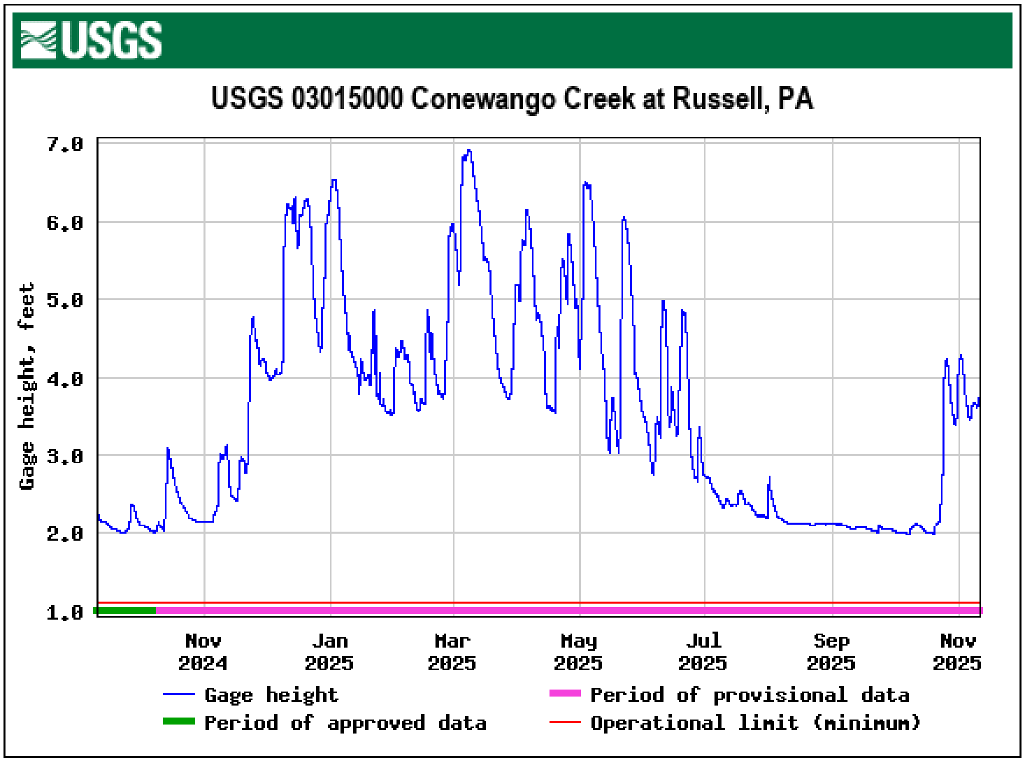


Figure 8: USGS Station 03015000 gage height along the Conewango Creek at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

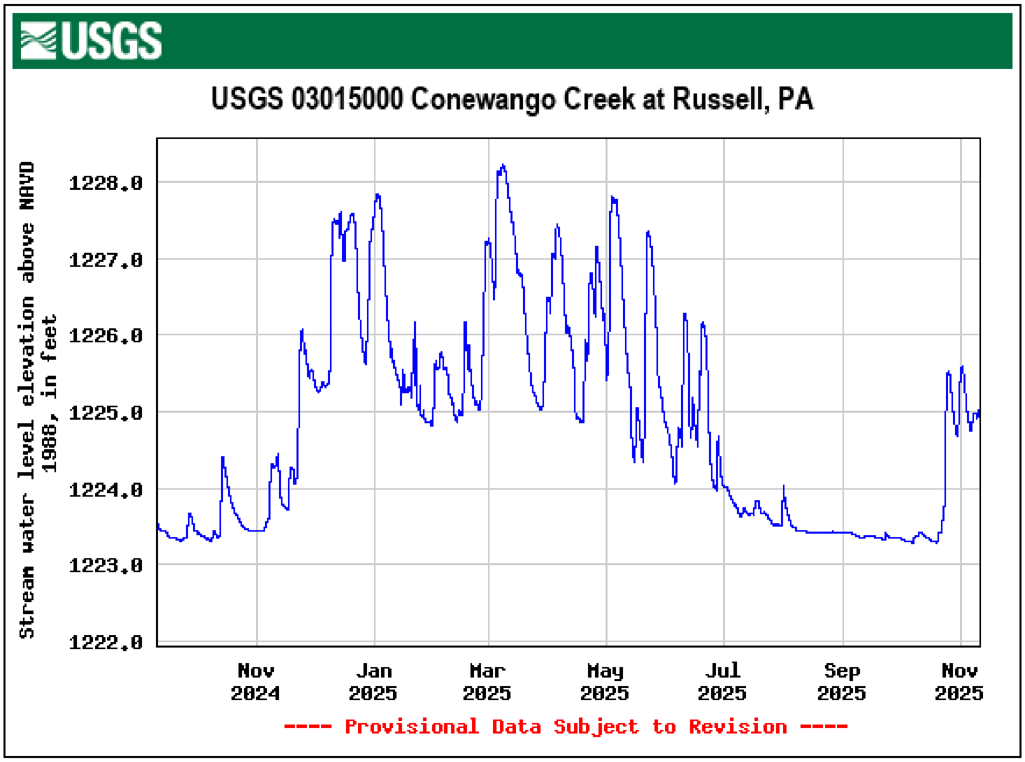


Figure 9: USGS Station 03015000 flow rates along the Conewango Creek at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

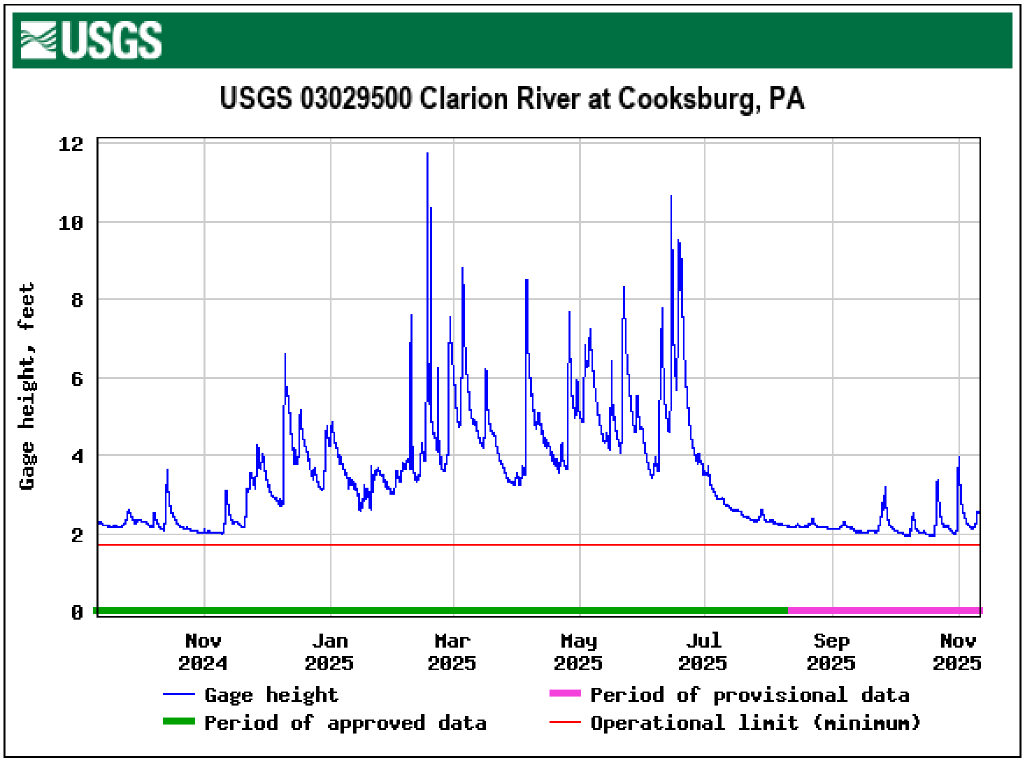


Figure 10: USGS Station 03029500 gage height along the Clarion River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

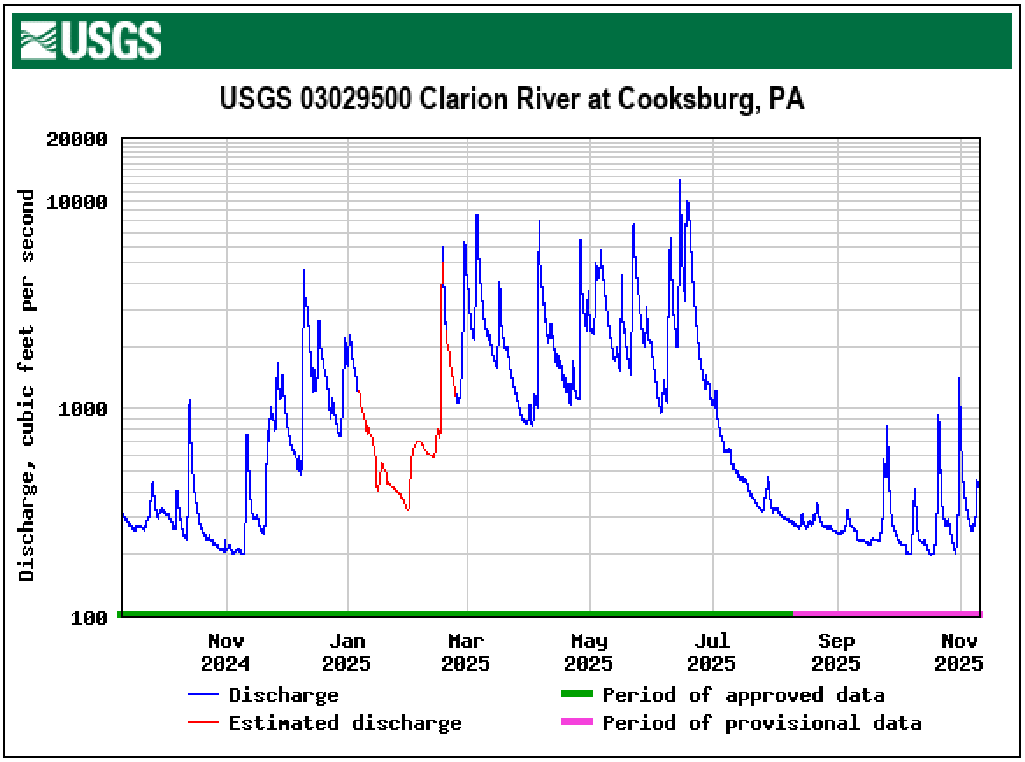


Figure 11: USGS Station 03029500 flow rates along the Clarion River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

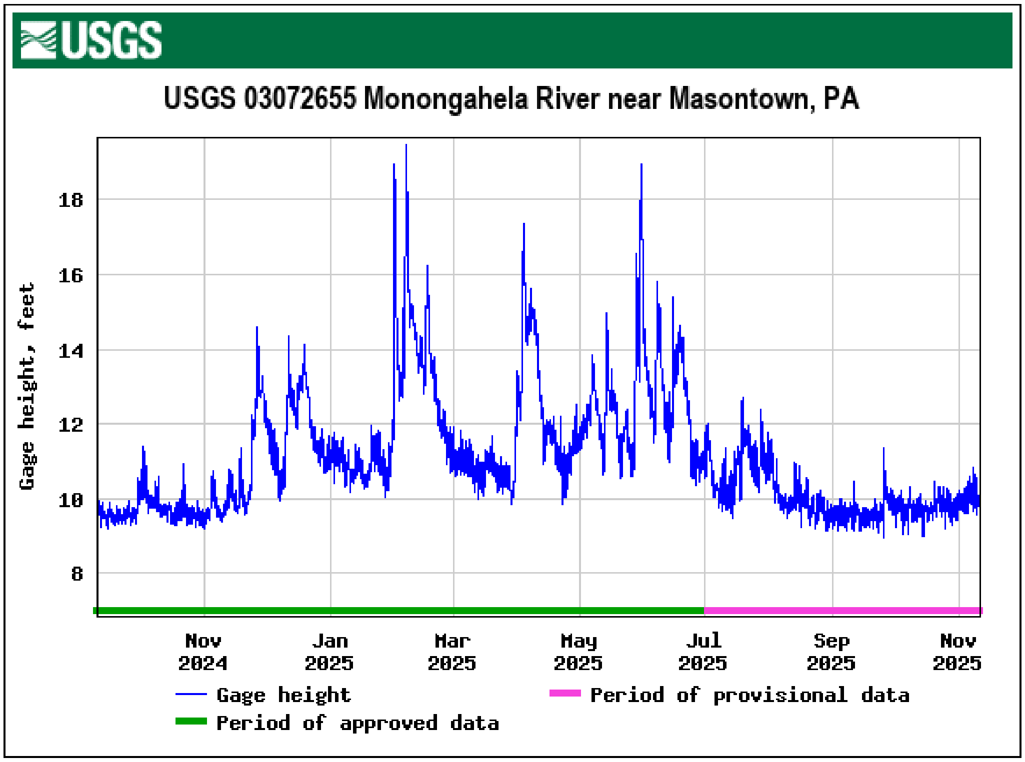


Figure 12: USGS Station 03072655 gage height along the Monongahela River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

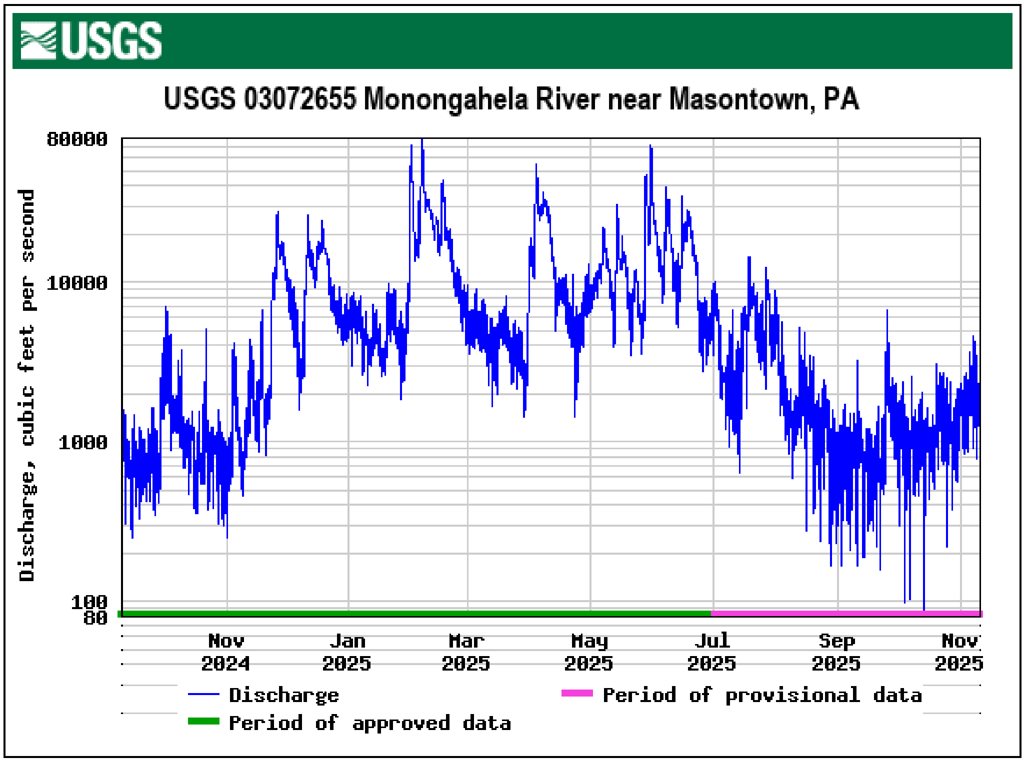


Figure 13: USGS Station 03072655 flow rates along the Monongahela River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

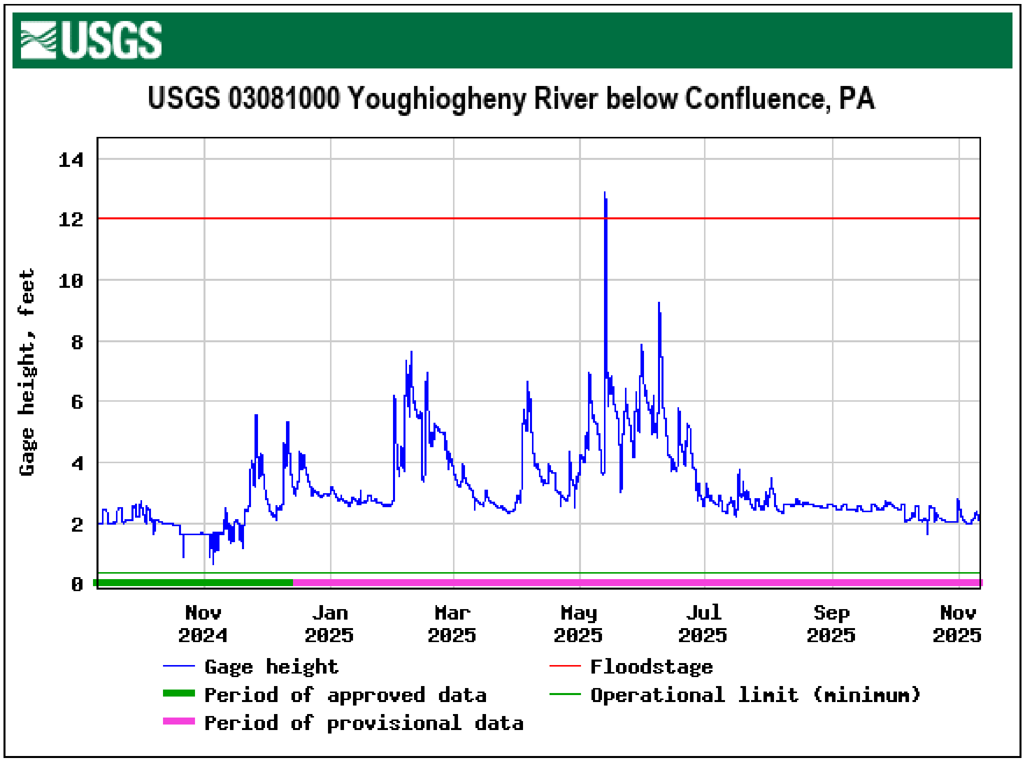


Figure 14: USGS Station 03081000 gage height along the Youghiogheny River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

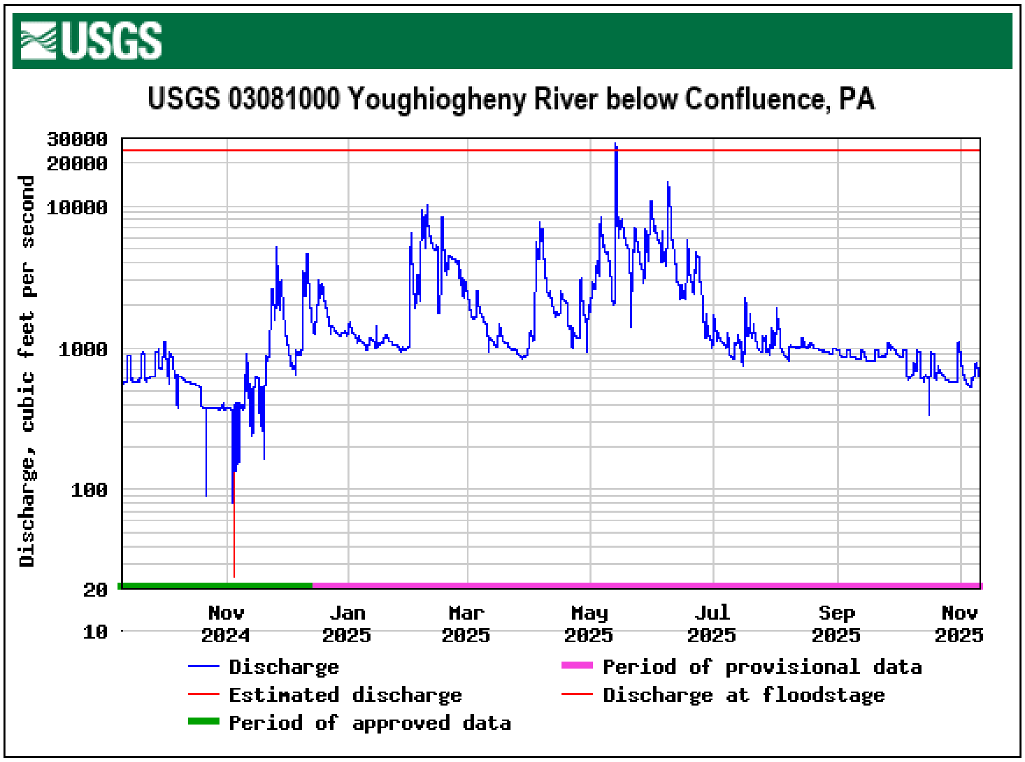


Figure 15: USGS Station 03081000 flow rates along the Youghiogheny River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

