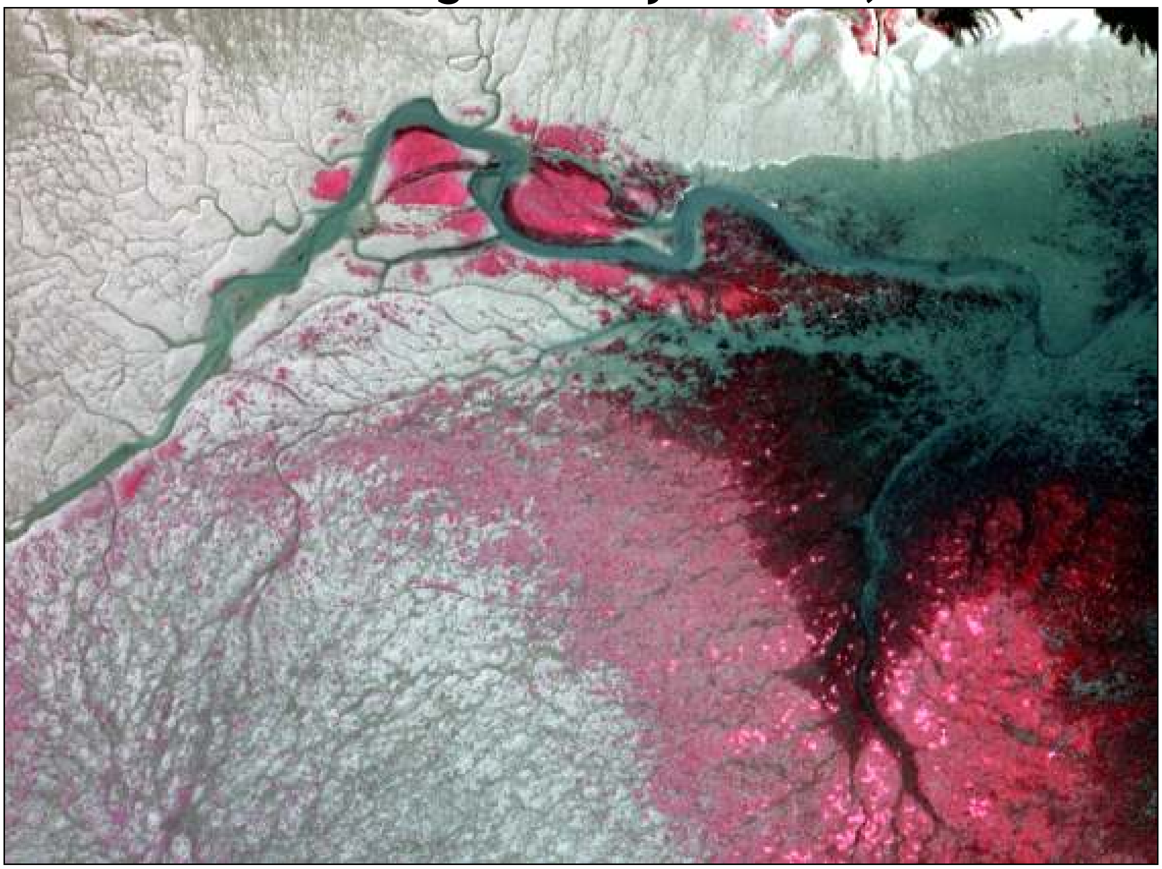
LiDAR/NIR Remote Sensing Data Collection: South Slough Estuary Reserve, OR



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Light Detection and Ranging (LiDAR)

Overview

Watershed Sciences, Inc. (WS) collected Light Detection and Ranging (LiDAR) data over Coos Bay on September 6, 2005. The survey area encompasses the area between Coos Bay in the north and the confluence of Winchester Creek and the South Slough at the southern edge of the study area, and covers a swath approximately 2.73 miles wide. The initial study area (~10,155 acres) was expanded to ensure complete coverage, resulting in a survey area measuring 13,863 acres (figure next page).

A total of 246,695,566 laser points were collected over the study area using an Optech ALTM 3100 LiDAR system set to acquire points at average spacing of >4 points per square meter. The system also recorded individual return intensities (per laser return) that are used to create combined elevation models that display both elevation and surface reflectivity.

One differential two-phase GPS unit was deployed and used to process kinematic solutions to the onboard GPS and inertial measurement unit (IMU) using PosPAC v4.2. Points were computed per flight line using the REALM Survey Suite v3.5.2. Microstation V8 and TerraScan were used to import the points into bins, remove pits and birds, and compute the bare earth model. TerraModeler was then used to create TINs and output ARCINFO ASCII lattice models, which were then imported into ArcMap to render one-meter mosaics of first and ground models.

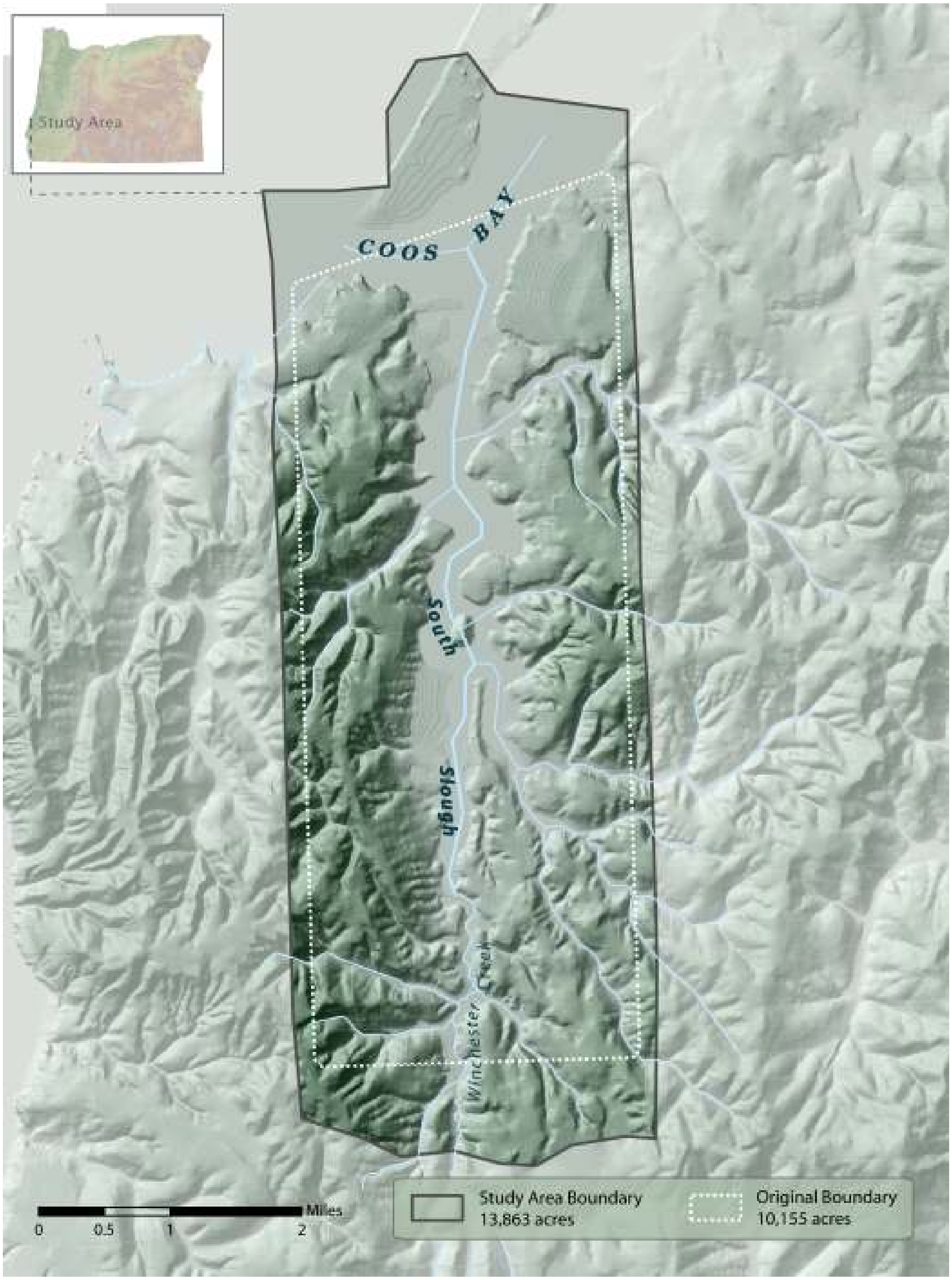
Laser point absolute accuracy is largely a function of internal consistency and laser noise:

- **Absolute Accuracy**: This is the comparison of laser points to real time kinematic (RTK) ground level survey data. A total of 574 RTK GPS measurements were compared to ground laser points collected for comparison with the LiDAR point data. The deviation RMSE and standard deviation are both 0.039 meters, with a median (50^{th} percentile) absolute deviation of 0.027 meters and a 95^{th} percentile of 0.085 meters.

- **Internal Consistency**: Internal consistency refers to the ability to place a laser point in the same location over multiple flight lines, GPS conditions and aircraft attitudes. The data were analyzed for internal consistency between opposing and orthogonal flight lines and passed divergence test requirements of less than 0.15 meters per any one overlapping flight line.

- **Laser Noise**: For any given target, laser noise is the breadth of the data cloud per laser return (i.e., last, first, etc.). Lower intensity surfaces (roads, rooftops, still/calm water) will experience higher laser noise. The laser noise range for this mission varies between .04 - .07 meters.

Figure 1. Full extent of Study Area covering 13,863 acres.



Technical Approach

Data Collection

Our LiDAR system is mounted in the belly of a Cessna Caravan 208 (see figure below). Quality control (QC) pre-mission flights were performed based on manufacturer's specifications prior to the survey. The QC flight was conducted at the Ashland Airport using known surveyed control points. The positional accuracy of the LiDAR (x, y, z) returns are checked against these known locations to verify the calibration and to report base accuracy.

The Optech 3100 system was set to a 71kHz laser repetition rate and flown at 1,100 meters above ground level (AGL), capturing a 32^{o} scan width (16^{o} from NADIR). These settings yielded points with an average spacing of greater than 4 points per square meter. The entire area was surveyed with opposing flight line overlap of 60% to reduce laser shadowing and increase surface laser painting. The system allows up to four range measurements per pulse, and all were processed for the output datasets. The data stream from the IMU was stored independently during the flight, and was differentially corrected and integrated with LiDAR pulse data during post processing. Throughout the survey, a dual frequency DGPS base station recorded fast static (1 Hz) data. The station was located at the northern edge of the study area at Chicken Point (Table 1, figure next page).

Figure 2. The Cessna Caravan 208 - A removable composite cargo pod provides housing for GPS equipment and the LiDAR system and other remote sensing sensors.

Flight Parameters

System:	Optech 3100
Flight AGL (m):	1,100 m
Flight Speed:	105 knots
Scan Width:	32^{o} (16^{o} from NADIR)
Scan Pulse Repetition Frequency (PRF):	71,000 pulses per second (71kHz)

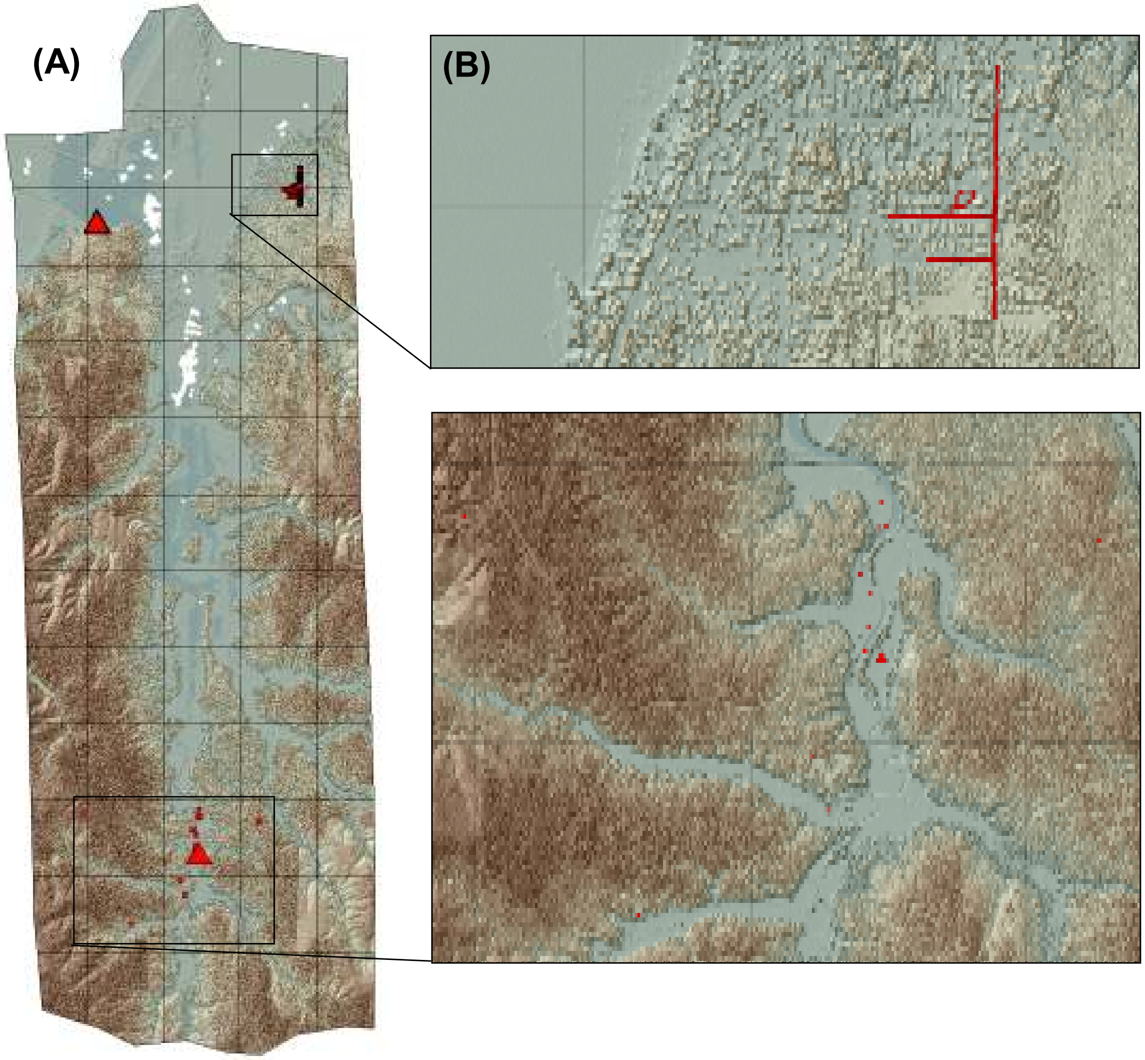
A total of 574 quality control real-time kinematic (RTK) GPS data points were collected within the project area using a ground based DGPS station. Data collected were then compared to the processed LiDAR data to ensure accuracies across the project area.