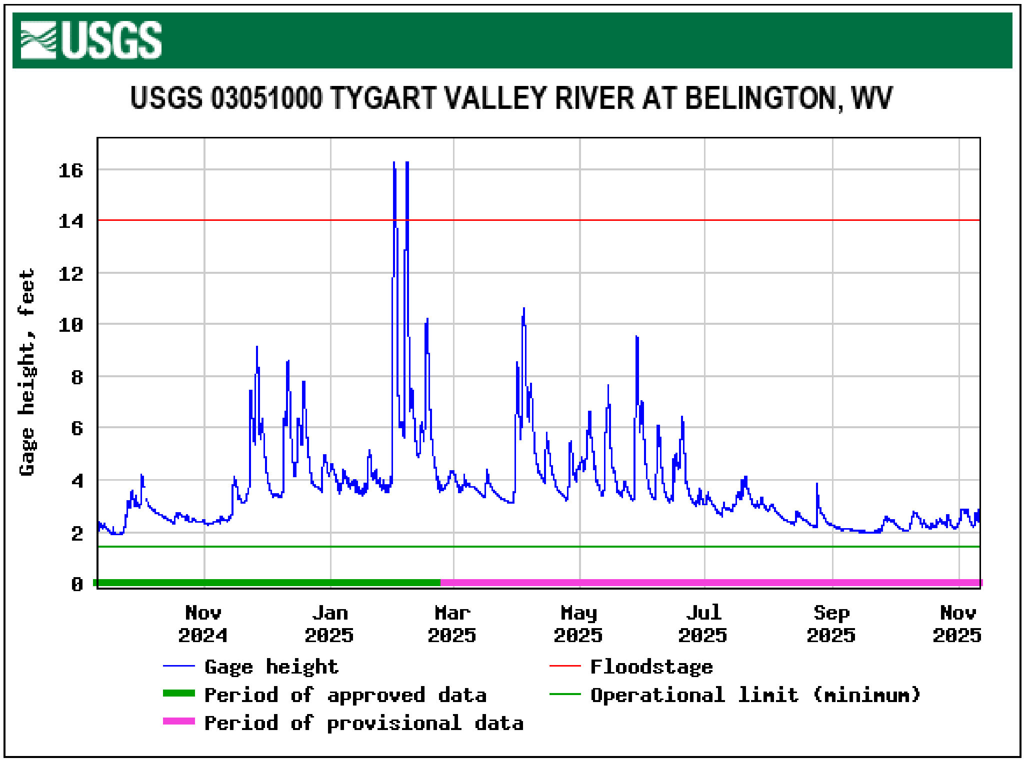


Figure 16: USGS Station 03051000 gage height along the Tygart Valley River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

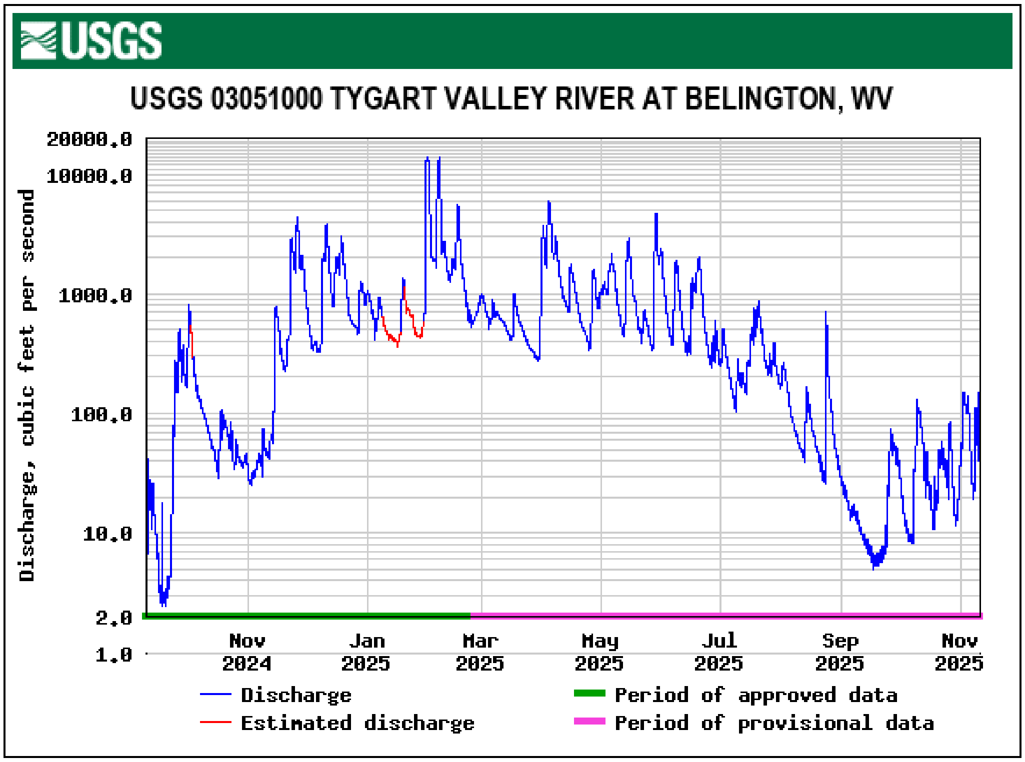


Figure 17: USGS Station 03051000 flow rates along the Tygart Valley River at the time of lidar acquisition (September 11, 2024 – November 10, 2025)

Airborne Lidar Survey

The lidar survey was accomplished using Chiroptera 4X (CH4X) and Chiroptera 5 (CH5) dual green and NIR laser systems mounted in Cessna Grand Caravans. The CH4X and CH5 sensors allow for a depth penetration of K*Dmax=2.7/k and 3.2/k at 15% seabed reflectance, respectively. Chiroptera shallow green laser sensors perform well in both shallow and deep waters with dynamic surfaces and automatically correct for water refraction making them useful in collecting riverine data. These sensors detect obstructions, such as vegetation and anthropogenic features, with oblique lidar. This means they can provide additional information from multiple positions that more closely resemble the actual features and can allow for further analyses compared to traditional imagery. These systems provide seamless integration between the NIR and green channels.

Chiroptera systems acquire full waveform data for every pulse. The recorded waveform enables range measurements for all discernible targets for a given pulse. It is not uncommon for some types of surfaces (e.g., dense vegetation or water) to return fewer pulses to the lidar sensor than the laser originally emitted. The discrepancy between first return and overall delivered density will vary depending on terrain, land cover, and the prevalence of water bodies. All discernible laser returns were processed for the output dataset. Table 5 summarizes the settings used to yield an average pulse density of ≥ 3 and ≥ 8 pulses/m^2 for bathymetric and NIR returns, respectively, over the NOAA Appalachia project area. Figure 19 shows the flightlines acquired over each state using these lidar specifications.

Figure 18: Leica Chiroptera 4X (left) and 5 (right) sensors

Table 5: Lidar specifications and aerial survey settings

Parameter	NIR Sensor	Shallow Green Sensor
Acquisition Dates	9/7/2024 – 8/5/2025	9/7/2024 – 8/5/2025
Aircraft Used	Cessna Caravan	Cessna Caravan
Sensor	Leica Chiroptera 4X and 5	Leica Chiroptera 4X and 5
Resolution/Density	Average 8 pulses/m^2	Average 3 pulses/m^2
Nominal Pulse Spacing	0.35 m	0.58 m
Survey Altitude (AGL)	400 – 600 m	400 – 600 m
Survey speed	140 knots	140 knots
Field of View	40^o	40^o
Mirror Scan Rate	4200 RPM	2500 RPM
Target Pulse Rate	210 – 250 kHz	35 – 50 kHz
Laser Pulse Footprint Diameter	20 – 30 cm	190 – 285 cm
Laser Wavelength	1064 nm	515 nm
Pulse Mode	Continuous Multipulse	Continuous Multipulse
Beam Divergence	0.25 mrad, 0.50 mrad	4.00 mrad, 4.75 mrad
Swath Width	291 – 437 m	291 – 437 m
Swath Overlap	60%	60%
Intensity	16-bit	16-bit

All areas were surveyed with an opposing flightline side-lap of at least 60% (≥ 120% overlap) in order to reduce laser shadowing and increase surface laser painting. To accurately solve for laser point position (geographic coordinates x, y, and z), the positional coordinates of the airborne sensor and the orientation of the aircraft to the horizon (attitude) were recorded continuously throughout the lidar data collection mission. Position of the aircraft was measured twice per second (2 Hz) by an onboard differential GPS unit, and aircraft attitude was measured 200 times per second (200 Hz) as pitch, roll, and yaw (heading) from an onboard inertial measurement unit (IMU). To allow for post-processing correction and calibration, aircraft and sensor position and attitude data are indexed by GPS time.

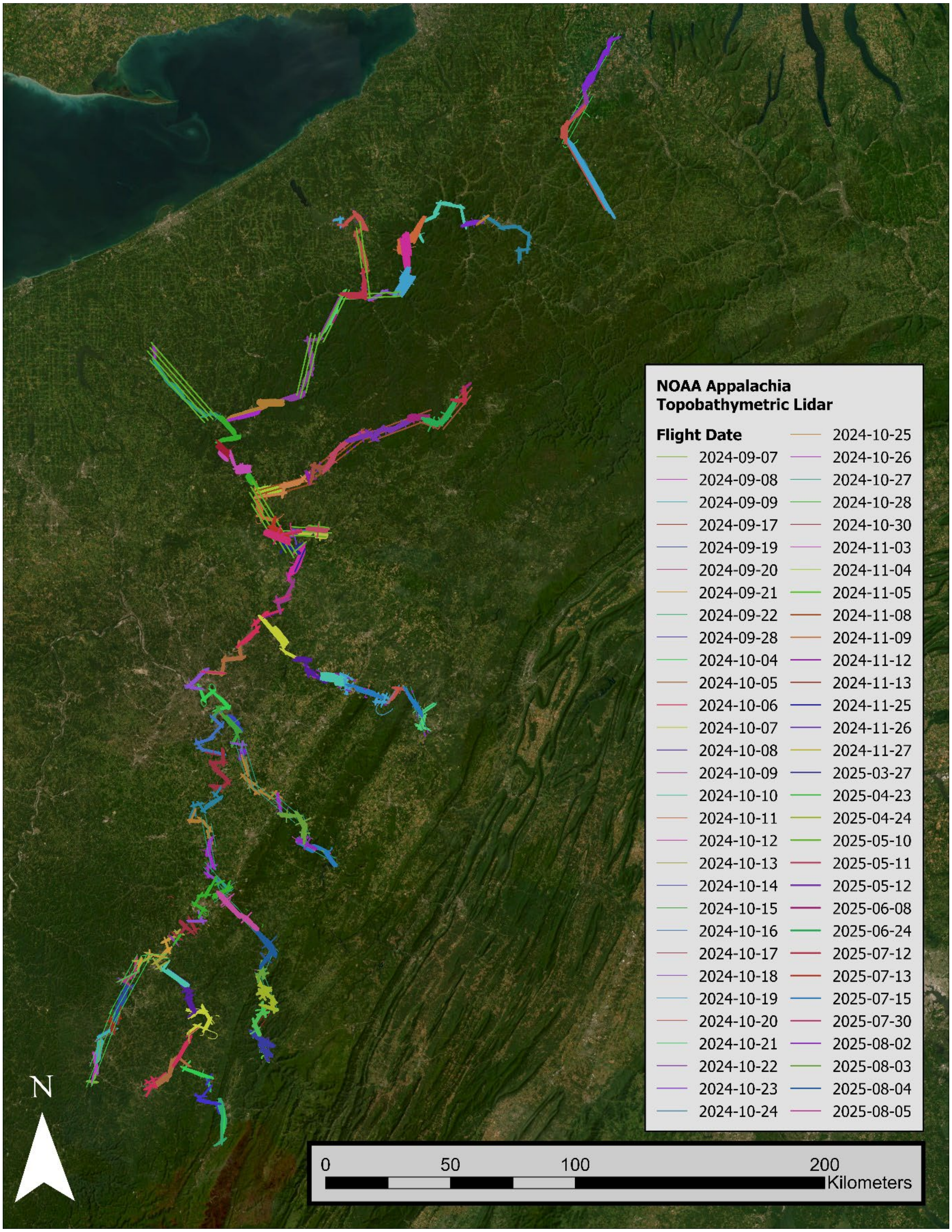


Figure 19: Flightlines map

Ground Survey

Ground control surveys, including monumentation and ground survey points (GSPs), were conducted to support the airborne acquisition. Ground control data were used to geospatially correct the aircraft positional coordinate data and to perform quality assurance checks on final lidar data.

Existing NGS Monument

NV5-Established Monument

Base Stations

Base stations were used for collection of ground survey points using real time kinematic (RTK), post processed kinematic (PPK), and fast static (FS) survey techniques.

Base station locations were selected with consideration for satellite visibility, field crew safety, and optimal location for GSP coverage. NV5 utilized 35 permanent real-time network (RTN) base stations including 16 from the Hexagon SmartNet network, 18 from the KeyNet network, and one NGS. Two (2) existing NGS monuments and three (3) new monuments were also established for the NOAA Appalachia Lidar project (Table 6, Figure 20). New monuments were set using 6” mag hub nails with orange survey washers. NV5’s professional land surveyor, Steven J. Hyde (NYPLS#051123-01, PAPLS# SU075359, WVPLS#2015), oversaw and certified the ground survey.

Table 6: Base station positions for the NOAA Appalachia acquisition. Coordinates are on the NAD83 (2011) datum, epoch 2010.00

Monument ID	Latitude	Longitude	Ellipsoid (meters)	State	Network	Type
AE2173	42° 03' 09.13469" N	79° 10' 30.75070" W	346.778	New York	NGS	AL Cap
BEC1	40° 14' 45.51566" N	79° 33' 03.85371" W	306.237	Pennsylvania	KeyNet	RTN
CLAR	41° 12' 31.01362" N	79° 22' 47.49609" W	439.670	Pennsylvania	KeyNet	RTN
DE7799	41° 53' 01.88848" N	79° 08' 52.86328" W	340.966	Pennsylvania	NGS	AL Cap
DSS2	41° 50' 18.42289" N	79° 07' 41.76563" W	349.655	Pennsylvania	KeyNet	RTN
EDU1	41° 52' 08.25449" N	80° 07' 27.30634" W	345.939	Pennsylvania	KeyNet	RTN
LS08	38° 58' 49.21701" N	80° 13' 11.03449" W	407.306	West Virginia	SmartNet	RTN

Monument ID	Latitude	Longitude	Ellipsoid (meters)	State	Network	Type
NCP1	41° 26' 04.47405" N	78° 44' 39.24905" W	492.730	Pennsylvania	KeyNet	RTN
NOAA_APPA_24_01	41° 42' 47.23753" N	79° 24' 59.86018" W	487.319	Pennsylvania	NV5	Nail
NOAA_APPA_24_02	41° 29' 07.64336" N	79° 27' 08.65070" W	288.471	Pennsylvania	NV5	Nail
NOAA_APPA_426	39° 35' 40.86449" N	79° 44' 51.04374" W	266.733	West Virginia	NV5	Nail
NYDV	42° 32' 56.09352" N	77° 41' 52.59553" W	188.575	New York	SmartNet	RTN
NYEV	42° 16' 30.55561" N	78° 40' 05.31684"	444.815	New York	SmartNet	RTN
NYFD	42° 25' 41.78577" N	79° 20' 22.71924" W	212.478	New York	SmartNet	RTN
NYFS	42° 12' 16.79295" N	78° 08' 37.93883" W	442.543	New York	SmartNet	RTN
NYSM	42° 11' 31.38162" N	78° 44' 50.46542" W	410.614	New York	KeyNet	RTN
NYWW	42° 44' 23.64264" N	78° 07' 58.82343" W	284.241	New York	SmartNet	RTN
PACS	41° 14' 21.79859" N	79° 25' 45.29354" W	414.497	Pennsylvania	KeyNet	RTN
PACY	41° 20' 55.44636" N	79° 43' 08.51902" W	403.596	Pennsylvania	SmartNet	RTN
PADM	40° 23' 58.04825" N	79° 35' 22.45694" W	369.675	Pennsylvania	SmartNet	RTN
PAFU	39° 55' 35.68892" N	79° 41' 50.51027" W	328.002	Pennsylvania	KeyNet	RTN
PAGA	40° 37' 21.54876" N	79° 56' 48.92324" W	336.461	Pennsylvania	SmartNet	RTN
PAGC	41° 10' 04.43830" N	80° 06' 50.40163" W	370.524	Pennsylvania	SmartNet	RTN
PAII	40° 36' 20.24818" N	79° 11' 09.32853" W	379.135	Pennsylvania	NGS	RTN
PAMD	41° 37' 21.48240" N	80° 12' 46.82334" W	402.122	Pennsylvania	SmartNet	RTN

Monument ID	Latitude	Longitude	Ellipsoid (meters)	State	Network	Type
PAMM	41° 13' 46.29125" N	80° 14' 41.81804" W	355.602	Pennsylvania	KeyNet	RTN
PANH	40° 38' 45.91022" N	79° 42' 48.41517" W	319.991	Pennsylvania	SmartNet	RTN
PASE	40° 03' 05.10719" N	79° 04' 14.10392" W	656.979	Pennsylvania	SmartNet	RTN
PAWG	40° 18' 19.24219" N	79° 30' 22.37738" W	336.163	Pennsylvania	KeyNet	RTN
PAWM	40° 20' 27.62623" N	79° 56' 46.01008" W	360.348	Pennsylvania	SmartNet	RTN
PAWN	40° 10' 58.32757" N	80° 13' 14.33593" W	347.291	Pennsylvania	SmartNet	RTN
PAWS	40° 01' 32.74546" N	79° 53' 54.04348" W	314.040	Pennsylvania	SmartNet	RTN
PL10	39° 55' 08.73986" N	79° 47' 04.66875" W	364.396	Pennsylvania	KeyNet	RTN
PLI6	40° 22' 50.70326" N	78° 51' 05.71530" W	405.132	Pennsylvania	KeyNet	RTN
RBM1	40° 48' 54.79318" N	79° 31' 06.78387" W	222.755	Pennsylvania	KeyNet	RTN
UPTC	41° 37' 43.70176" N	79° 39' 50.62099" W	343.156	Pennsylvania	KeyNet	RTN
WVBR	39° 18' 28.88440" N	80° 16' 38.61885" W	270.246	West Virginia	KeyNet	RTN
WVCV	39° 00' 55.07616" N	79° 27' 25.00965" W	969.235	West Virginia	KeyNet	RTN
WVNR	38° 53' 44.50553" N	79° 51' 30.27007" W	582.773	West Virginia	KeyNet	RTN
WVTA	39° 26' 16.64385" N	79° 30' 52.95331" W	726.058	West Virginia	KeyNet	RTN

NV5 utilized static Global Navigation Satellite System (GNSS) data collected at 1 Hz recording frequency for each base station. During post-processing, the static GNSS data was triangulated with nearby Continuously Operating Reference Stations (CORS) using the Online Positioning User Service (OPUS[1]) for precise positioning. Multiple independent sessions over the same monument were processed to confirm antenna height measurements and to refine position accuracy.

[1] OPUS is a free service provided by the National Geodetic Survey to process corrected monument positions: OPUS website

Monuments were established according to the national standard for geodetic control networks, as specified in the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards for geodetic networks.[2] This standard provides guidelines for classification of monument quality at the 95% confidence interval as a basis for comparing the quality of one control network to another. The monument rating for this project is shown in Table 7.

Table 7: Federal Geographic Data Committee monument rating for network accuracy

Direction	Rating
1.96 * St Dev $_{NE}$:	0.020 m
1.96 * St Dev $_{z}$:	0.050 m

For the NOAA Appalachia lidar project, the monument coordinates contributed no more than 5.6 cm of positional error to the geolocation of the final ground survey points and lidar, with 95% confidence.

Ground Survey Points

GSPs were collected using RTK, PPK, and FS survey techniques. For RTK surveys, a roving receiver receives corrections from a nearby base station or Real-Time Network (RTN) via radio or cellular network, enabling rapid collection of points with relative errors less than 1.5 cm horizontal and 2.0 cm vertical. PPK and FS surveys compute these corrections during post-processing to achieve comparable accuracy. RTK and PPK surveys record data while stationary for at least five seconds, calculating the position using at least three one-second epochs. FS surveys record observations for up to fifteen minutes on each GSP in order to support longer baselines. All GSP measurements were made during periods with a Position Dilution of Precision (PDOP) of less than 3.0 with at least six satellites in view of the stationary and roving receivers. See Table 8 for NV5 ground survey equipment information.

GSPs were collected in areas where good satellite visibility was achieved on paved roads and other hard surfaces such as gravel or packed dirt roads. GSP measurements were not taken on highly reflective surfaces such as center line stripes or lane markings on roads due to the increased noise seen in the laser returns over these surfaces. GSPs were collected within as many flightlines as possible; however, the distribution of GSPs depended on ground access constraints and monument locations and may not be equably distributed throughout the study area (Figure 20).

Table 8: NV5 ground survey equipment identification

Receiver Model	Antenna	OPUS Antenna ID	Use
Trimble R750	Zephyr Model 3 GNSS	TRM115000.10	Static
Trimble R12	Integrated Antenna	TRMR12	Rover

[2] Federal Geographic Data Committee, Geospatial Positioning Accuracy Standards (FGDC-STD-007.2-1998). Part 2: Standards for Geodetic Networks, Table 2.1, page 2-3: FGDC Standards Website

Land Cover Class

In addition to ground survey points, land cover class checkpoints were collected throughout the study area to evaluate vertical accuracy. Vertical accuracy statistics were calculated for all land cover types to assess confidence in the lidar derived ground models across land cover classes (Table 9, see Lidar Vegetated Vertical Accuracies).

Table 9: Land cover types and descriptions

Land cover type	Land cover code	Example	Description	Accuracy Assessment Type
Shrub	SH		Low growth shrub	VVA
Tall Grass	TG		Herbaceous grasslands in advanced stages of growth	VVA
Forest	FR		Forested areas	VVA
Bare Earth	BARE, BE		Areas of bare earth surface	NVA
Urban	UA		Areas dominated by urban development, including parks	NVA

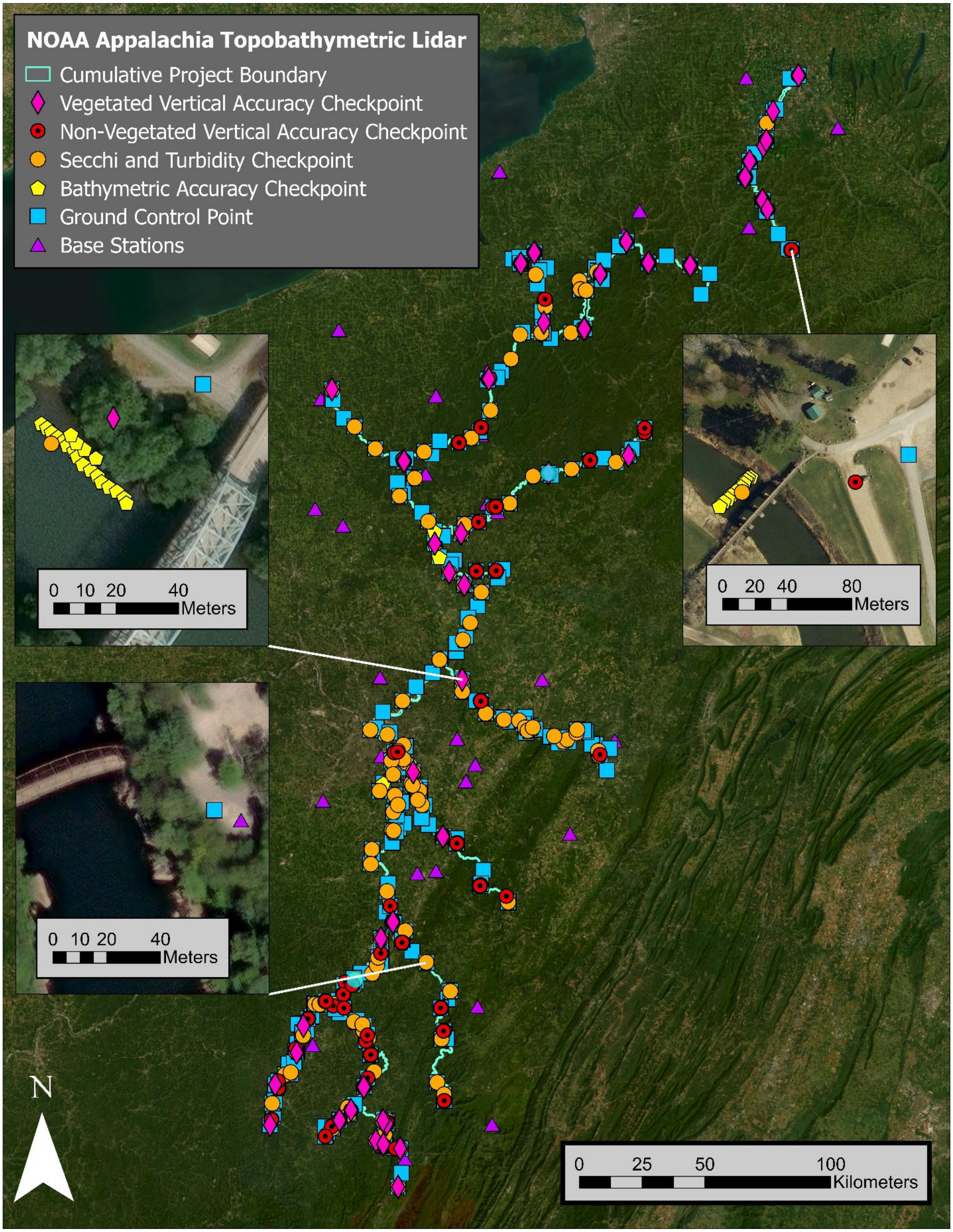
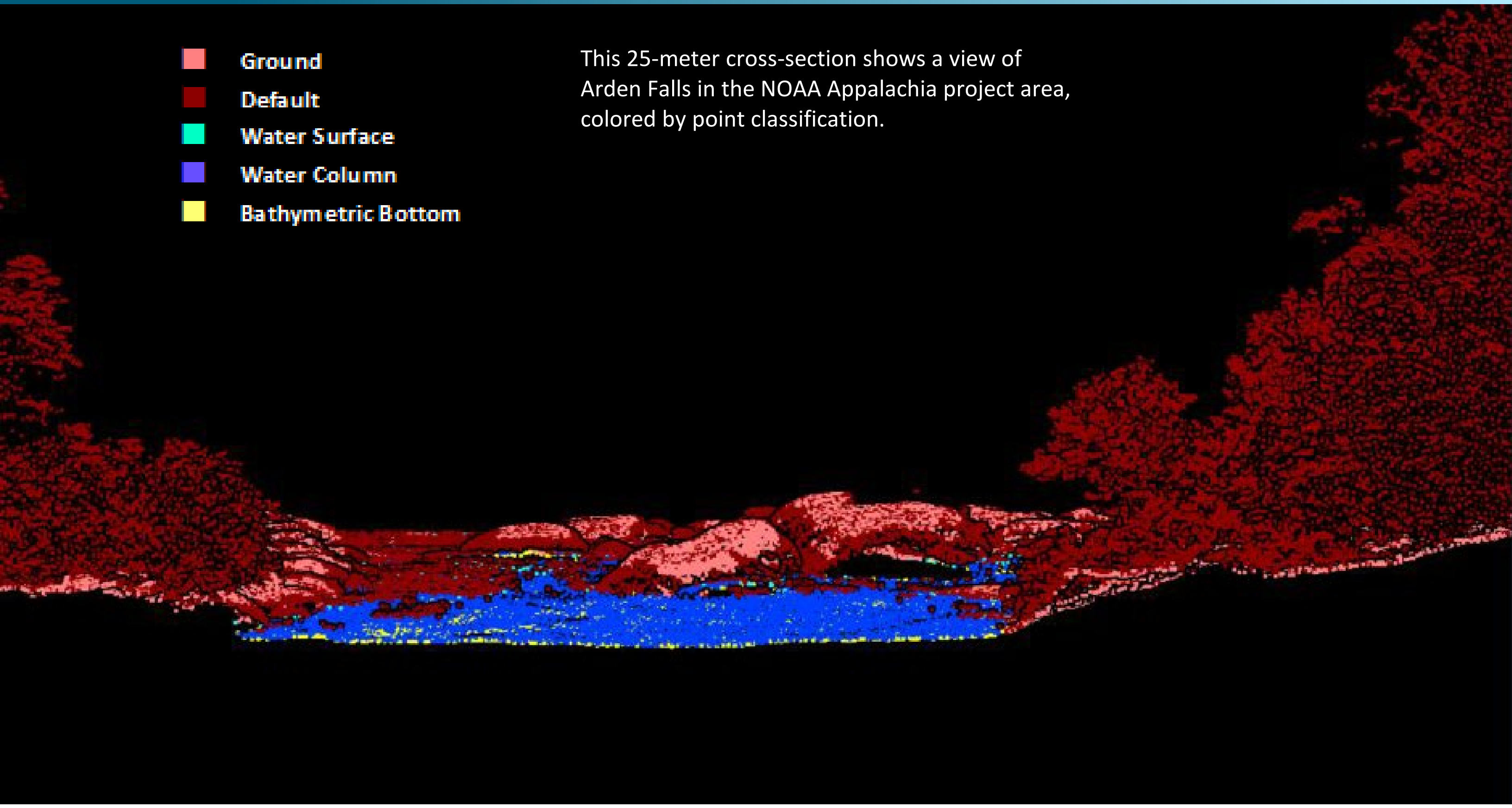


Figure 20: Ground survey location map



This 25-meter cross-section shows a view of Arden Falls in the NOAA Appalachia project area, colored by point classification.

Boresight Calibration

Prior to the lidar acquisition, NV5 collects sample lidar data in support of sensor calibration and geometric adjustments for all sensor and aircraft combinations utilized in the airborne acquisition. These data support boresight analysis to properly position the sensor orientation within the aircraft. This process is essential for data interswath adjustments performed during the calibration phase. Additional details on geometric adjustments can be found in Appendix A – Accuracy Controls.

Topobathymetric Lidar Data

Upon completion of data acquisition, NV5 processing staff initiated a suite of automated and manual techniques to process the data into the requested deliverables. Processing tasks included GPS control computations, smoothed best estimate trajectory (SBET) calculations, kinematic corrections, calculation of laser point position, sensor and data calibration for optimal relative and absolute accuracy, and lidar point classification. The point classification scheme is detailed in Table 10, brief descriptions of processing tasks are shown in Table 11, and example raster layers for processing and review can be visualized in Figure 21. Processing methodologies were tailored to the NOAA Appalachia landscape.

Table 10: ASPRS LAS classification standards applied to the NOAA Appalachia dataset

Classification Number	Classification Name	Classification Description
1	Unclassified	Processed, but unclassified
2	Ground	Bare-earth ground
7 Withheld	Low Noise	Noise (low manually identified)
18 Withheld	High Noise	Noise (high manually identified)
22	Temporal Exclusion	Consolidated adjacent lift unclassified, ground, water surface, water column associated with areas where temporal differences are present
40	Bathymetric Bottom	Bathymetric point (e.g., seafloor or riverbed; also known as submerged topography)
41	Water Surface	Water's surface (sea/river/lake surface from topographic-bathymetric lidar
42- Synthetic	Derived Water Surface	Synthetic water surface location used in computing refraction at water surface
43	Submerged Feature	Submerged object, not otherwise specified (e.g., wreck, rock, submerged piling)
45	Water Column	Refracted returns not determined to be water surface or bathymetric bottom
46	Submerged Aquatic Vegetation	Benthic vegetation in submerged, refracted areas
47-Withheld	Bathymetric Noise	Bathymetric noise below water surface
48	Overlap Water Surface and Water Column	Consolidated adjacent lift water surface and water column associated with areas where temporal differences are present
1-Withheld	Edge Clip	Unclassified points flagged as withheld. These are primarily "edge" points from the higher scan angle being removed
1-Overlap Withheld	Unrefracted Green Chiroptera Points	Unrefracted green data from the Chiroptera systems

Original SOW classification scheme	Delivered in LAS files
Additional classification codes	Delivered in LAS files
Original SOW classification code not used	Not delivered in LAS files
Deleted points	Not delivered in LAS files

Table 11: Lidar processing workflow

Lidar Processing Step	Software Used
Resolve kinematic corrections for aircraft position data using kinematic aircraft GPS and static ground GPS data. Develop a SBET file that blends post-processed aircraft position with sensor head position and attitude recorded throughout the survey.	Inertial Explorer v.9.00
Calculate laser point position by associating SBET position to each laser point return time, scan angle, intensity, etc. Create raw laser point cloud data for the entire survey in *.las (ASPRS v.1.4) format. Convert data to orthometric elevations by applying a geoid correction.	Lidar Survey Studio v.3.4.3 Las Projector v.1.6 (NV5 proprietary)
Import raw laser points into manageable blocks to perform manual relative accuracy calibration and filter erroneous points. Classify ground points for individual flightlines.	TerraScan v.25.007
Using ground classified points per each flightline, test the relative accuracy. Perform automated line-to-line calibrations for system attitude parameters (pitch, roll, heading), mirror flex (scale), and GPS/IMU drift. Calculate calibrations on ground classified points from paired flightlines and apply results to all points in a flightline. Use every flightline for relative accuracy calibration.	Lidar Survey Studio v.3.4.3 Las Projector v.1.6
Apply refraction correction to all subsurface returns.	Lidar Survey Studio v.3.4.3
Classify resulting data to ground and other client designated ASPRS classifications (Table 10). Assess statistical absolute accuracy via direct comparisons of ground classified points to ground control survey data.	TerraScan v.25.007 TerraModeler v.25.001
Generate bare earth models as triangulated surfaces. Export all surface models as Cloud-Optimized GeoTIFFs at a 1-meter pixel resolution.	LasTools Software Suite Las Product Creator v.4.0 (NV5 proprietary) ArcMap v.10.8
Normalize seabed intensity values for angle of incidence and depth and export intensity images as cloud optimized GeoTIFFs at a 1-meter pixel resolution.	Las Monkey v.2.6.10 (NV5 proprietary) Inpho OrthoVista v.14.0.3 Las Product Creator 4.0 (NV5 software)

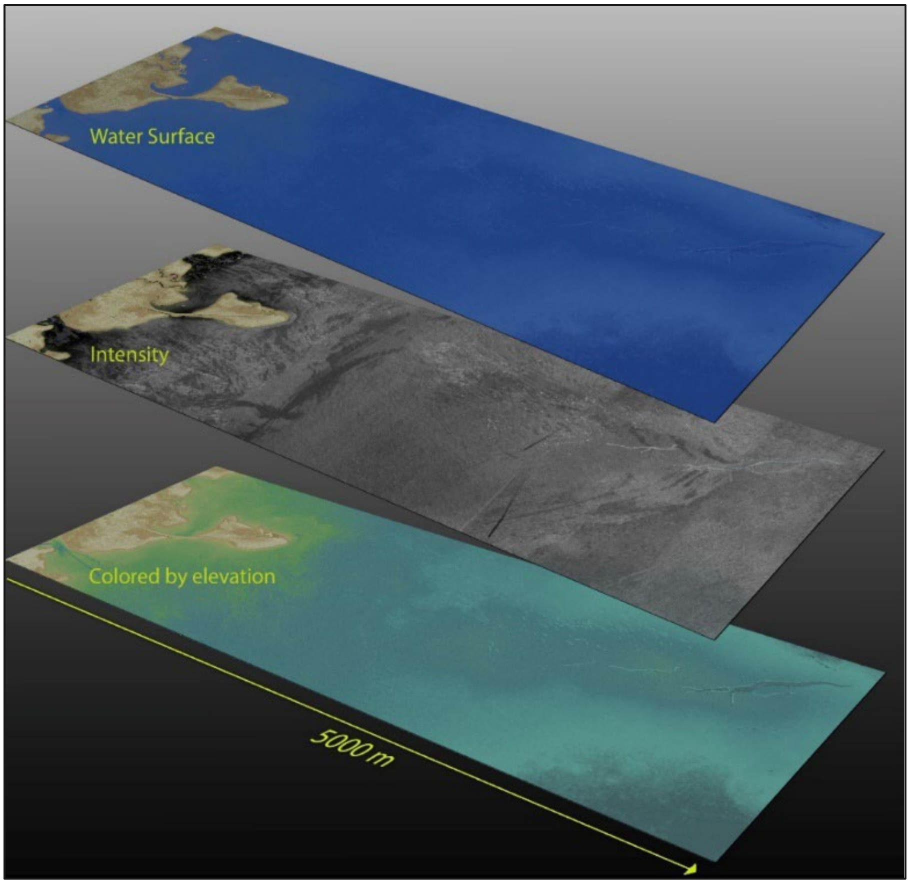


Figure 21: Example processing data layers

GNSS-Inertial Processing

Inertial Explorer software was used for post-processing of airborne GPS and inertial data (IMU), which is critical to the positioning and orientation of the lidar sensor during all flights. The post-processing combines aircraft raw trajectory data with stationary GNSS base station data yielding a "Smoothed Best Estimate Trajectory" (SBET) necessary for additional post processing software to develop the resulting geo-referenced point cloud from the lidar missions.

During the sensor trajectory processing (combining GNSS & IMU datasets) certain statistical graphs and tables are generated within the software processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis includes max horizontal and vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory.

Bathymetric Refraction

Green lidar pulses that map bathymetry must have their position corrected for the refraction of the light as it enters the water, which results in a change in speed and direction described by Snell's Law. This correction was applied as part of the raw data extraction process in Leica's Lidar Survey Studio (LSS) software. To determine how much time the laser pulse spent traveling through water and at what angle it entered, water surface models (WSMs) were developed for each flightline swath to cover all submerged returns. Synthetic points representing the water surface were generated automatically based on information derived primarily from the sensor's NIR channel; the NIR wavelength of light does not penetrate the water and therefore generally provides the most consistent information about the surface. The NIR and green channels are coaligned, meaning water surfaces based on NIR are representative of the associated green pulses and can help accurately model even variable water surfaces with tide changes or wave action. The use of synthetic points makes it clear in the point cloud exactly where the water surfaces were placed, especially over any localized areas where the algorithm interpolated or extrapolated the surface to ensure complete coverage of submerged points.