Table 1. Base Station Surveyed Coordinates / First Order NGS Monument

Point ID	***NAD83NAVD88***		
	Latitude (North)	***Longitude (West)***	***Ellipsoid Height (m)***
OA1562 (NGS Monument, published coordinates)	43°21'03.51895"	124°20'13.59839"	N/A
OA1562 (NGS Monument, OPUS corrected)	43°21'03.52681"	124°20'13.59545"	-4.807
Secondary monument (OPUS corrected) Used Only as Base for RTK	43°16'33.68625" (σ=0.012 m)	124°19'08.31738" (σ=0.015 m)	-23.981 (σ=0.014 m)

NOTE: Prior to processing, OA1562 (PID) position information was corrected using an Online Positioning User System (OPUS) solution provided by the National Geodetic Survey (NGS). The LiDAR and RTK data were processed based on these corrected coordinates.

Figure 3. GPS Monuments and Ground Survey Points. (A) The NGS monument at Chicken Point was used to survey fast static (1 Hz) data during the LiDAR survey. (B) A total of 574 ground survey points (RTK) were collected throughout the study area. These RTK points are used to assess data quality and accuracy.



Data Gaps: The original study area was buffered to ensure complete coverage, with the final area totaling 13,863 acres. While there may be the appearance of data gaps, these are limited to areas under large buildings or over very still/calm water surfaces (ponds, pools, etc.) where the bare ground model required greater than 50 meters to build a triangle in the one meter GRID dataset. In these cases, the models recorded no data, instead of reporting interpolated data.

Data Processing

Coordinate System and Units

All data and imagery are developed as:

UTM zone 10, NAD83, NAVD88, Geoid03 S.I. Units

Laser point return coordinates were computed using the REALM software suite based on independent data from the LiDAR system (pulse time, scan angle), IMU (aircraft attitude), and aircraft position (differentially corrected and optimized using the DGPS base station data). The inertial measurement data were used to calculate the kinematic corrections for the aircraft trajectories using PosPAC v4.2. Flight lines and LiDAR data were reviewed to insure complete coverage of the study area and positional accuracy of the laser points.

TerraScan Processing

To facilitate laser point processing, the first step is to create bins (polygons) that divide the data set into manageable sizes. The entire buffered study area was divided into 64 individual bins, approximately 1 km^2 each (see figure at right).

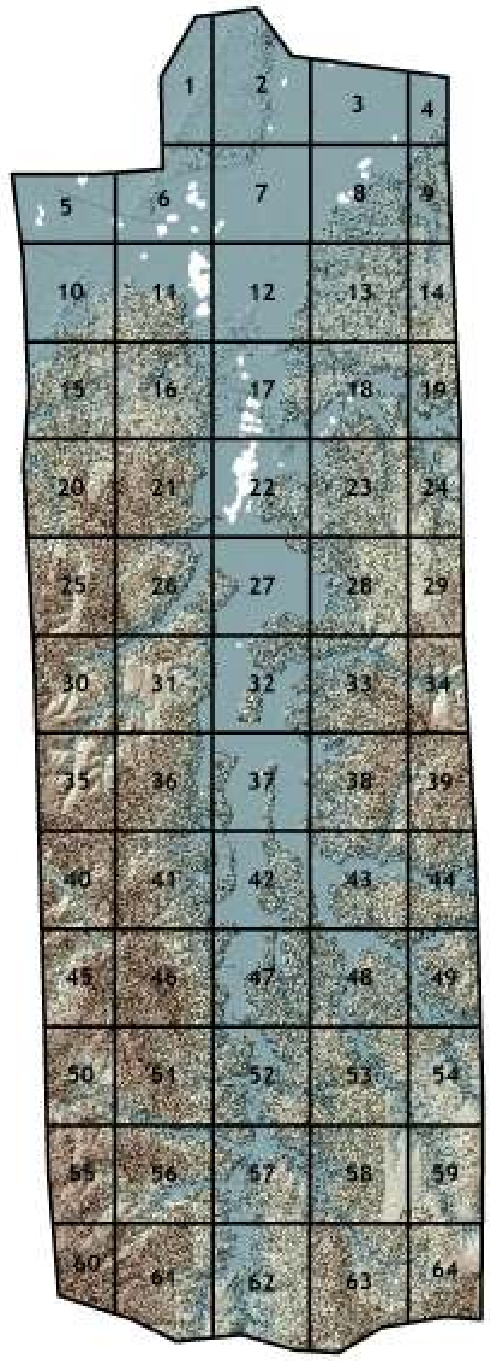
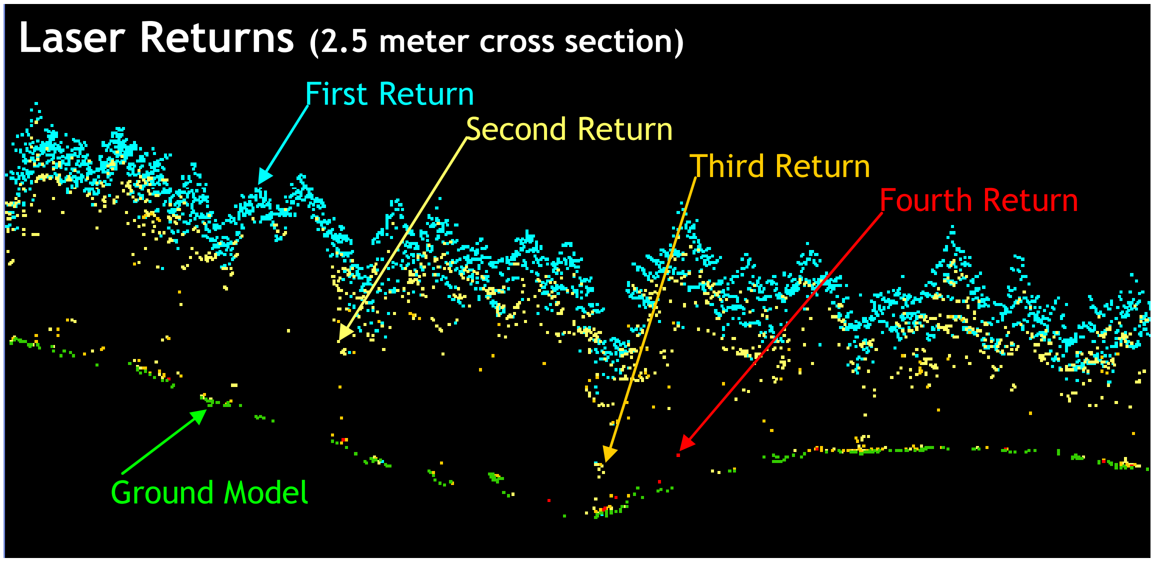


Figure 4. Processing Bins – 64 Total Bins; approximately 1 km x 1 km each

Laser point returns (first and last) are assigned an associated (x, y, z) coordinate, along with unique intensity values (figure below). The raw LiDAR points are filtered for noise, pits and birds by screening for absolute elevation limits, isolated points and height above ground. These data have passed initial screening and are deemed accurate; however, ground modeling processing has not been completed on these filtered laser points.