Once the WSMs were generated, LSS applied a refraction correction to each submerged point by intersecting the trajectory of the green pulses with their WSM to determine the angle of incidence with the water surface and the submerged component of the pulse vector. This provides the information necessary to correct the position of underwater points by adjusting the submerged vector length and orientation. After the refraction correction was applied, the point cloud was reviewed for any improper placement of water surface, and any areas identified were reprocessed with adjusted parameters to ensure accurate positioning and classification. Finally, the submerged points were compared against bathymetric checkpoints to assess absolute accuracy.

Lidar Derived Products

Because hydrographic laser scanners penetrate the water surface to map submerged topography, this affects how the data should be processed and presented in derived products from the lidar point cloud. The following section discusses certain derived products that vary from the traditional (NIR) specification and delivery format.

Topobathymetric DEMs

Bathymetric bottom returns can be limited by depth, water clarity, and bottom surface reflectivity. Water clarity and turbidity affect the depth penetration capability of the green wavelength laser with returning laser energy diminishing by scattering throughout the water column. Additionally, the bottom surface must be reflective enough to return the remaining laser energy back to the sensor at a detectable level. Although the predicted depth penetration range of the CH4X and CH5 sensors are 1.5- and 1.8-times the recorded Secchi depth, respectively. Therefore, it is not unexpected to have no bathymetric bottom returns in turbid or non-reflective areas.

As a result, creating DEMs presents a challenge with respect to interpolation of areas with no returns. Traditional DEMs are "unclipped", meaning areas lacking ground returns are interpolated from neighboring ground returns (or breaklines in the case of hydro-flattening), with the assumption that the interpolation is close to reality. In bathymetric modeling, these assumptions are prone to error because a lack of bathymetric returns can indicate a change in elevation that the laser can no longer map due to increased depths. The resulting void areas may suggest greater depths, rather than similar elevations from neighboring bathymetric bottom returns. Therefore, NV5 created a water polygon with bathymetric coverage to delineate areas with successfully mapped bathymetry. This shapefile was used to control the extent of the delivered clipped topobathymetric model to avoid false triangulation (interpolation from TIN'ing) across areas in the water without bathymetric bottom returns.

Normalized Bathymetric Bottom Reflectance

A lidar echo return signal has a recorded amplitude associated for each point and is logged in LAS files as an Intensity record. Laser return intensity is generally a unitless measure of discrete return signal strength, stored as a 16-bit integer value (0 to 65,535). Intensity values roughly correspond to the reflectivity of the surface, which is a function of surface material composition. The magnitude of intensity values can vary across similar surfaces due to variability in atmospherics, water clarity, range, submerged depth, and the angle of incidence on the object. The result is line to line inconsistency and streaking in the images that can reduce the utility of these data for analytics. The Intensity value in the LAS file has been updated with corrected values that have normalized the effects of the variables described above.

When a laser pulse enters the water column, the return signal fades exponentially with depth (Figure 22); the diminishing rate depends on water properties such as turbidity and composition. This exponential decay can be corrected after determining the rate of decline by comparing similar substrates across multiple flightlines and varying depths. The seabed intensity values for this dataset have been normalized for depth, angle of incidence, and absolute flying altitude (Figure 23 and Figure 24). Please note that intensity values are still subject to localized changes of water properties within the water column across a water body.

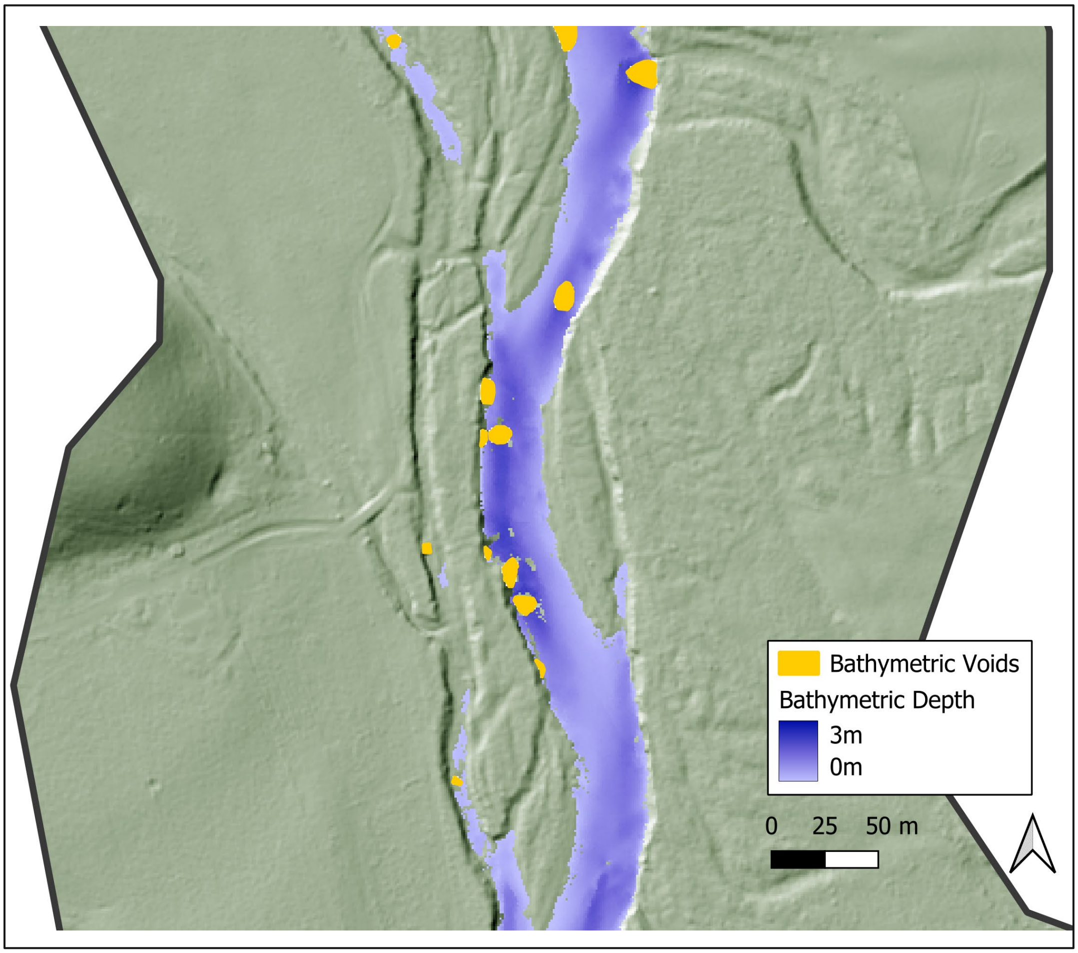


Figure 22: Depth raster shows an example of areas of deeper bathymetry which correlated to diminished bathymetric bottom intensity values

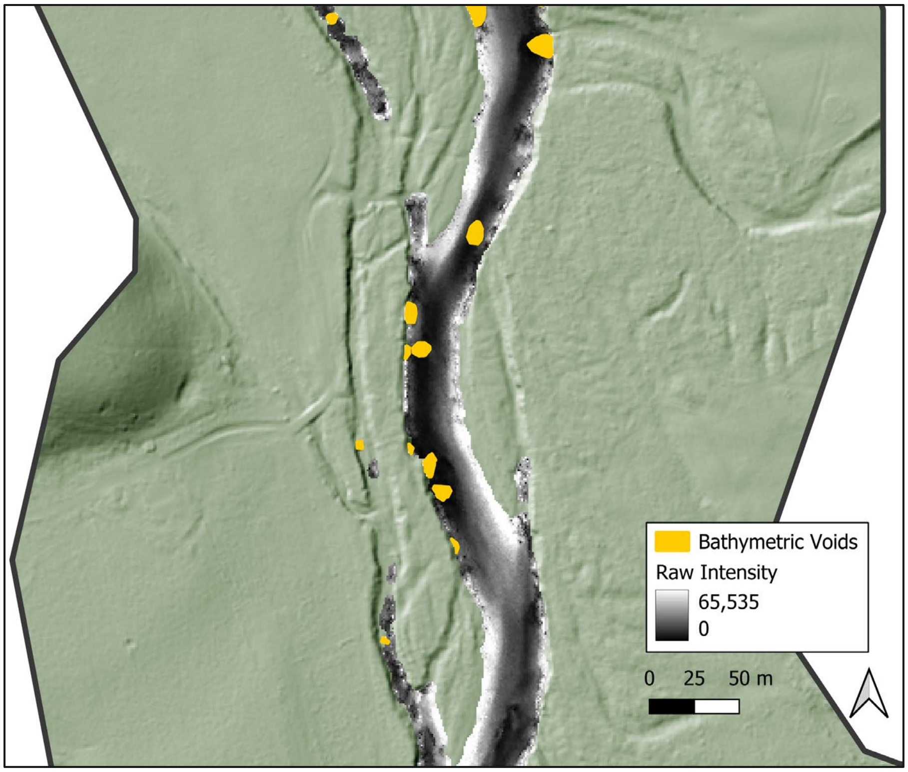


Figure 23: An example of Raw Bathymetric Bottom Intensity values

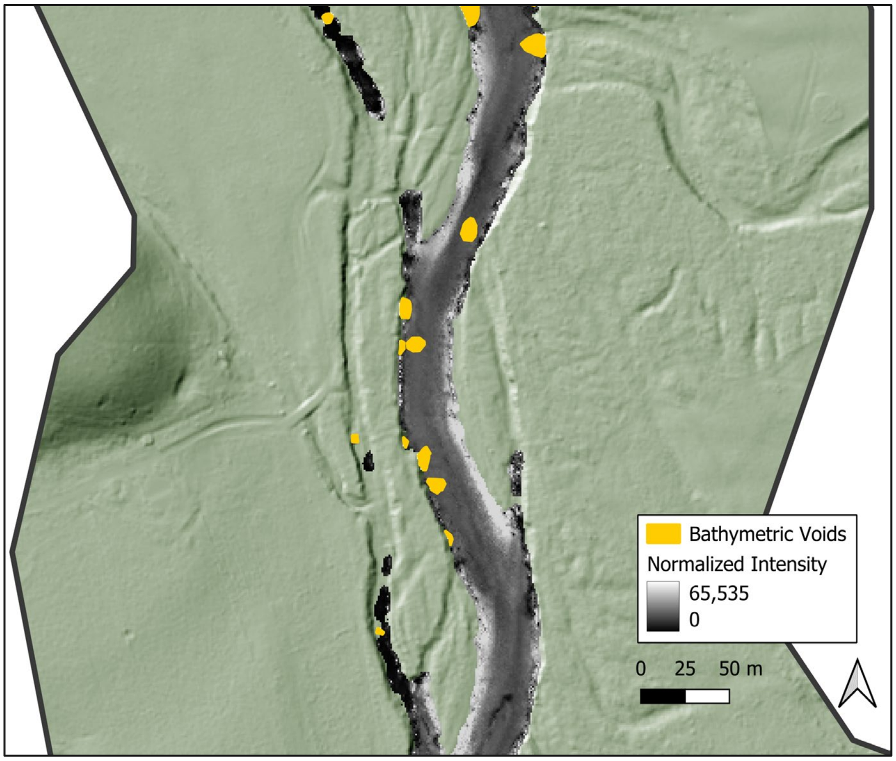
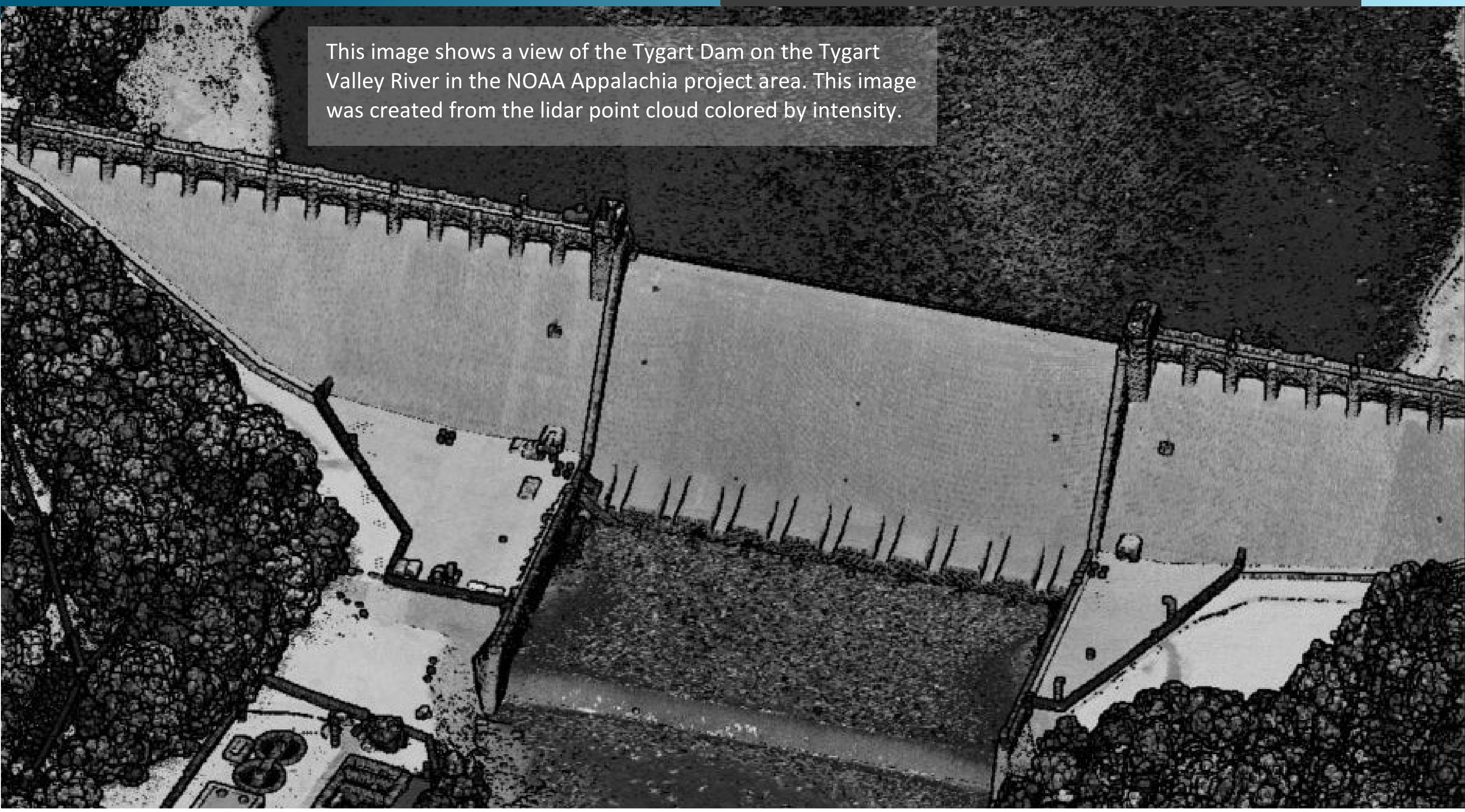


Figure 24: An example of bathymetric bottom intensity values that were normalized for depth, angle of incidence, and absolute flying altitude



This image shows a view of the Tygart Dam on the Tygart Valley River in the NOAA Appalachia project area. This image was created from the lidar point cloud colored by intensity.

Bathymetric Lidar

An underlying principle for collecting hydrographic lidar data is to survey near-shore areas that can be difficult to collect with other methods, such as multi-beam sonar, particularly over large areas. The capability and effectiveness of the bathymetric lidar is impacted by several parameters including depth penetrations below the water surface, bathymetric return density, and spatial accuracy.

Mapped Bathymetry and Depth Penetration

Under optimal conditions, the specified depth penetration range of the CH4X and CH5 sensors are about 1.5 and 1.8 Secchi depths, respectively; therefore, bathymetry data below these depths at the time of acquisition are not to be expected. To assist in evaluating performance results of the sensor, a polygon layer was created to delineate areas where bathymetry was successfully mapped.

This shapefile was used to control the extent of the delivered clipped topo-bathymetric model and to avoid false triangulation across areas in the water with no returns. Insufficiently mapped areas were identified by triangulating bathymetric bottom points with an edge length maximum of 4.56 meters. This ensured all areas of no returns (> 9 m^2) were identified as data voids. Overall NV5 successfully mapped

55.36% of the bathymetric areas in the entire NOAA Appalachia AOI. The percentage covered for each delivery project area was 28.50%, 54.90%, 58.19%, and 73.55% for the D1 through D4 project areas, respectively.

Lidar Point Density

First Return Point Density

The acquisition parameters were designed to acquire an average first-return density of 8 points/m^2 in terrestrial areas and 3 points/m^2 for bathymetric areas. First return density describes the density of pulses emitted from the laser that return at least one echo to the system. Multiple returns from a single pulse were not considered in first return density analysis. Some types of surfaces (e.g., breaks in terrain, water, and steep slopes) may have returned fewer pulses than originally emitted by the laser.

First returns typically reflect off the highest feature on the landscape within the footprint of the pulse. In forested or urban areas, the highest feature could be a tree, building, or power line, while in areas of unobstructed ground, the first return will be the only echo and represents the bare earth surface.

The average first-return density of the cumulative NOAA Appalachia lidar project was 23.86 points/m^2 for the NIR sensor and 4.34 points/m^2 for the green sensors (Table 12). The statistical and spatial distributions of all first return densities per 100 m x 100 m cell for the cumulative project area are portrayed in Figure 25 to Figure 27 and Figure 29 to Figure 33.

Bathymetric and Ground Classified Point Densities

The density of ground classified lidar returns and bathymetric bottom returns were also analyzed for this project. Terrain character, land cover, and ground surface reflectivity all influenced the density of ground surface returns. In vegetated areas, fewer pulses may have penetrated the tree canopy, resulting in lower ground density. Similarly, the density of bathymetric bottom returns was influenced by turbidity, depth, and bottom surface reflectivity. In turbid areas, fewer pulses may have penetrated the water surface, resulting in lower bathymetric density.

The ground and bathymetric bottom classified density of lidar data for the NOAA Appalachia project was 9.01 points/m^2. The return density for each delivery is shown in Table 12. The statistical and spatial distributions per 100 m x 100 m cell of the ground and bathymetric bottom classified return densities are portrayed in Figure 28 and Figure 33 through Figure 37.

Additionally, for the NOAA Appalachia project, density values of only bathymetric bottom returns were calculated for areas containing at least one bathymetric bottom return. Areas lacking bathymetric returns (voids) were not considered in calculating an average density value. Within the successfully mapped area for the entire project, a bathymetric bottom return density of 7.63 points/m^2 was achieved. Figure 29 displays the statistical distribution for the bathymetric bottom classified return density without the ground classified data.

Table 12: Average lidar point densities

Delivery	NIR First Returns	Green First Returns	Combined First Returns	Ground and Bathymetric Bottom Classified Returns	Bathymetric Bottom Classified Returns
D1	22.14 points/m^2	3.92 points/m^2	26.06 points/m^2	8.94 points/m^2	7.13 points/m^2
D2	25.94 points/m^2	4.30 points/m^2	30.24 points/m^2	9.64 points/m^2	7.37 points/m^2
D3	23.66 points/m^2	4.88 points/m^2	28.54 points/m^2	8.35 points/m^2	7.90 points/m^2
D4	23.40 points/m^2	4.18 points/m^2	27.58 points/m^2	9.10 points/m^2	7.74 points/m^2
Cumulative	23.86 points/m^2	4.34 points/m^2	28.20 points/m^2	9.01 points/m^2	7.63 points/m^2

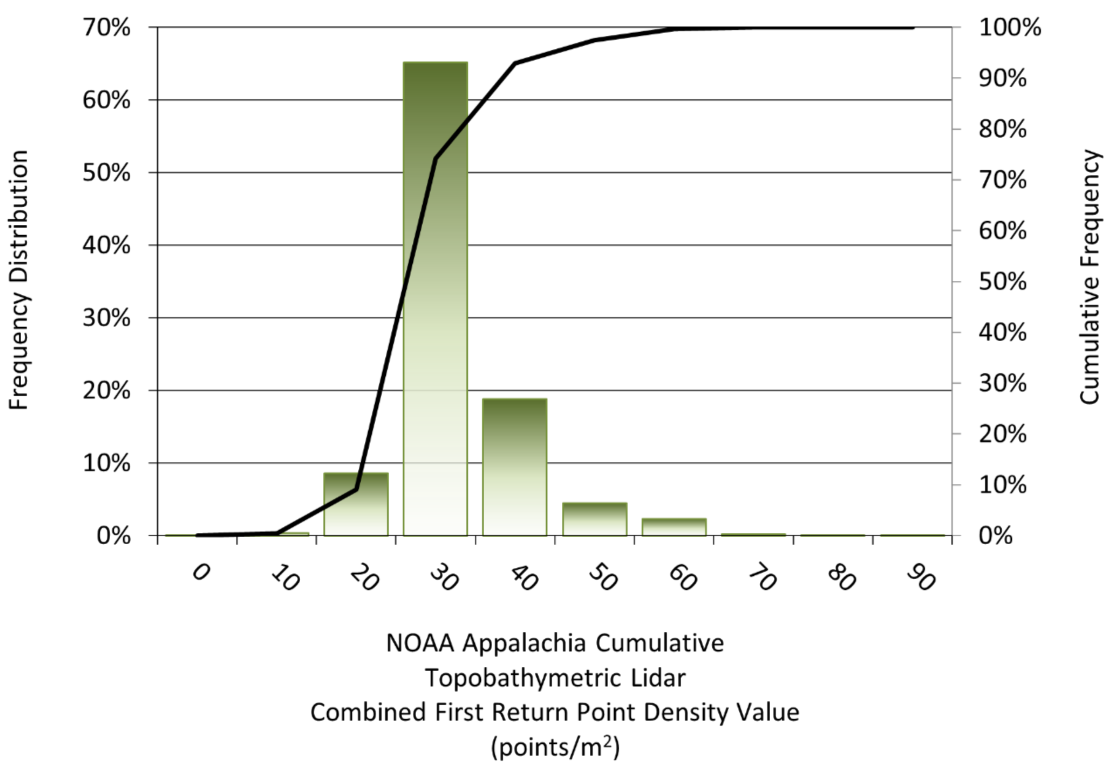


Figure 25: Frequency distribution of first return densities per 100 x 100 m cell for all the sensors

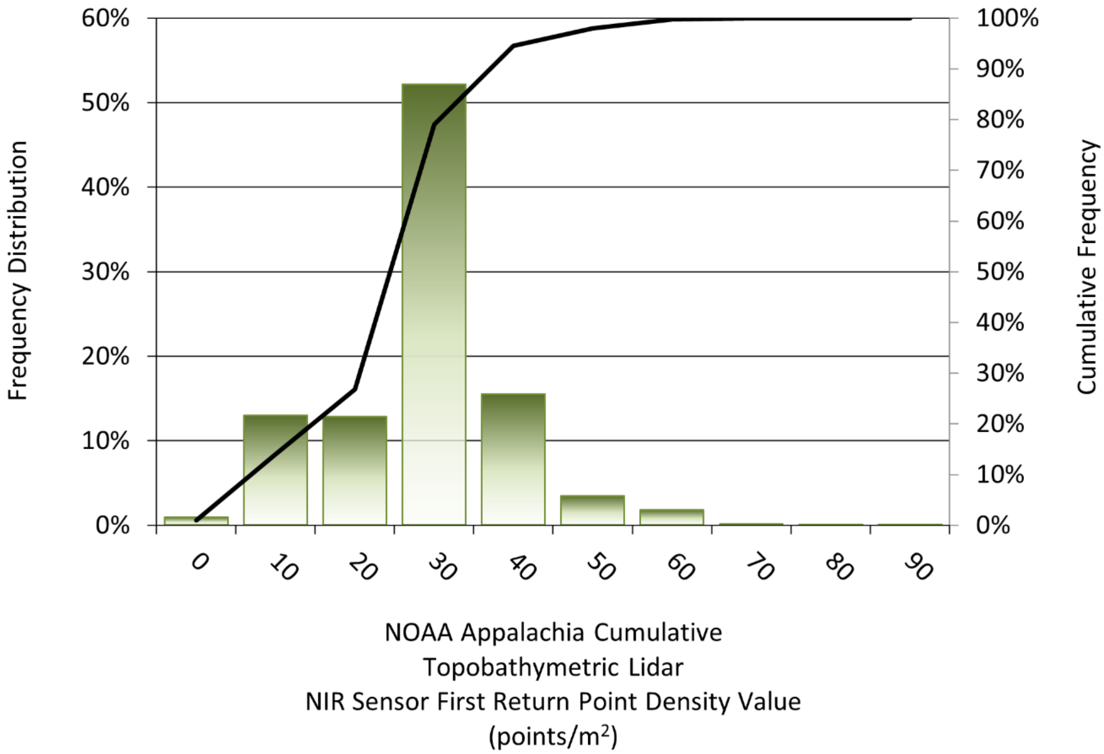


Figure 26: Frequency distribution of first return densities per 100 x 100 m cell for the NIR sensor

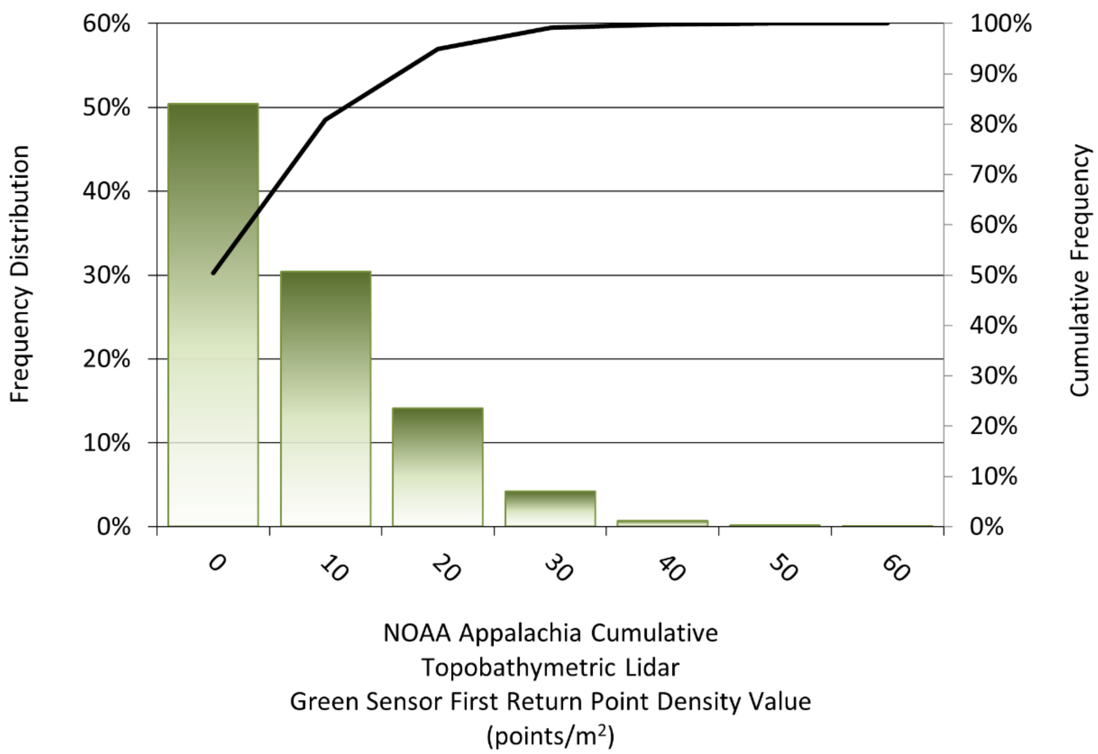


Figure 27: Frequency distribution of first return densities per 100 x 100 m cell for the green sensor

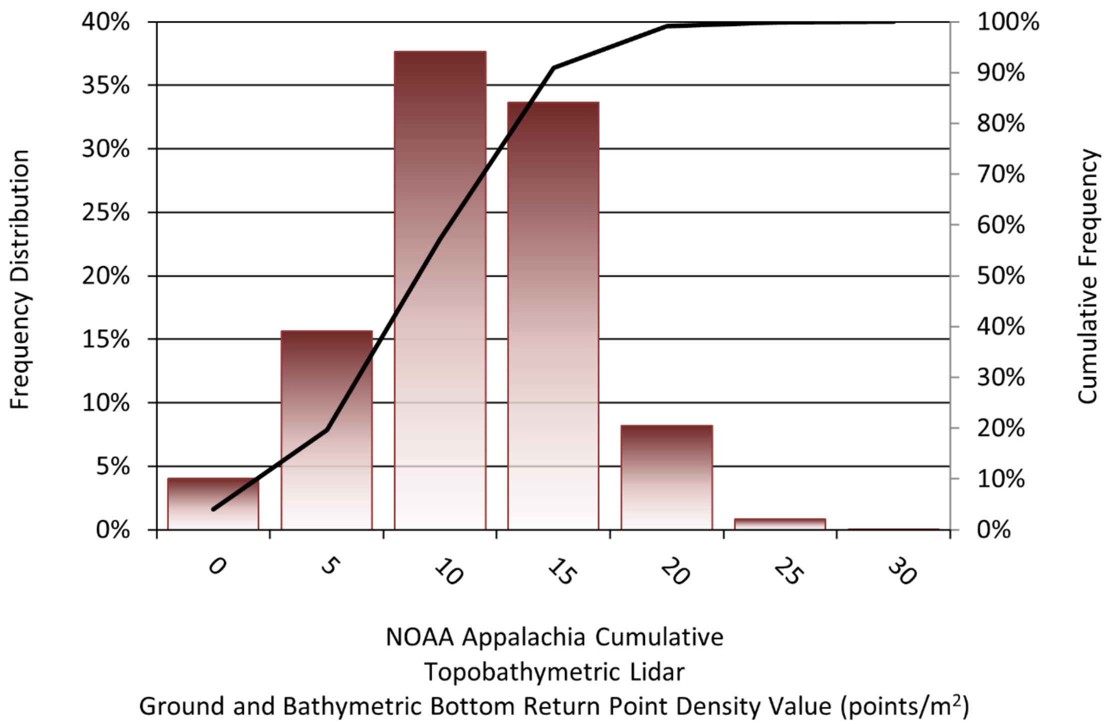


Figure 28: Frequency distribution of ground and bathymetric bottom classified return densities per 100 x 100 m cell for all the sensors

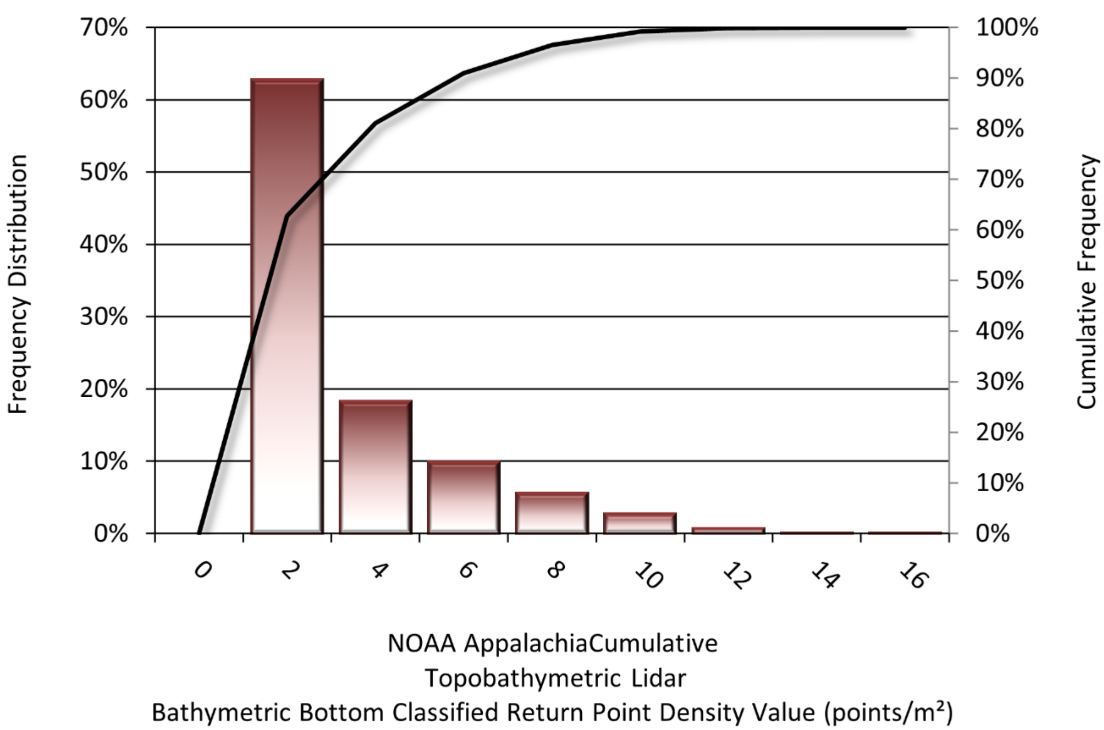


Figure 29: Frequency distribution of bathymetric bottom classified return densities per 100 x 100 m cell for all the sensors

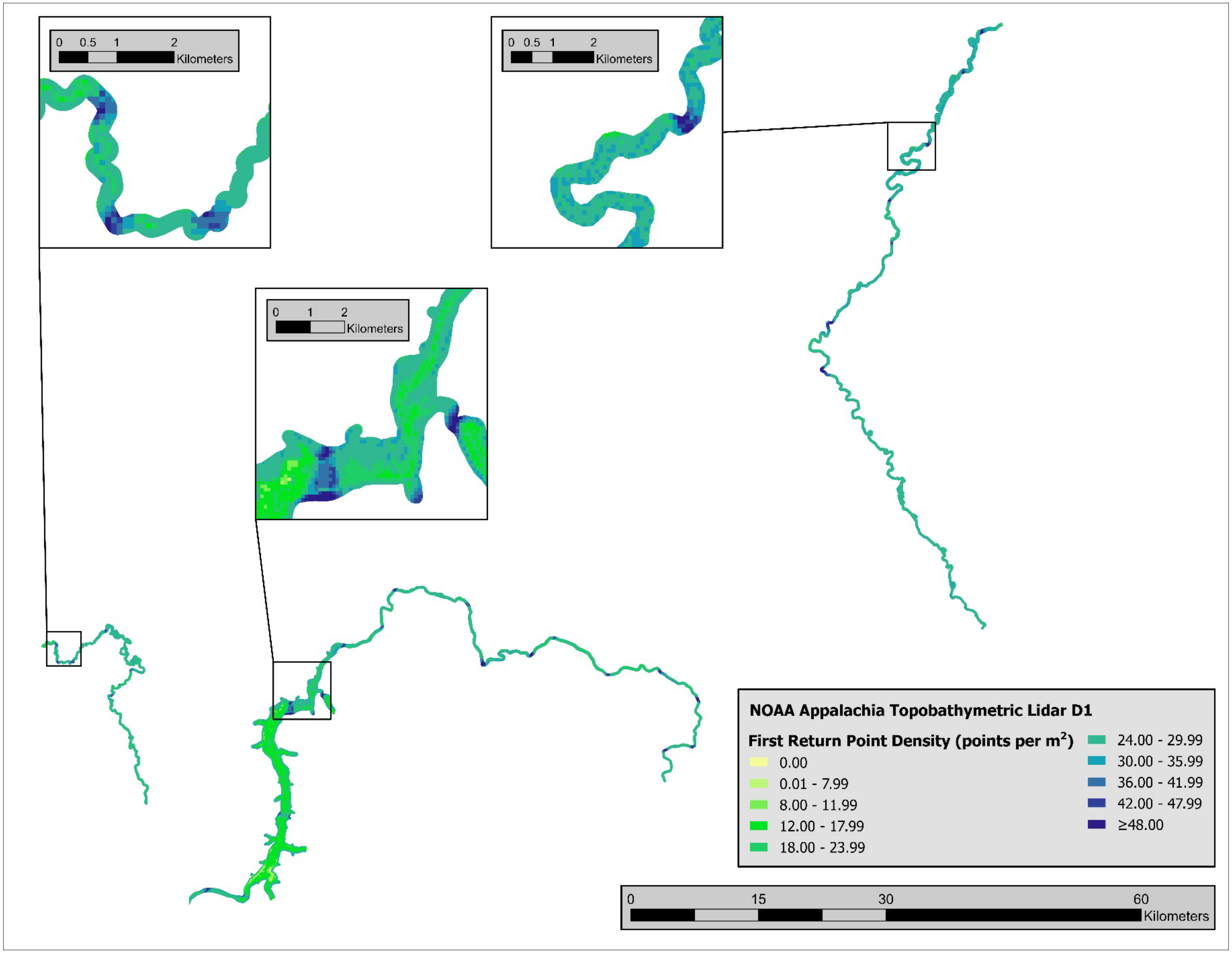


Figure 30: First return density map for the D1 NOAA Appalachia site (100 m x 100 m cells)

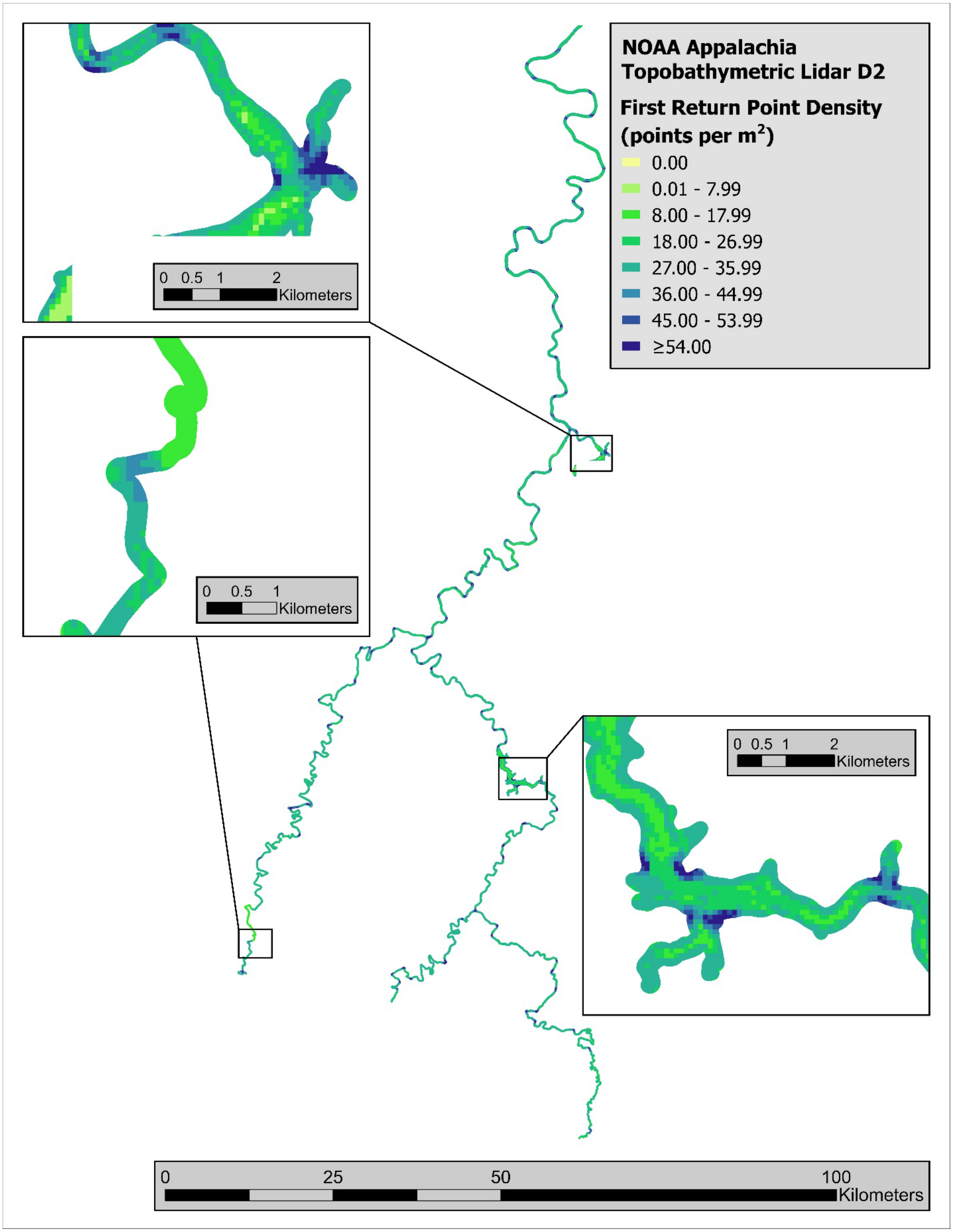


Figure 31: First return density map for the D2 NOAA Appalachia site (100 m x 100 m cells)