Figure 5. Laser Returns – First and Last Returns, along with Classified Ground Points.



The TerraScan software suite is designed specifically for developing a standard bare earth model to remove buildings, vegetation, and other features. The high point density and multiple returns result in uncomplicated identification of vegetated and obscured areas using first and last returns. The processing sequence begins by removing all points that are not "near" the earth based on evaluation of the multi-return layers. The resulting bare earth (ground) model is visually inspected and additional ground modeling is performed in site specific areas (over a 50 meter radius) to improve ground detail. This is only done in areas with known ground modeling deficiencies, such as: bedrock outcrops, cliffs, deeply incised stream banks, and dense vegetation.

Description of Processing Steps:

Units: Meters
Projection: UTM Zone 10, Nad83, NAVD88, Geoid03

1. Import point data into 64 bins
2. Perform relative accuracy testing.
3. Remove False LiDAR Points: False high and low points are removed by establishing thresholds for point removal that are above and below the known terrain elevations.
4. Calculate bare ground model from last return points, with the maximum building size of 100 m^2 and maximum terrain angle of 80^o. The challenge is to remove buildings and vegetation, but leave rock outcrops and cliffs.

   Important: Water points are left in the bare earth model because it is unclear which points are water and which are mud flat, river bed, rocks, etc.

5. Manual removal of major bridges and highway spans.
6. Generate TINs within all bins (including points 25 m outside for overlap) and export ASCII lattice files for first return and ground points at one meter resolution.

No weeding or superfluous point removal was performed. The intent of a LiDAR survey is to accurately place points on targets, not remove points. If laser noise is low and internally consistent, aside from pits and birds, it assumed that the remaining laser returns are from targets within the survey area.

Statement of Accuracy

Table 2. **Absolute Accuracy** – Divergence between laser points and RTK survey points.

			Points 1-560	**Points 561-574**
Standard Deviation:	0.042 m			
RMSE:	0.042 m	5th Percentile:	0.002 m	0.004 m
n:	574	25th Percentile:	0.011 m	0.025 m
Minimum Δz:	-0.220	50th Percentile:	0.025 m	0.051 m
Maximum Δz:	0.144	75th Percentile:	0.045 m	0.113 m
Ave Magnitude:	0.032 m	95th Percentile:	0.085 m	0.174 m

Figure 6. Point Divergence Statistics

(A) Ground survey point deviation from laser points

(B) Absolute deviation from laser points, with percentile statistics

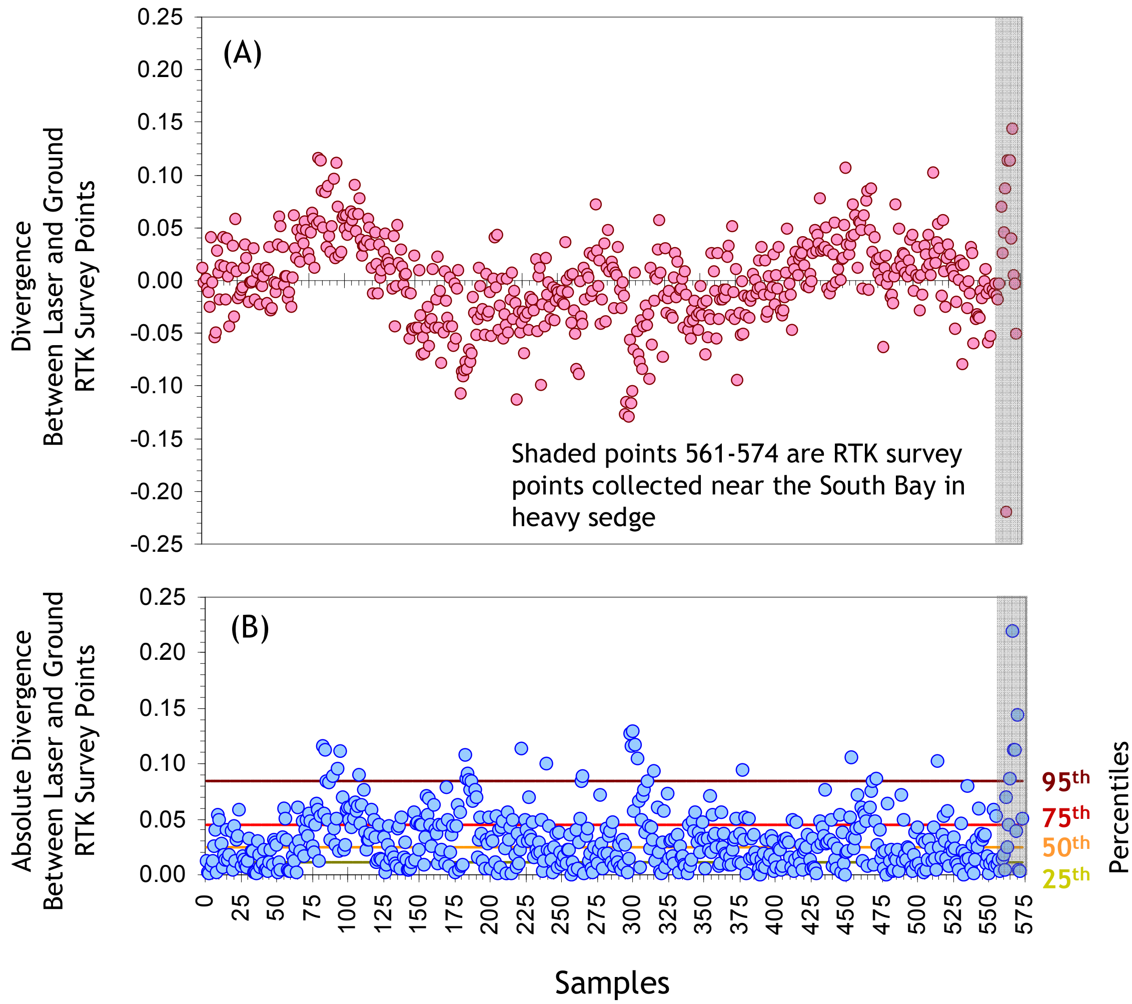


Table 3. LiDAR accuracy is a combination of several sources of error. These sources of error are cumulative. Some error sources that are biased and act in a patterned displacement can be resolved in post processing.