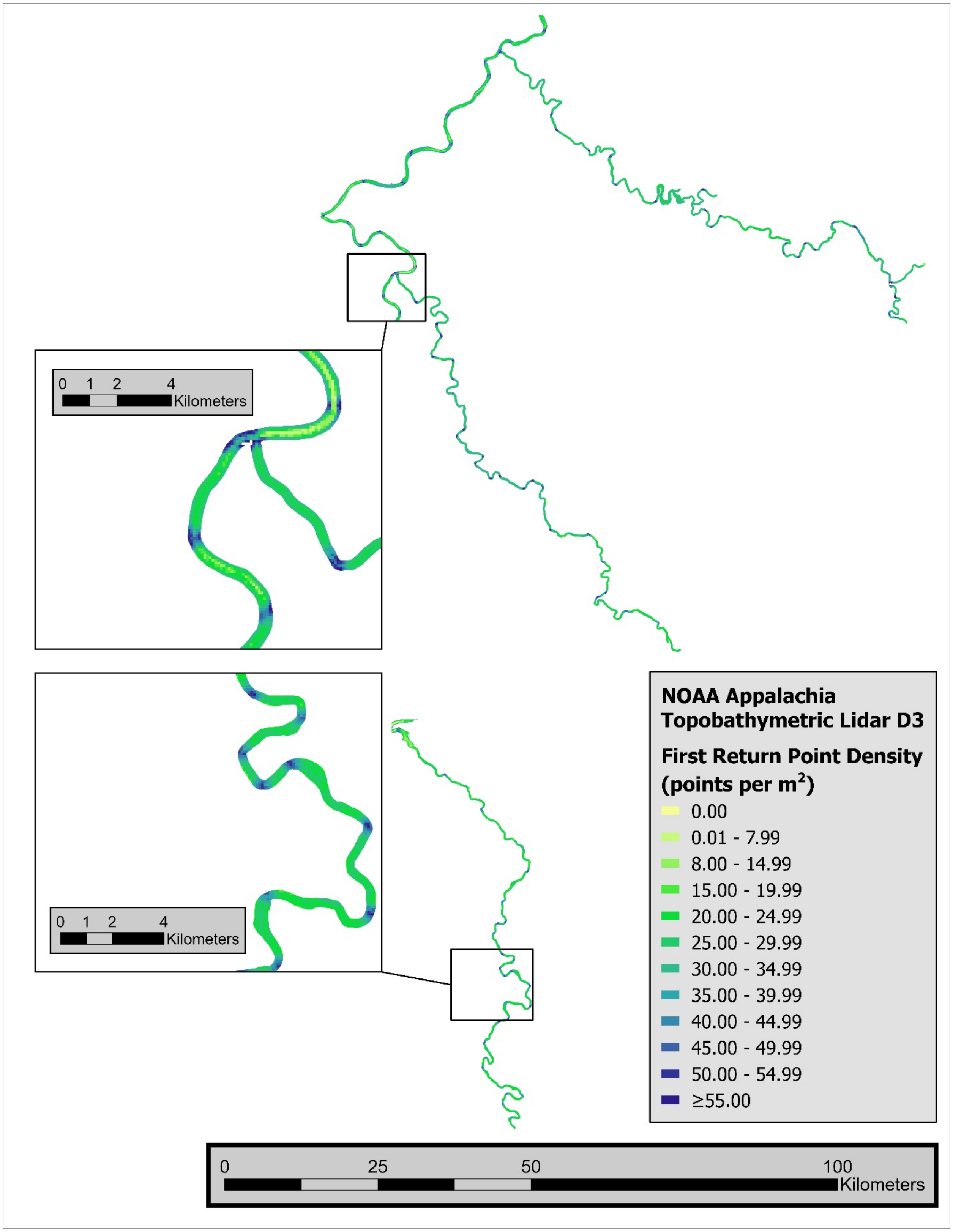


Figure 32: First return density map for the D3 NOAA Appalachia site (100 m x 100 m cells)

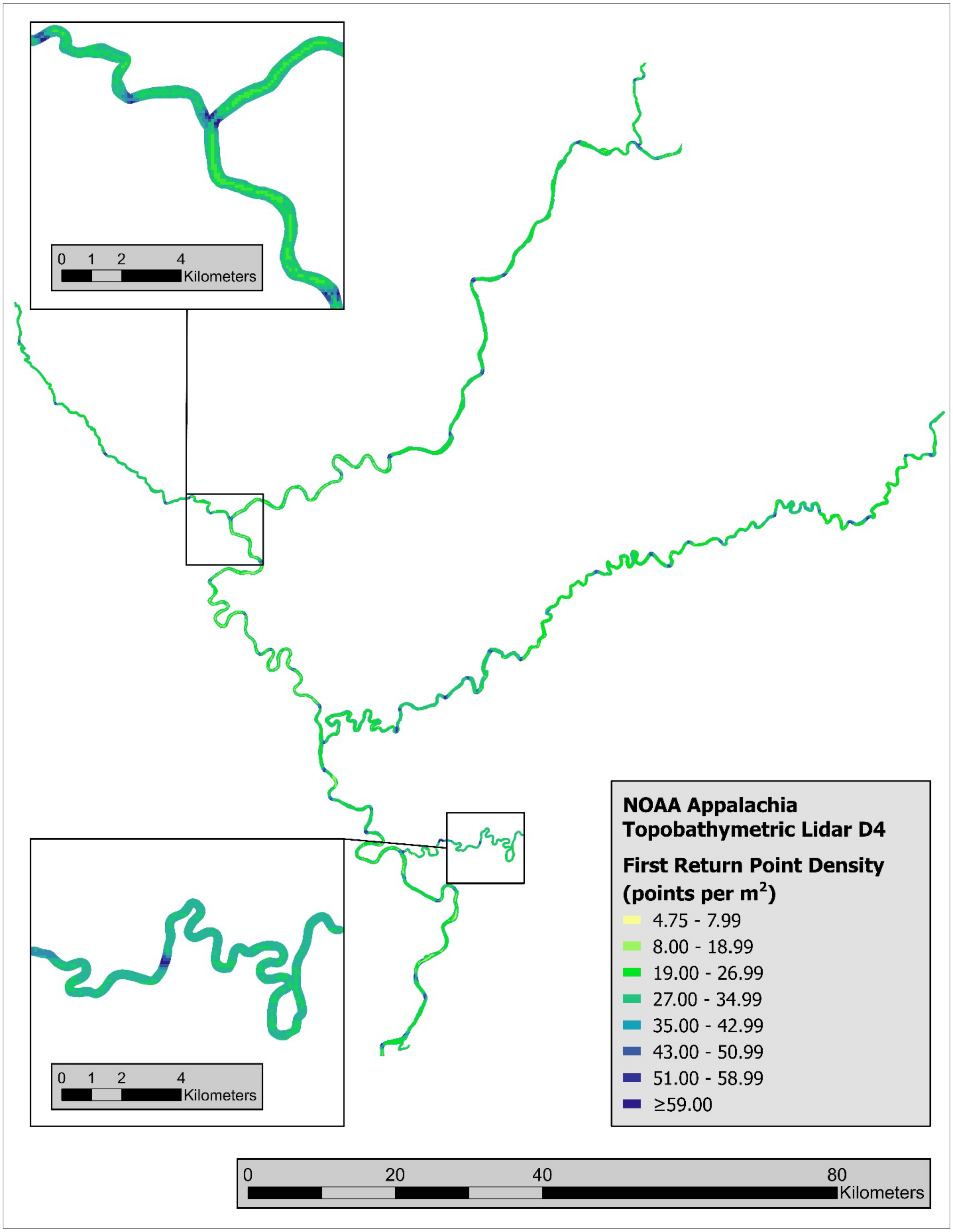


Figure 33: First return density map for the D4 NOAA Appalachia site (100 m x 100 m cells)

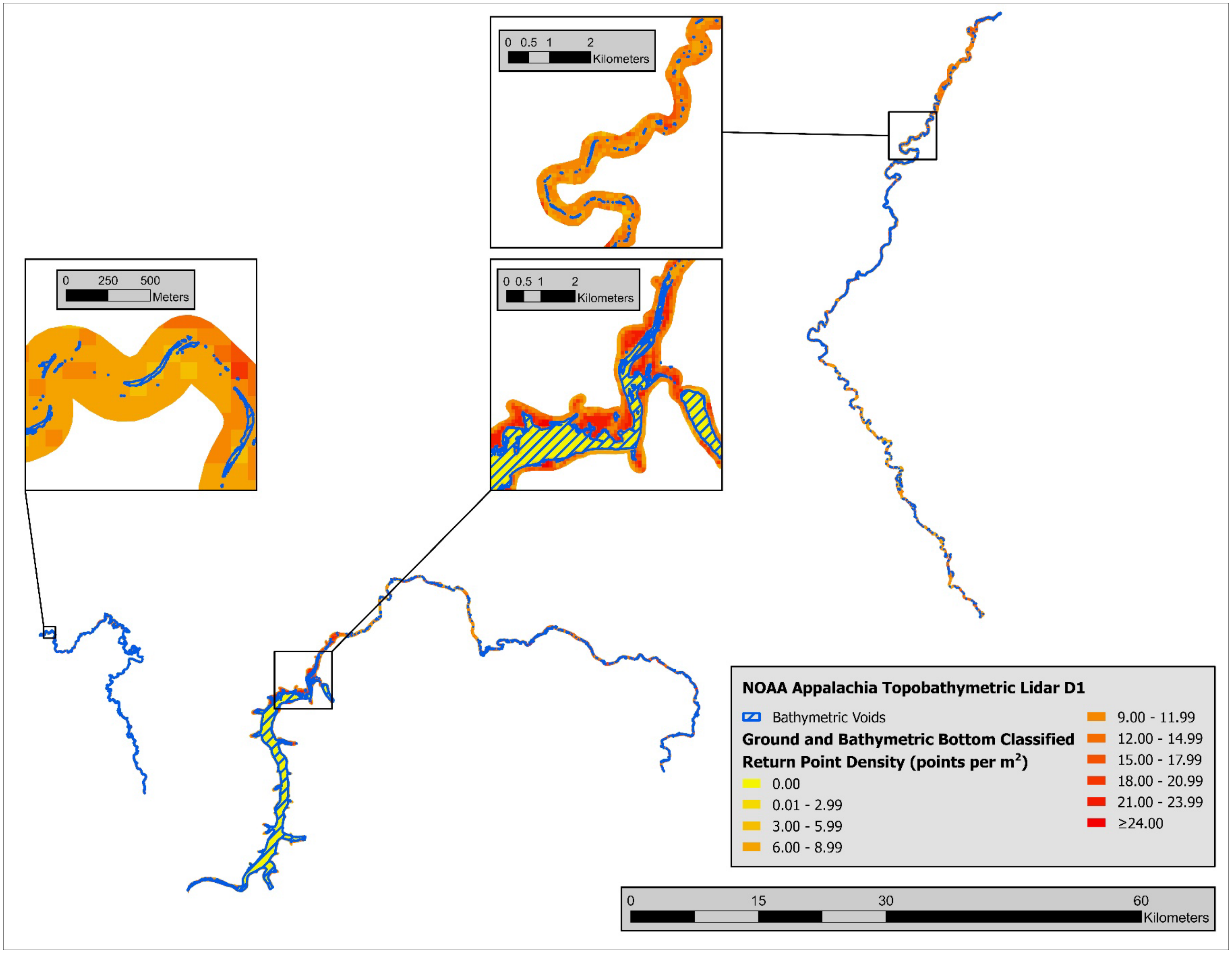


Figure 34: Ground and bathymetric bottom density map for the D1 NOAA Appalachia site (100 m x 100 m cells)

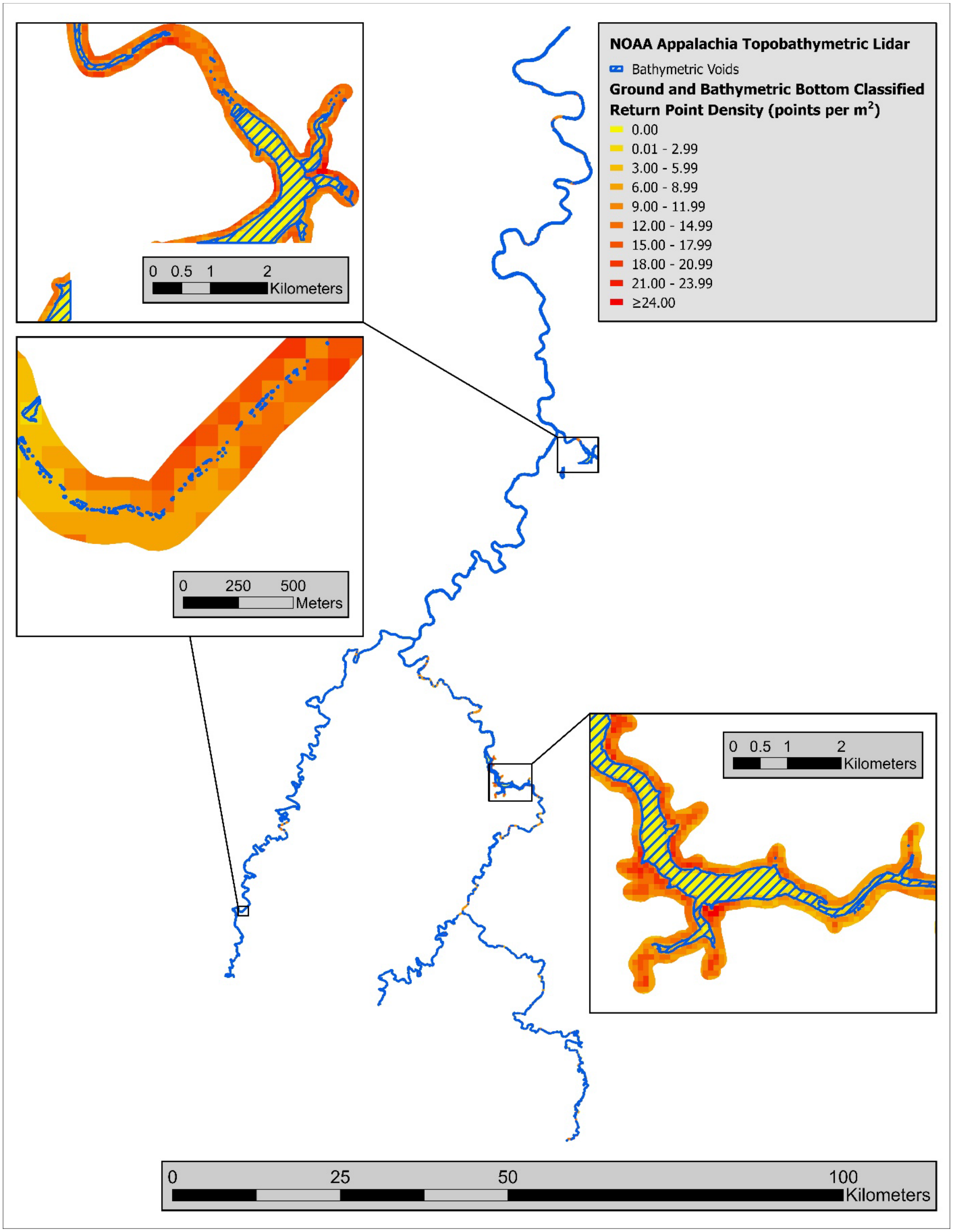


Figure 35: Ground and bathymetric bottom density map for the D2 NOAA Appalachia site (100 m x 100 m cells)

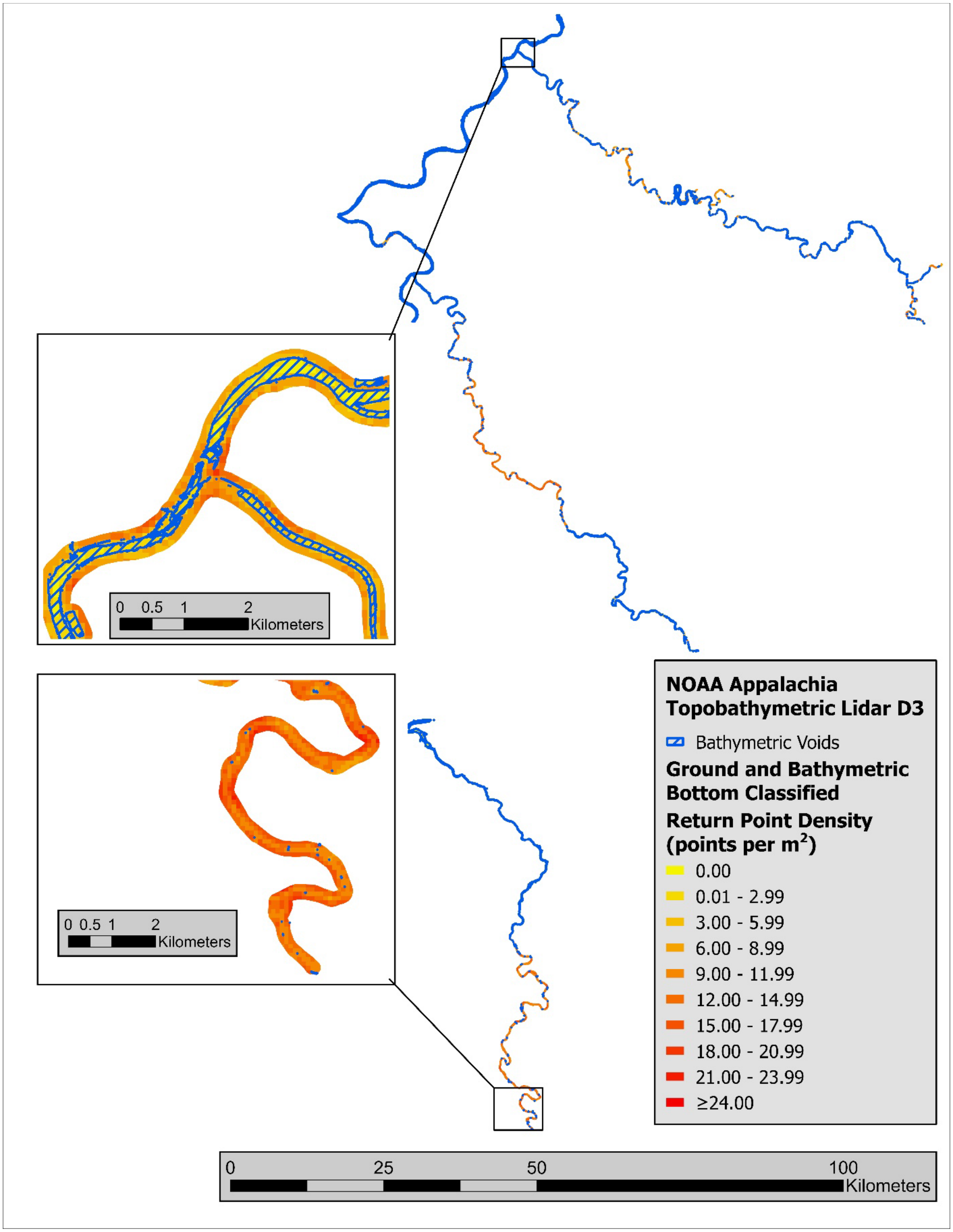


Figure 36: Ground and bathymetric bottom density map for the D3 NOAA Appalachia site (100 m x 100 m cells)