Type of Error	Source	Post Processing Solution	Effect
GPS (Static/Kinematic)	Long Base Lines	None	
	Poor Satellite Constellation	None	
	Poor Antenna Visibility	Reduce Visibility Mask	Slight
Internal Consistency	Poor System Calibration	Recalibration IMU and sensor offsets/settings	Large
	Inaccurate System	None	
Laser Noise	Poor Laser Timing	None	
	Poor Laser Reception	None	

Quality Assurance and Control

Quality assurance and control is built into the overall methodology. The data collection was monitored using the diagnostic features of the system during the flight. The precise navigation system and 60% side overlap during acquisition is designed to eliminate missing coverage and ensure laser painting of multiple sides of surfaces. The quality of the GPS signal (or PDOP) is recorded throughout the flight and only PDOP values less than 3.0 are accepted.

Near-Infrared Images

Section To Be Completed.

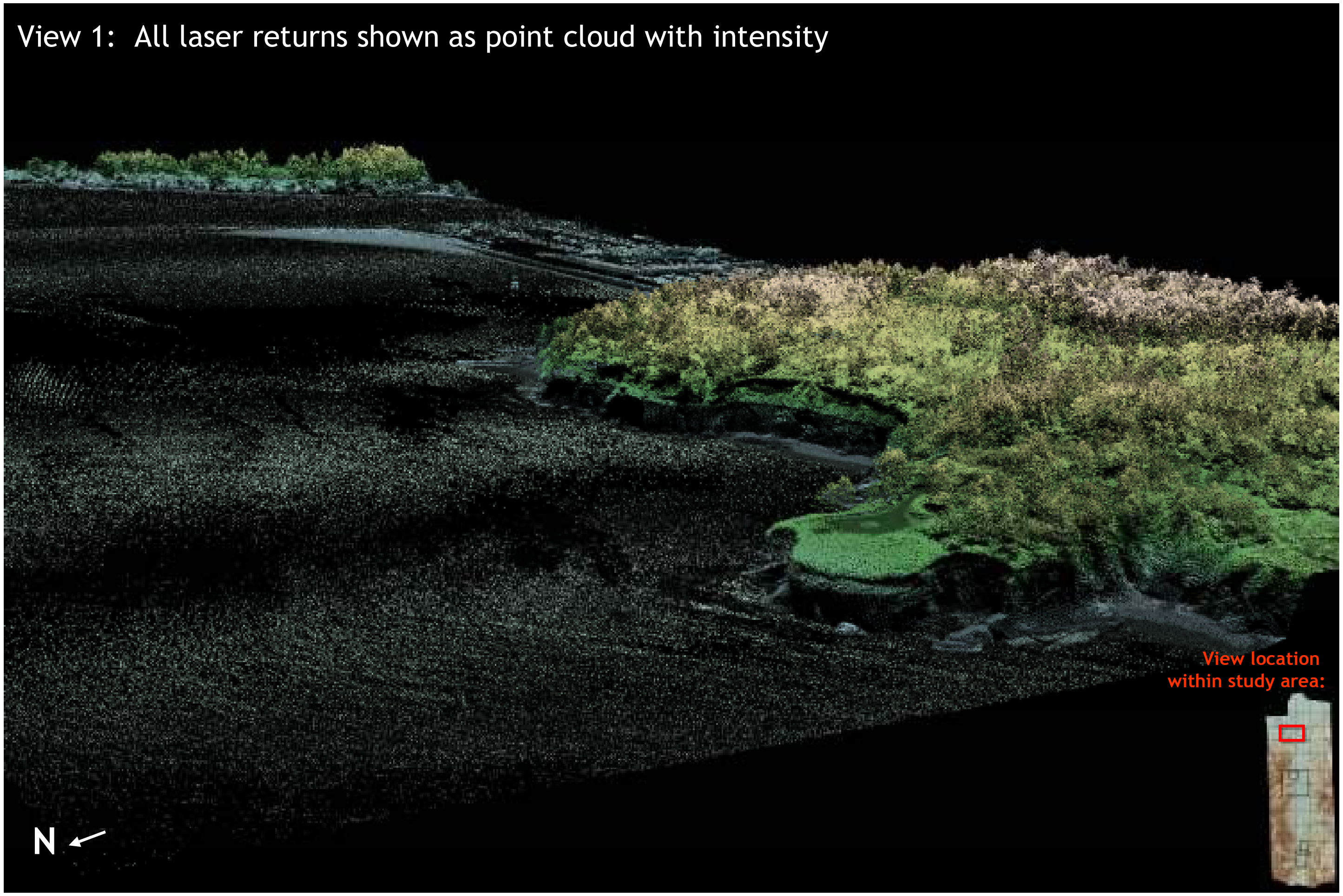
Deliverables

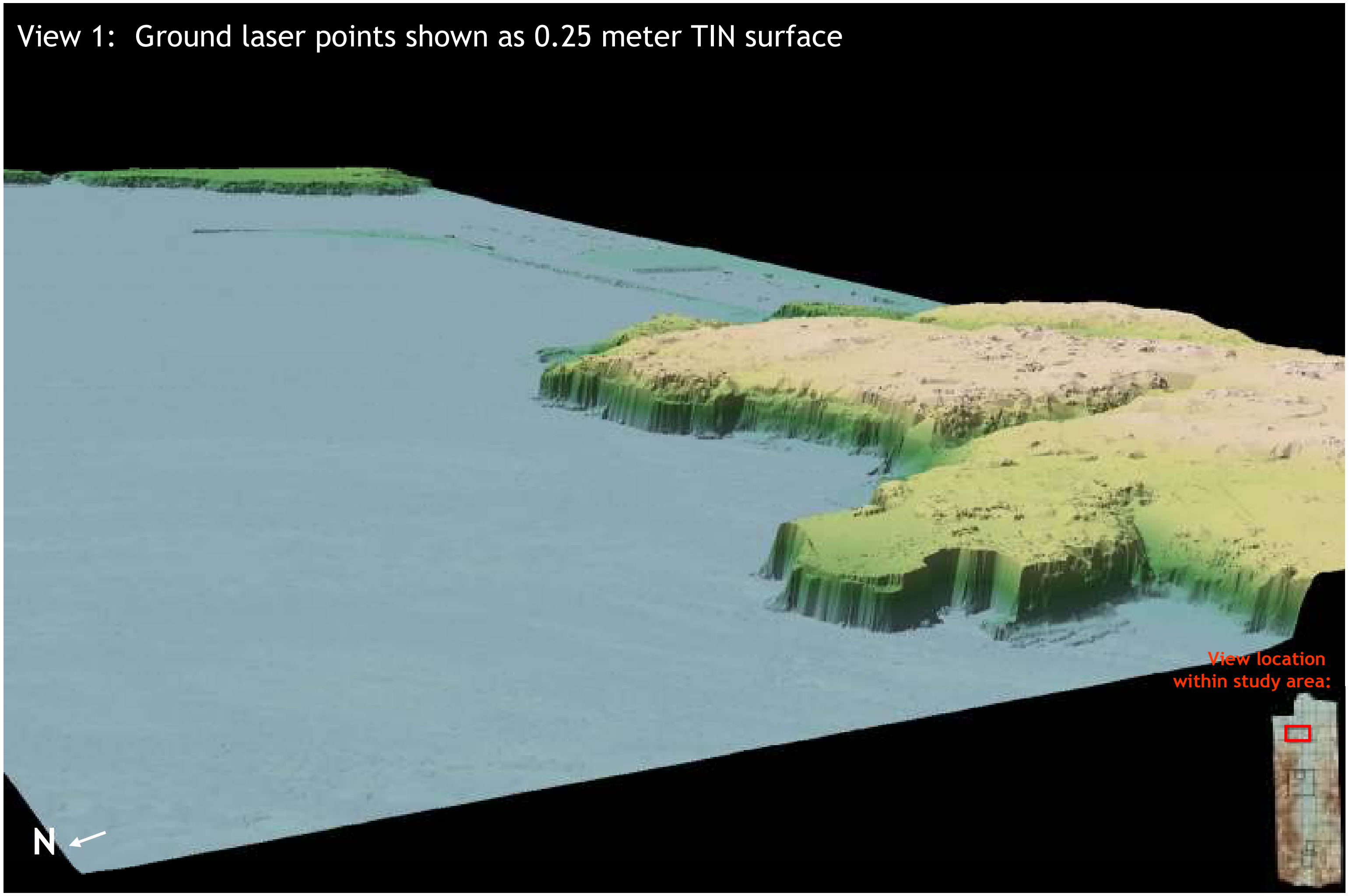
LiDAR Deliverables:

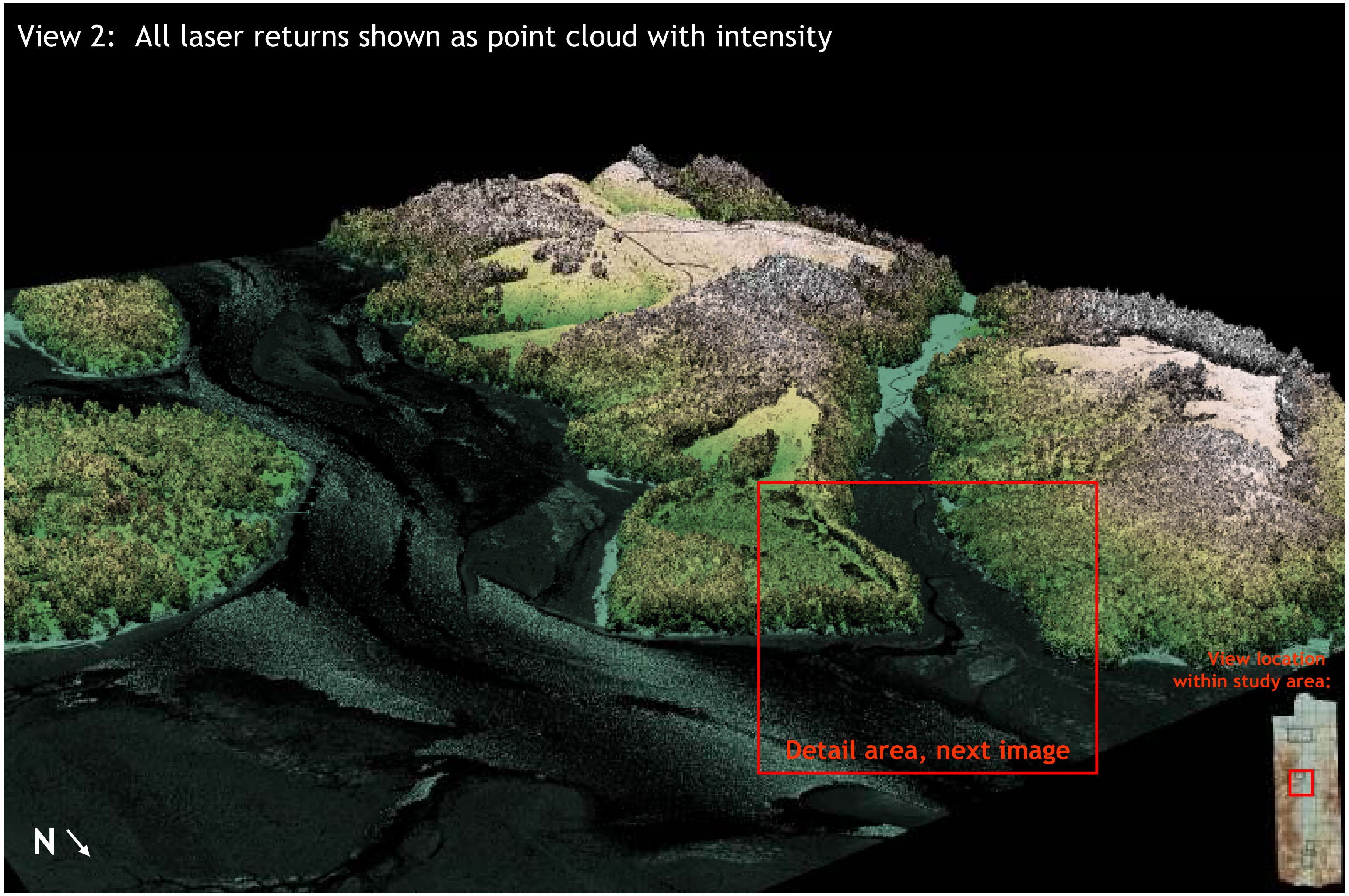
Deliverables are provided on a removable hard drive and organized in the following directories:

- **ASCII_points**
  - All laser points in ASCII format (13.7 Gbytes)
- **Coverages**
  - Shapefiles relevant to the survey (bins, adjusted_rtk, photo_locations)
  - Intensity Images (Lowest, Average, Highest)
- **Grids**
  - 1 meter ESRI GRIDs for bare earth and first returns (1.5 Gbytes)
- **NIR Images**
  - Raw Un-rectified NIR Images (tiff) format
- **Report**
  - Report for LiDAR (226 Mbytes)
- **RTK**
  - RTK survey points (excel) adjusted for NGS control

Selected Images




View 1: Ground laser points shown as 0.25 meter TIN surface
N
View location
within study area:


View 2: All laser returns shown as point cloud with intensity
Detail area, next image
View location
within study area:
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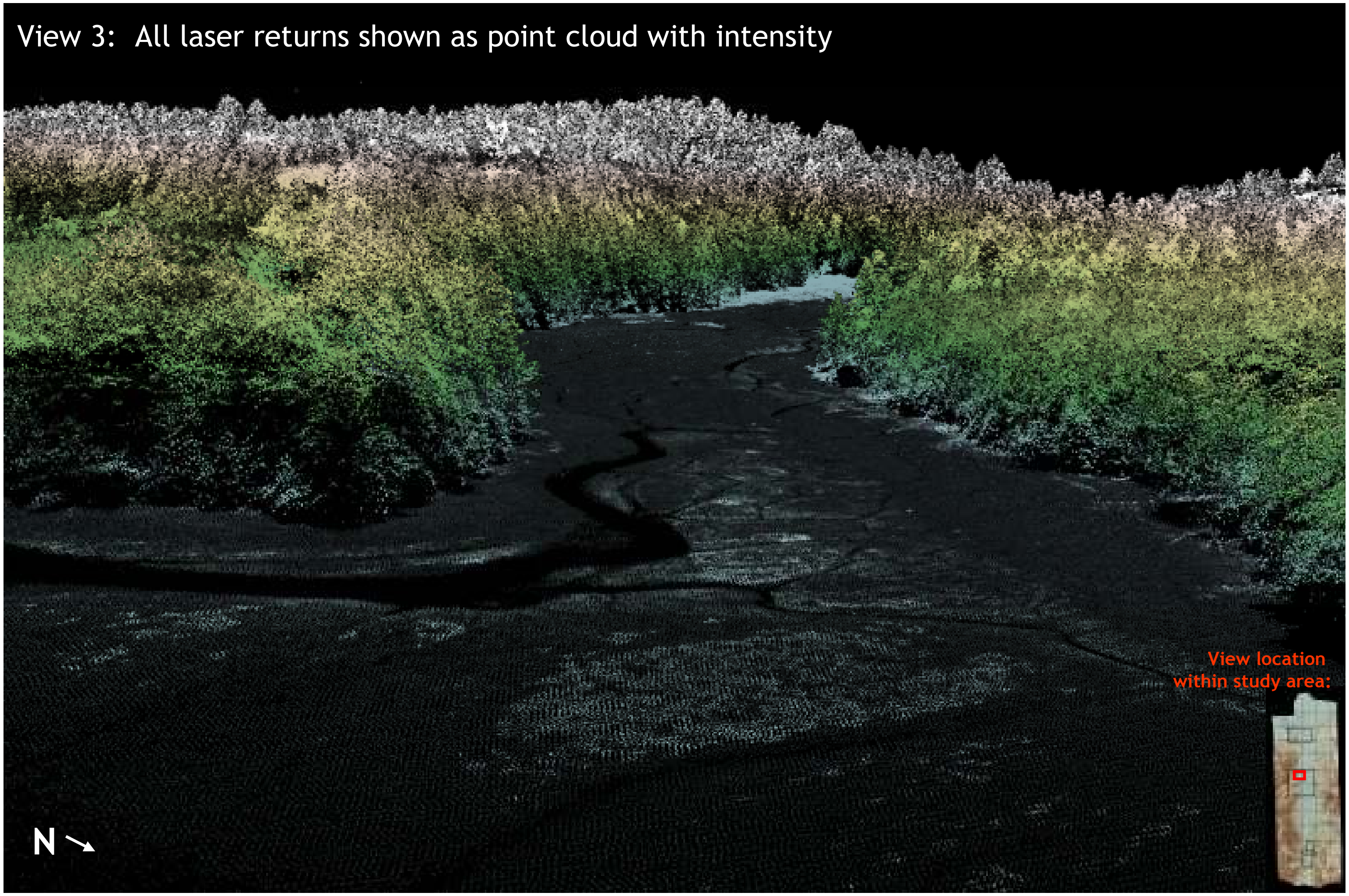
View 3: All laser returns shown as point cloud with intensity
View location within study area:
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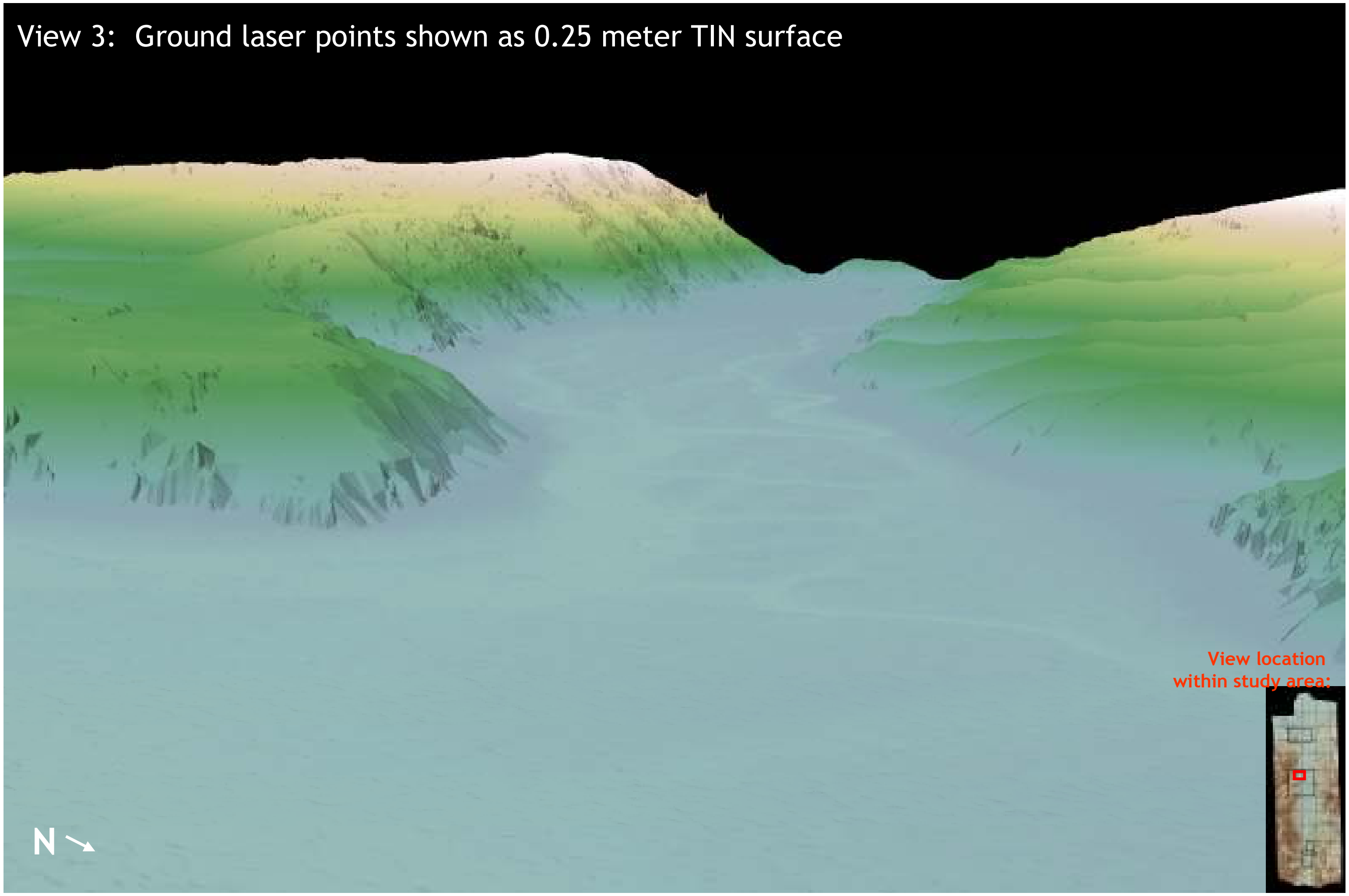
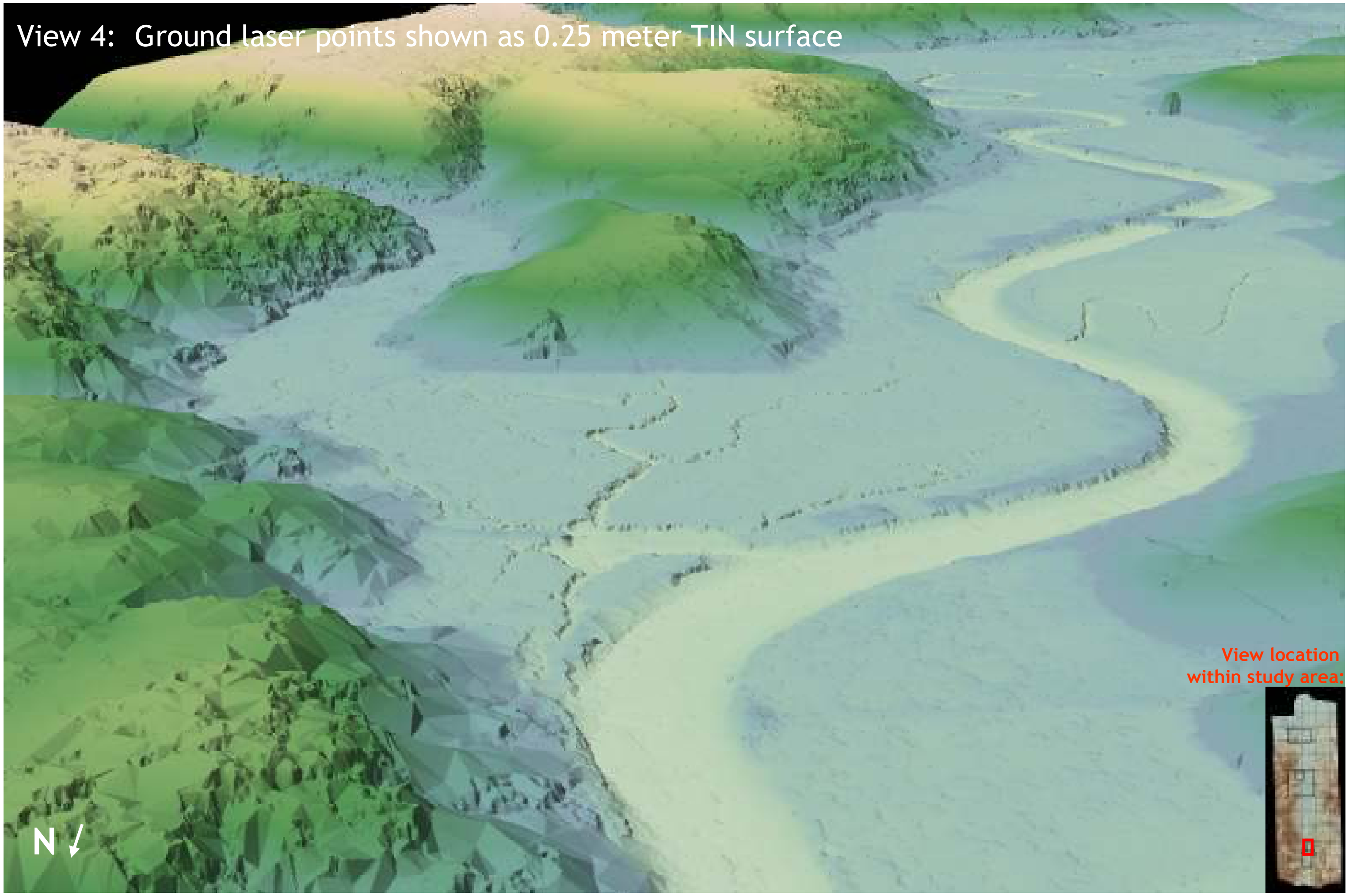