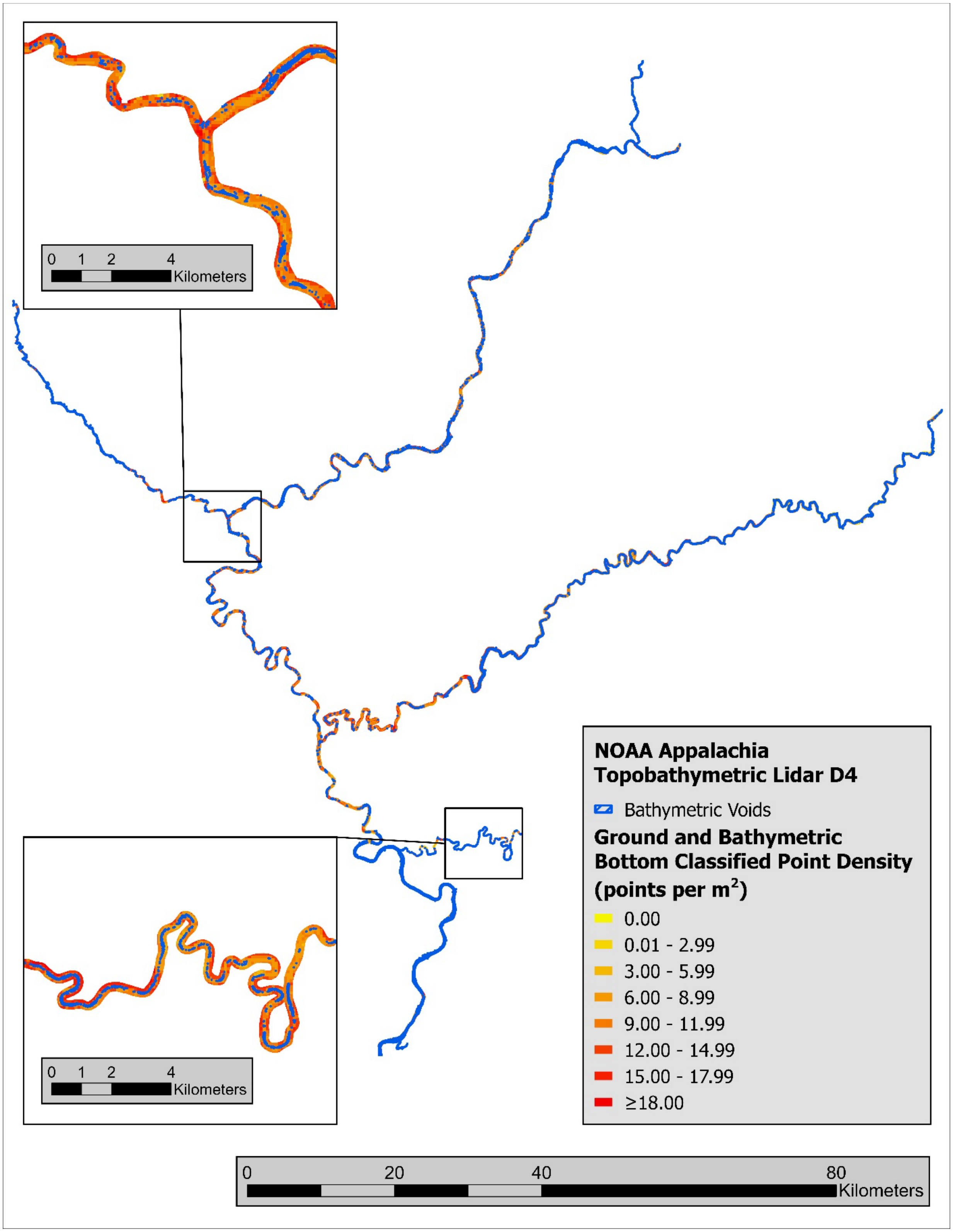


Figure 37: Ground and bathymetric bottom density map for the D4 NOAA Appalachia site (100 m x 100 m cells)

Lidar Accuracy Assessments

The accuracy of the lidar data collection can be described in terms of absolute accuracy (the consistency of the data with external data sources) and relative accuracy (the consistency of the dataset with itself). See Appendix A for further information on sources of error and operational measures used to improve relative accuracy.

Lidar Non-Vegetated Vertical Accuracy

Absolute accuracy was assessed using Non-Vegetated Vertical Accuracy (NVA) reporting designed to meet guidelines presented in the FGDC National Standard for Spatial Data Accuracy.[3] NVA compares known ground checkpoint data that were withheld from the calibration and post-processing of the lidar point cloud to the triangulated surface generated by the classified lidar point cloud as well as the derived gridded bare earth DEM. NVA is a measure of the accuracy of lidar point data in open areas where the lidar system has a high probability of measuring the ground surface and is evaluated at the 95% confidence interval (1.96 * RMSE), as shown in Table 13 through Table 15.

The mean and standard deviation (sigma σ) of divergence of the ground surface model from ground check point coordinates are also considered during accuracy assessment. These statistics assume the error for x, y and z is normally distributed, and therefore the skew and kurtosis of distributions are also considered when evaluating error statistics. For the cumulative NOAA Appalachia survey, 77 ground checkpoints were withheld from the calibration and post-processing of the lidar point cloud, with resulting non-vegetated vertical accuracy of 0.088 meters as compared to the classified LAS, and 0.090 meters against the bare earth DEM, with 95% confidence (Figure 38 and Figure 39).

NV5 also assessed absolute accuracy using 265 ground control points. Although these points were used in the calibration and post-processing of the lidar point cloud, they still provide a good indication of the overall accuracy of the lidar dataset and have therefore been provided in Table 15 and Figure 40.

Table 13: NVA, as compared to Classified LAS

Delivery	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	17 points	0.064 m	0.006 m	0.006 m	0.033 m	0.033 m
D2	30 points	0.108 m	-0.040 m	-0.036 m	0.055 m	0.039 m
D3	15 points	0.048 m	-0.015 m	-0.013 m	0.024 m	0.020 m
D4	15 points	0.097 m	0.034 m	0.037 m	0.050 m	0.038 m
Cumulative	77 points	0.088 m	-0.011 m	-0.013 m	0.045 m	0.044 m

[3] Federal Geographic Data Committee, ASPRS POSITIONAL ACCURACY STANDARDS FOR DIGITAL GEOSPATIAL DATA Edition 2, Version 2, 2024. https://publicdocuments.asprs.org/PositionalAccuracyStd-Ed2-V2

Table 14: NVA, as compared to bare earth DEM

Delivery	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	17 points	0.065 m	0.006 m	0.004 m	0.033 m	0.034 m
D2	30 points	0.110 m	-0.043 m	-0.048 m	0.056 m	0.037 m
D3	15 points	0.045 m	-0.013 m	-0.013 m	0.023 m	0.019 m
D4	15 points	0.100 m	0.036 m	0.045 m	0.051 m	0.038 m
Cumulative	77 points	0.090 m	-0.011 m	-0.013 m	0.046 m	0.045 m

Table 15: Ground control points

Delivery	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	36 points	0.043 m	0.004 m	0.003 m	0.022 m	0.022 m
D2	95 points	0.090 m	-0.011 m	-0.020 m	0.046 m	0.045 m
D3	82 points	0.060 m	0.002 m	0.003 m	0.031 m	0.031 m
D4	52 points	0.082 m	0.022 m	0.023 m	0.042 m	0.036 m
Cumulative	265 points	0.075 m	0.001 m	-0.001 m	0.038 m	0.038 m

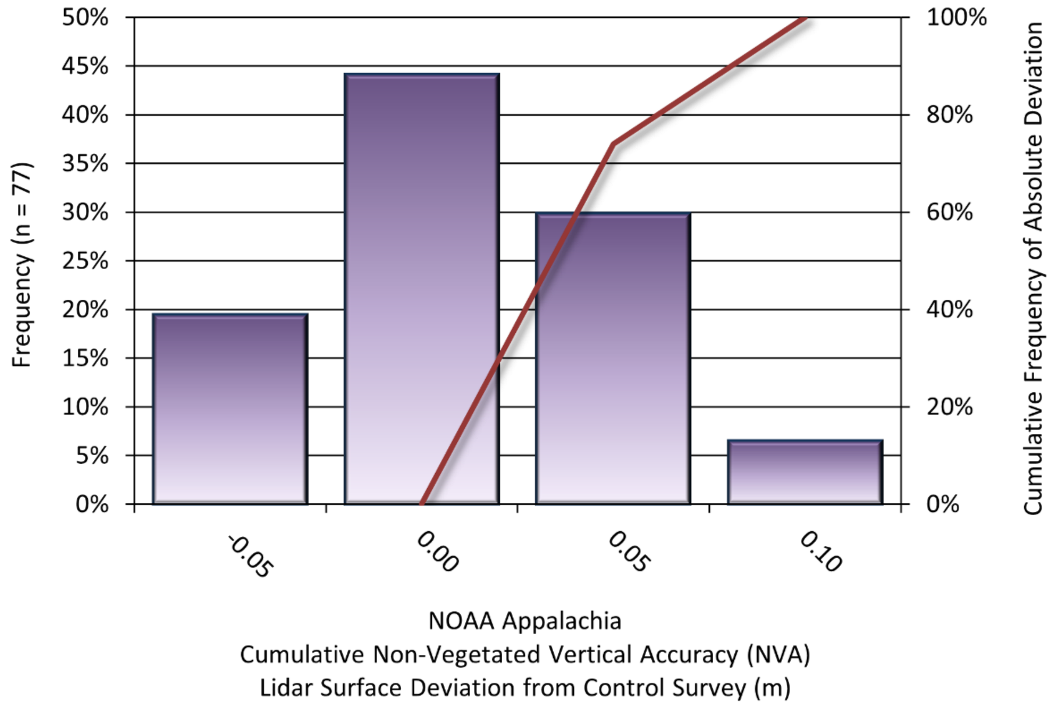


Figure 38: Frequency histogram for classified LAS deviation from ground checkpoint values

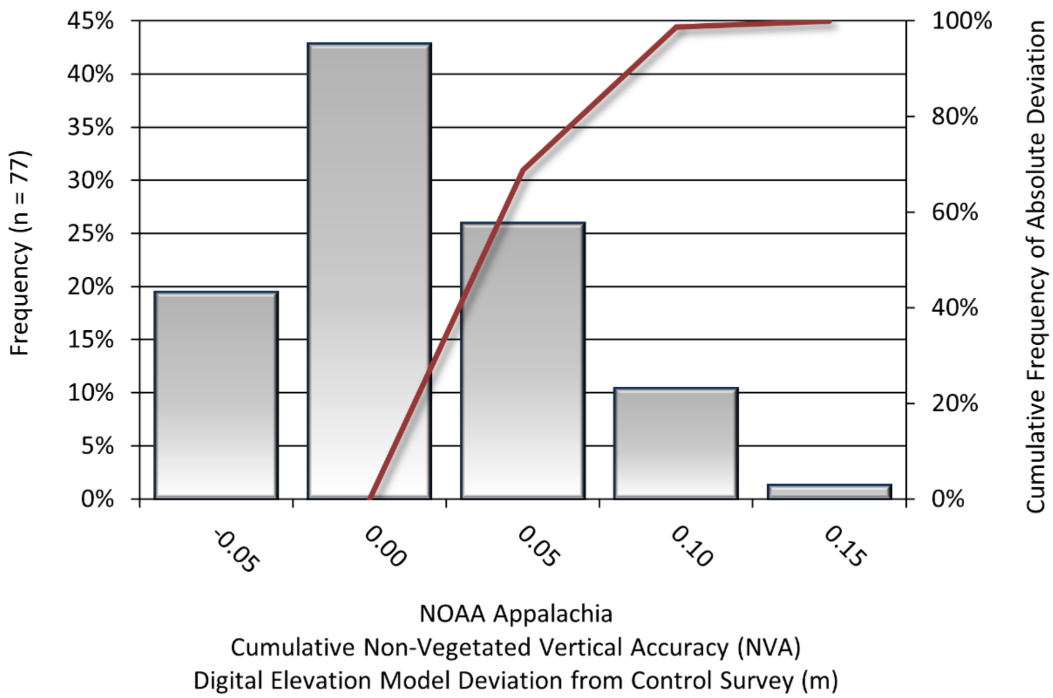


Figure 39: Frequency histogram for lidar bare earth DEM deviation from ground checkpoint values

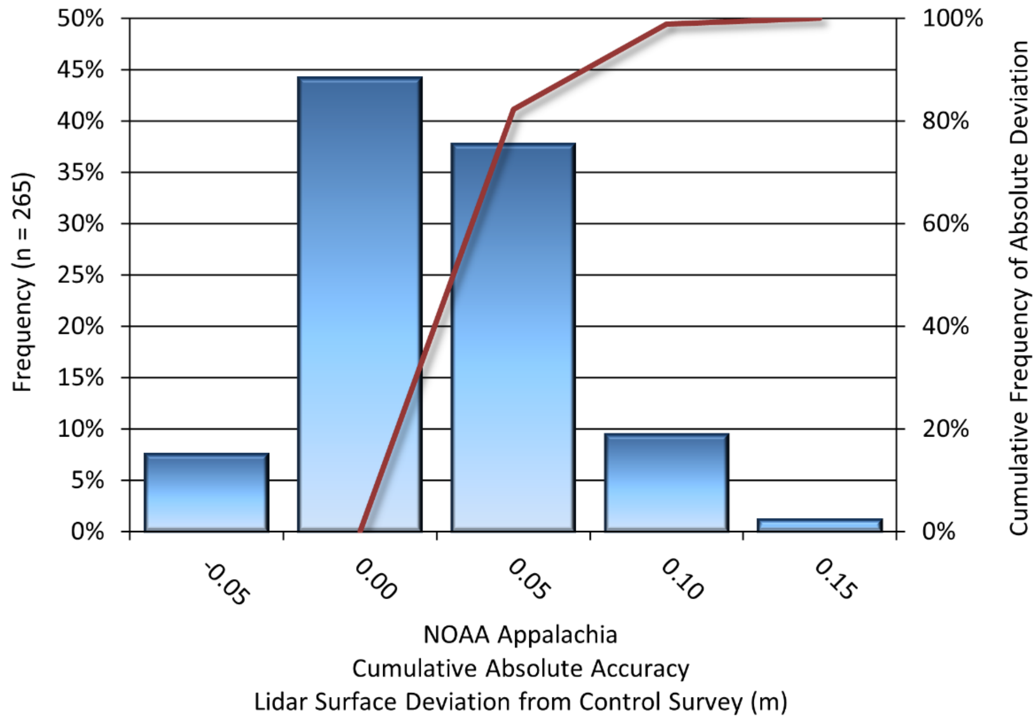


Figure 40: Frequency histogram for lidar surface deviation ground control point values

Lidar Vegetated Vertical Accuracies

NV5 also assessed vertical accuracy using Vegetated Vertical Accuracy (VVA) reporting. VVA compares known ground checkpoint data collected over vegetated surfaces using land class descriptions to the triangulated ground surface generated by the ground classified lidar points. Unlike in non-vegetated areas, the errors associated with data collected in vegetated areas cannot be assumed to approximate a normal distribution. For the NOAA Appalachia survey, 61 vegetated checkpoints were collected, with resulting vegetated vertical accuracy of 0238 meters as compared to the classified LAS, and 0.258 meters as compared to the bare earth DEM evaluated at the 95th percentile (Table 16, Table 17, Figure 41, and Figure 42).

Table 16: VVA, as compared to classified LAS

Delivery	Sample	95th Percentile	Average	Median	RMSE	Standard Deviation (1σ)
D1	24 points	0.185 m	0.082 m	0.066 m	0.107 m	0.071 m
D2	19 points	0.273 m	0.102 m	0.126 m	0.151 m	0.114 m
D3	3 points	0.081 m	0.053 m	0.046 m	0.058 m	0.029 m
D4	15 points	0.185 m	0.083 m	0.075 m	0.102 m	0.061 m
Cumulative	61 points	0.238 m	0.087 m	0.073 m	0.120 m	0.083 m

Table 17: VVA, as compared to Bare Earth DEM

Delivery	Sample	95th Percentile	Average	Median	RMSE	Standard Deviation (1σ)
D1	24 points	0.222 m	0.087 m	0.065 m	0.117 m	0.080 m
D2	19 points	0.264 m	0.099 m	0.105 m	0.148 m	0.113 m
D3	3 points	0.088 m	0.077 m	0.075 m	0.077 m	0.012 m
D4	15 points	0.205 m	0.079 m	0.067 m	0.104 m	0.070 m
Cumulative	61 points	0.258 m	0.088 m	0.067 m	0.123 m	0.087 m

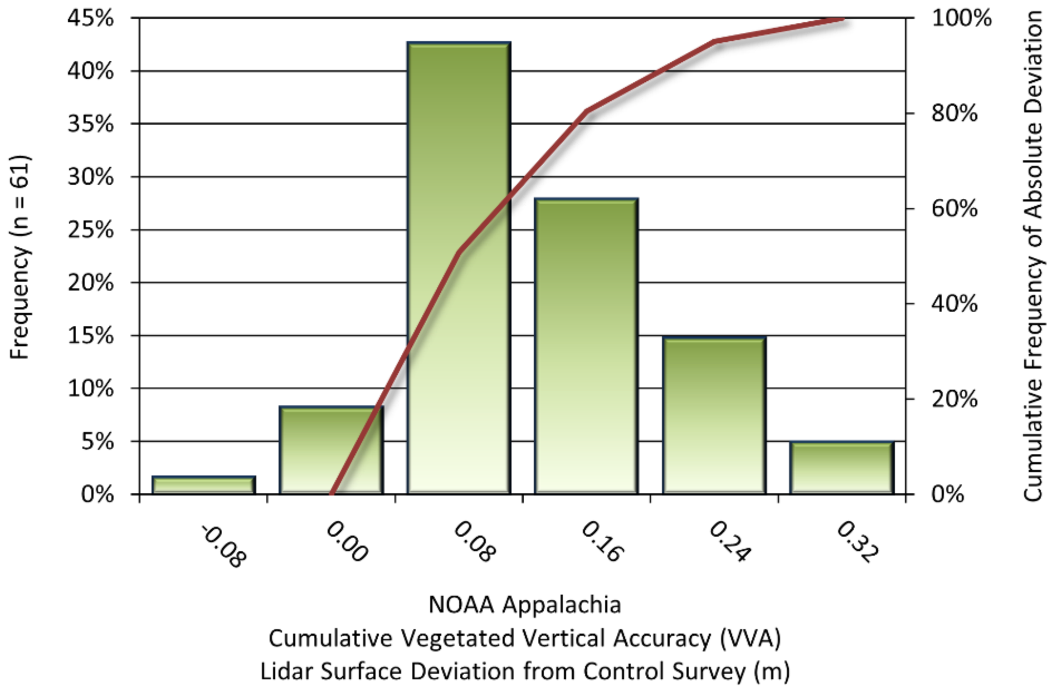


Figure 41: Frequency histogram for lidar surface deviation from all land cover class point values (VVA)

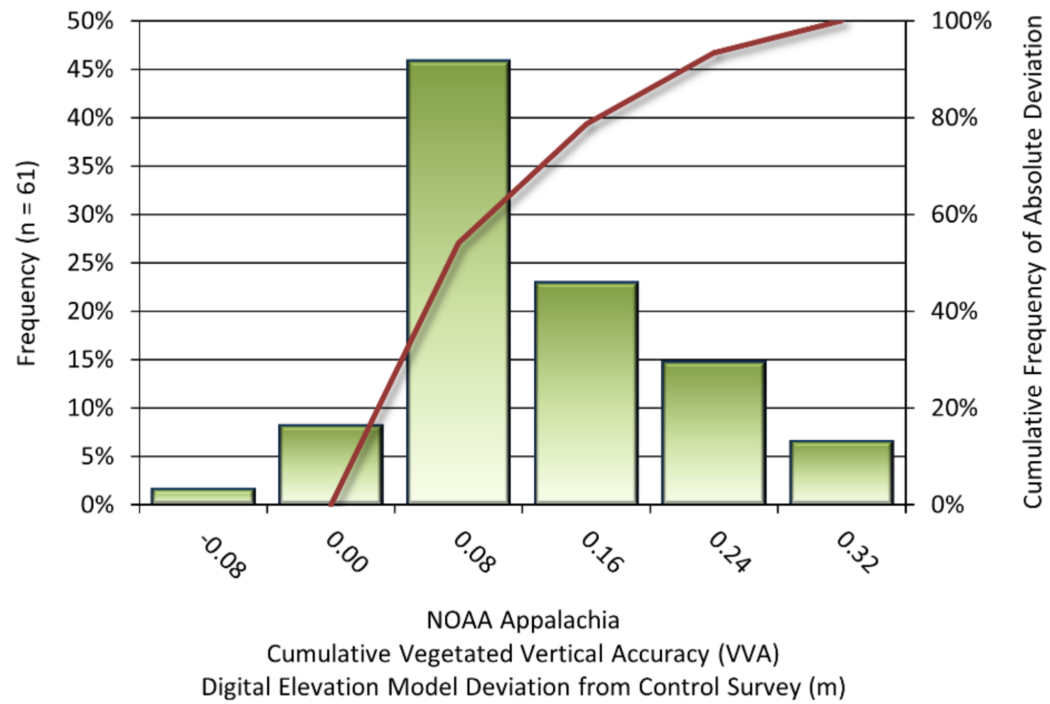


Figure 42: Frequency histogram for the lidar bare earth DEM deviation from vegetated checkpoint values (VVA)

Lidar Bathymetric Vertical Accuracies

Bathymetric (submerged or along the water's edge) checkpoints were also collected in order to assess the submerged surface vertical accuracy. Assessment of 3,018 submerged bathymetric checkpoints resulted in a vertical accuracy of 0.170 meters, evaluated at 95% confidence interval (Table 18, Figure 43).

Table 18: Bathymetric Vertical Accuracy for the NOAA Appalachia project

Delivery	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	362 points	0.170 m	0.030 m	0.015 m	0.087 m	0.082 m
D2	1067 points	0.177 m	-0.014 m	-0.019 m	0.090 m	0.089 m
D3	1029 points	0.163 m	0.024 m	0.020 m	0.083 m	0.080 m
D4	560 points	0.169 m	0.056 m	0.048 m	0.086 m	0.066 m
Cumulative	3018 points	0.170 m	0.017 m	0.013 m	0.087 m	0.085 m

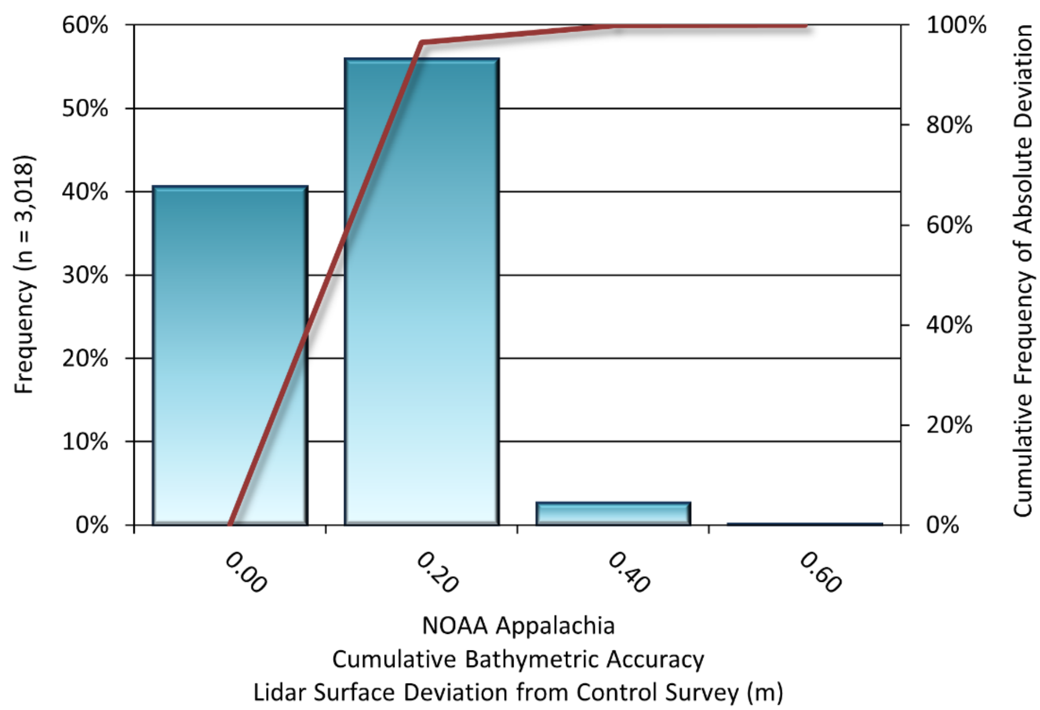


Figure 43: Frequency histogram for lidar surface deviation from submerged checkpoint values

Lidar Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the dataset as a whole: the ability to place an object in the same location given multiple flightlines, GPS conditions, and aircraft attitudes. When the lidar system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flightline with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the cumulative NOAA Appalachia lidar project was 0.022 meters (Table 19, Figure 44).

Table 19: Relative accuracy

Delivery	Sample	95% Confidence (1.96*RMSE)	Average	Median	RMSE	Standard Deviation (1σ)
D1	1152 flightline surfaces	0.064 m	0.024 m	0.027 m	0.052 m	0.033 m
D2	2413 flightline surfaces	0.063 m	0.022 m	0.025 m	0.052 m	0.032 m
D3	2336 flightline surfaces	0.014 m	0.016 m	0.018 m	0.021 m	0.007 m
D4	2246 flightline surfaces	0.054 m	0.027 m	0.031 m	0.047 m	0.028 m
Cumulative	8012 flightline surfaces	0.054 m	0.022 m	0.021 m	0.044 m	0.028 m

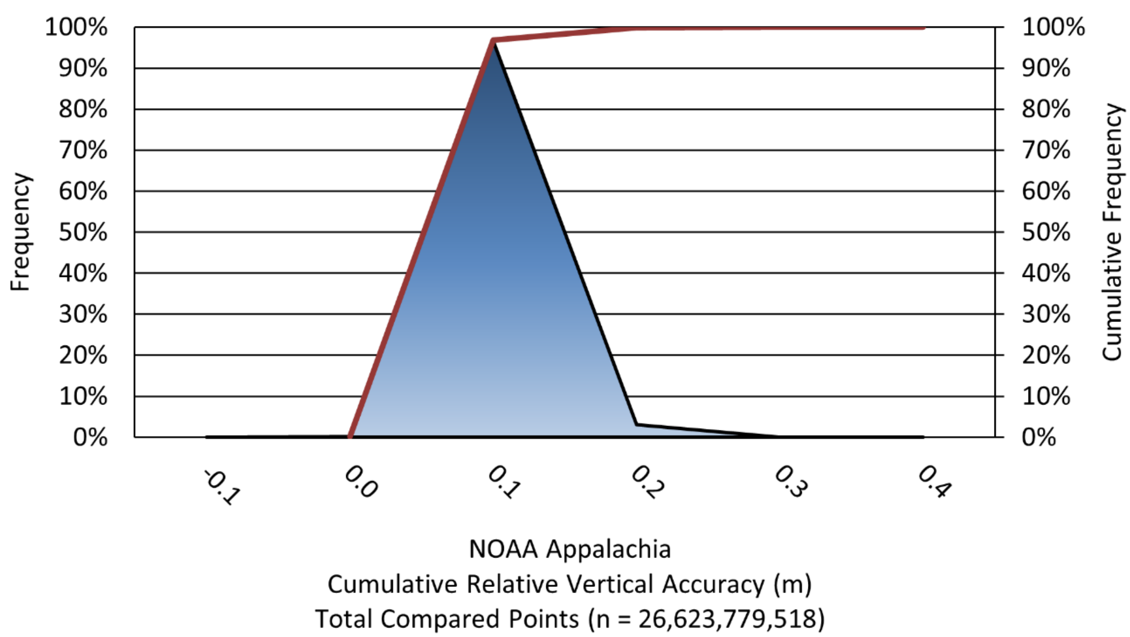


Figure 44: Frequency plot for relative vertical accuracy between flightlines

Lidar Horizontal Accuracy

Lidar horizontal accuracy is a function of Global Navigation Satellite System (GNSS) derived positional error, flying altitude, and inertial navigation system (INS) derived attitude error. The obtained $RMSE_r$ value is multiplied by a conversion factor of 1.7308 to yield the horizontal component of the National Standards for Spatial Data Accuracy (NSSDA) reporting standard where a theoretical point will fall within the obtained radius 95 percent of the time. Based on the parameters described in Table 20, summarized by sensor and flying altitude, this project was produced to meet between 0.023 meters and 0.034 meters horizontal accuracy at the 95% confidence level.

Table 20: Cumulative horizontal accuracy

Parameter	Green Sensor 400 m	Green Sensor 500 m	Green Sensor 600 m	NIR Sensor 400 m	NIR Sensor 500 m	NIR Sensor 600 m
IMU Error	0.001 degrees	0.001 degrees	0.001 degrees	0.001 degrees	0.001 degrees	0.001 degrees
GNSS Error	0.005 m	0.003 m	0.005 m	0.005 m	0.003 m	0.005 m
$RMSE_r$	0.013 m	0.016 m	0.019 m	0.013 m	0.016 m	0.019 m
ACC_r	0.023 m	0.028 m	0.034 m	0.023 m	0.028 m	0.034 m

CERTIFICATIONS

NV5 provided lidar services for the NOAA Appalachia project as described in this report.

I, Alex McManus, have reviewed the attached report for completeness and hereby state that it is a complete and accurate report of this project.

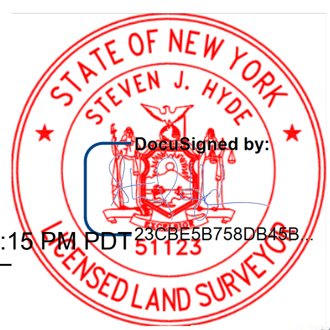
Signed by:
Alex McManus
1D65E3271523487... 6/17/2026 | 12:28 PM PDT

Alex McManus
Project Manager
NV5

I, Steven J. Hyde, PLS, being duly registered as a Professional Land Surveyor in and by the state of New York, Pennsylvania, and West Virginia hereby certify that the methodologies, static GNSS occupations used during airborne flights, and ground survey point collection were performed using commonly accepted Standard Practices. Field work conducted for this report was conducted between September 07, 2024, to August 05, 2025.

Accuracy statistics shown in the Accuracy Section of this Report have been reviewed by me and found to meet the "National Standard for Spatial Data Accuracy".

DocuSigned by:
23CBE5B758DB45B... 6/17/2026 | 2:15 PM PDT



Steven J. Hyde, PLS
NV5
Corvallis, OR 97330

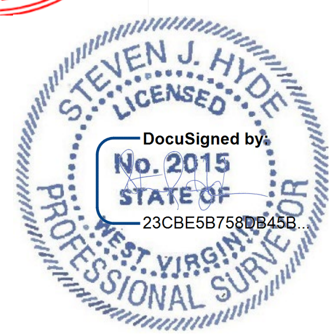


Figure 45: View looking south at Arden Falls on the Tygart Valley River in the NOAA Appalachia project area. The image was created from the lidar bare earth model overlaid with the above-ground point cloud and orthoimagery.

Figure 46: View looking southwest at the North River Road Bridge near Arden Falls on the Tygart Valley River in the NOAA Appalachia project area. The image was created from the lidar bare earth model overlaid with the above-ground point cloud and orthoimagery.

Figure 47: View looking northeast at the West Virginia University (WVU) Jackson's Mill on the West Fork River in the NOAA Appalachia project area.The image was created from the lidar bare earth model overlaid with the above-ground point cloud and orthoimagery.

Figure 48: View looking east at the Historic Point Marion Iron Bridge on the Monongahela River in the NOAA Appalachia project area. The image was created from the lidar bare earth model overlaid with the above-ground point cloud and orthoimagery.

Figure 49: View looking south at the Tygart Dam and the Tygart Dam Trail in the Tygart Lake State Park in the NOAA Appalachia project area. The image was created from the lidar bare earth model overlaid with the above-ground point cloud and orthoimagery.

GLOSSARY

1-sigma (σ) Absolute Deviation: Value for which the data are within one standard deviation (approximately 68th percentile) of a normally distributed dataset.

1.96 * RMSE Absolute Deviation: Value for which the data are within two standard deviations (approximately 95th percentile) of a normally distributed dataset, based on the FGDC standards for Non-Vegetated Vertical Accuracy (NVA) reporting.

Accuracy: The statistical comparison between known (surveyed) points and laser points. Typically measured as the standard deviation (sigma σ) and root mean square error (RMSE).

> **Absolute Accuracy:** The vertical accuracy of lidar data is described as the mean and standard deviation (sigma σ) of divergence of lidar point coordinates from ground survey point coordinates. To provide a sense of the model predictive power of the dataset, the root mean square error (RMSE) for vertical accuracy is also provided. These statistics assume the error distributions for x, y, and z are normally distributed, and thus we also consider the skew and kurtosis of distributions when evaluating error statistics.
>
> **Relative Accuracy:** Relative accuracy refers to the internal consistency of the dataset, i.e., the ability to place a laser point in the same location over multiple flightlines, GPS conditions, and aircraft attitudes. Affected by system attitude offsets, scale, and GPS/IMU drift, internal consistency is measured as the divergence between points from different flightlines within an overlapping area. Divergence is most apparent when flightlines are opposing. When the lidar system is well calibrated, the line-to-line divergence is low (<10 cm).
>
> **Root Mean Square Error (RMSE):** A statistic used to approximate the difference between real-world points and the lidar points. It is calculated by squaring all the values, then taking the average of the squares and taking the square root of the average.

Data Density: A common measure of lidar resolution, measured as points per square meter.

Digital Elevation Model (DEM): File or database made from surveyed points, containing elevation points over a contiguous area. Digital terrain models (DTM) and digital surface models (DSM) are types of DEMs. DTMs consist solely of the bare earth surface (ground points), while DSMs include information about all surfaces, including vegetation and man-made structures.

Intensity Values: The peak power ratio of the laser return to the emitted laser, calculated as a function of surface reflectivity.

Nadir: A single point or locus of points on the surface of the earth directly below a sensor as it progresses along its flightline.

Overlap: The area shared between flightlines, typically measured in percent. 100% overlap is essential to ensure complete coverage and reduce laser shadows.

Pulse Rate (PR): The rate at which laser pulses are emitted from the sensor; typically measured in thousands of pulses per second (kHz).

Pulse Returns: For every laser pulse emitted, the number of wave forms (i.e., echoes) reflected back to the sensor. Portions of the wave form that return first are the highest element in multi-tiered surfaces such as vegetation. Portions of the wave form that return last are the lowest element in multi-tiered surfaces.

Real-Time Kinematic (RTK) Survey: A type of survey conducted with a GPS base station deployed over a known monument with a radio connection to a GPS rover. Both the base station and rover receive differential GPS data, and the baseline correction is solved between the two. This type of ground survey is accurate to 1.5 cm or less.

Post-Processed Kinematic (PPK) Survey: GPS survey is conducted with a GPS rover collecting concurrently with a GPS base station set up over a known monument. Differential corrections and precisions for the GNSS baselines are computed and applied after the fact during processing. This type of ground survey is accurate to 1.5 cm or less.

Scan Angle: The angle from nadir to the edge of the scan, measured in degrees. Laser point accuracy typically decreases as scan angles increase.

Native Lidar Density: The number of pulses emitted by the lidar system, commonly expressed as pulses per square meter.

APPENDIX A – ACCURACY CONTROLS

Relative Accuracy Calibration Methodology:

Manual System Calibration: Calibration procedures for each mission require solving geometric relationships that relate measured swath-to-swath deviations to misalignments of system attitude parameters. Corrected scale, pitch, roll, and heading offsets were calculated and applied to resolve misalignments. The raw divergence between lines was computed after the manual calibration was completed and reported for each survey area.

Automated Attitude Calibration: All data was tested and calibrated using TerraMatch automated sampling routines. Ground points were classified for each individual flightline and used for line-to-line testing. System misalignment offsets (pitch, roll, and heading) and scale were solved for each individual mission and applied to respective mission datasets. The data from each mission were then blended when imported together to form the entire area of interest.

Automated Z Calibration: Ground points per line were used to calculate the vertical divergence between lines caused by vertical GPS drift. Automated Z calibration was the final step employed for relative accuracy calibration.

Lidar accuracy error sources and solutions:

Source	Type	Post Processing Solution
Long Base Lines	GPS	None
Poor Satellite Constellation	GPS	None
Poor Antenna Visibility	GPS	Reduce Visibility Mask
Poor System Calibration	System	Recalibrate IMU and sensor offsets/settings
Inaccurate System	System	None
Poor Laser Timing	Laser Noise	None
Poor Laser Reception	Laser Noise	None
Poor Laser Power	Laser Noise	None
Irregular Laser Shape	Laser Noise	None

Operational measures taken to improve relative accuracy:

Focus Laser Power at narrow beam footprint: A laser return must be received by the system above a power threshold to accurately record a measurement. The strength of the laser return (i.e., intensity) is a function of laser emission power, laser footprint, flight altitude, and the reflectivity of the target. While surface reflectivity cannot be controlled, laser power can be increased, and low flight altitudes can be maintained.

Reduced Scan Angle: Edge-of-scan data can become inaccurate. The scan angle was reduced to a maximum of ±20 degrees from Nadir for the green and NIR lasers, respectively, creating a narrow swath width and greatly reducing laser shadows from trees and buildings.

Quality GPS: Flights took place during optimal GPS conditions (e.g., 6 or more satellites and PDOP [Position Dilution of Precision] less than 3.0). Before each flight, the PDOP was determined for the survey day.

Ground Survey: Ground survey point accuracy (<1.5 cm RMSE) occurs during optimal PDOP ranges and targets a minimal baseline distance of 4 miles between GPS rover and base. Robust statistics are, in part, a function of sample size (n) and distribution. Ground survey points are distributed to the extent possible throughout multiple flightlines and across the survey area.

50% Side-Lap (100% Overlap): Overlapping areas are optimized for relative accuracy testing. Laser shadowing is minimized to help increase target acquisition from multiple scan angles. Ideally, with a 50% side-lap, the nadir portion of one flightline coincides with the swath edge portion of overlapping flightlines. A minimum of 50% side-lap with terrain-followed acquisition prevents data gaps.

Opposing Flightlines: All overlapping flightlines have opposing directions. Pitch, roll, and heading errors are amplified by a factor of two relative to the adjacent flightline(s), making misalignments easier to detect and resolve.