View 3: Ground laser points shown as 0.25 meter TIN surface
View location
within study area:
N

View 4: All laser returns shown as point cloud with intensity


View 4: Ground laser points shown as 0.25 meter TIN surface
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within study area:
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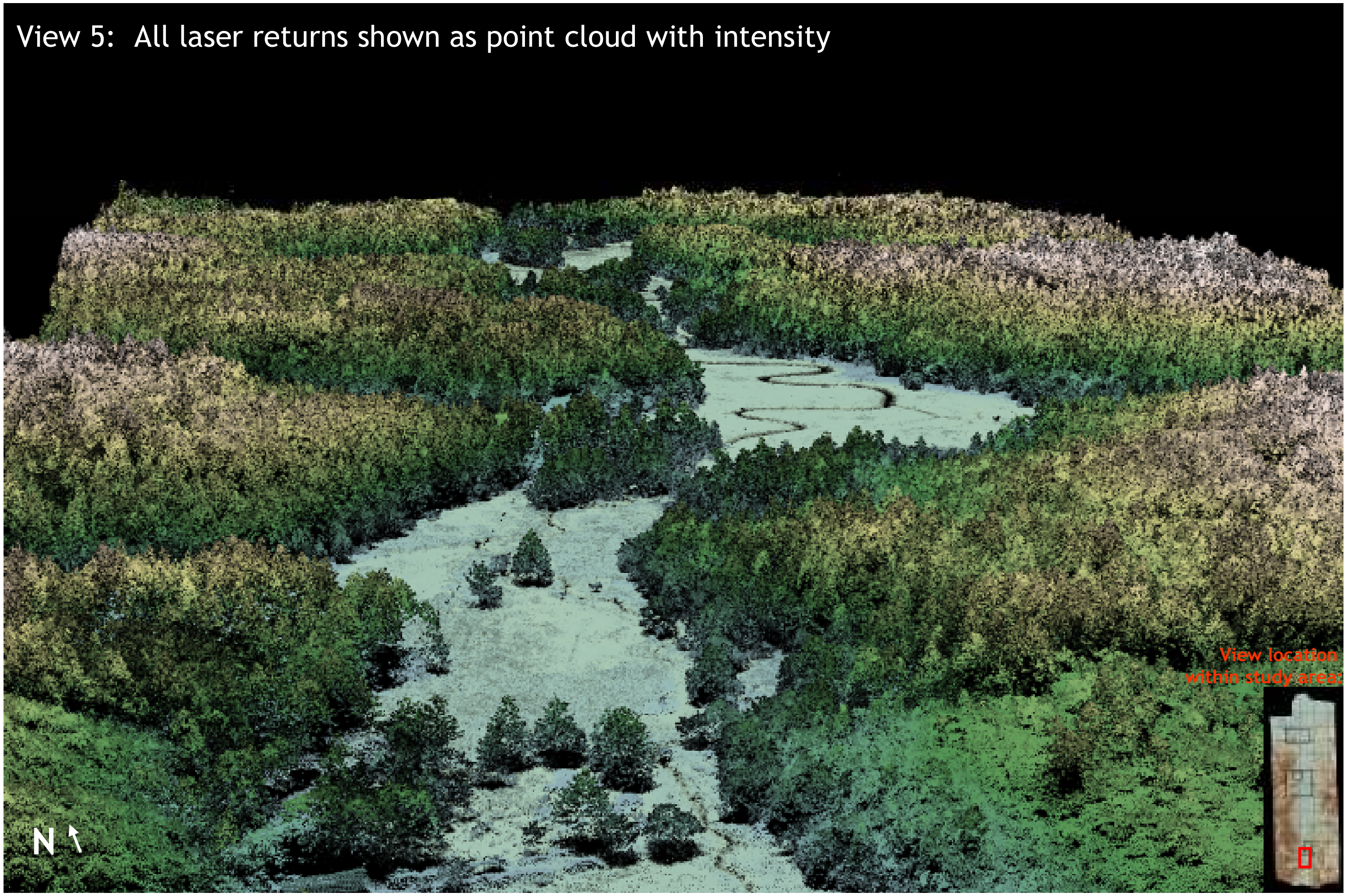
View 5: All laser returns shown as point cloud with intensity
View location within study area:
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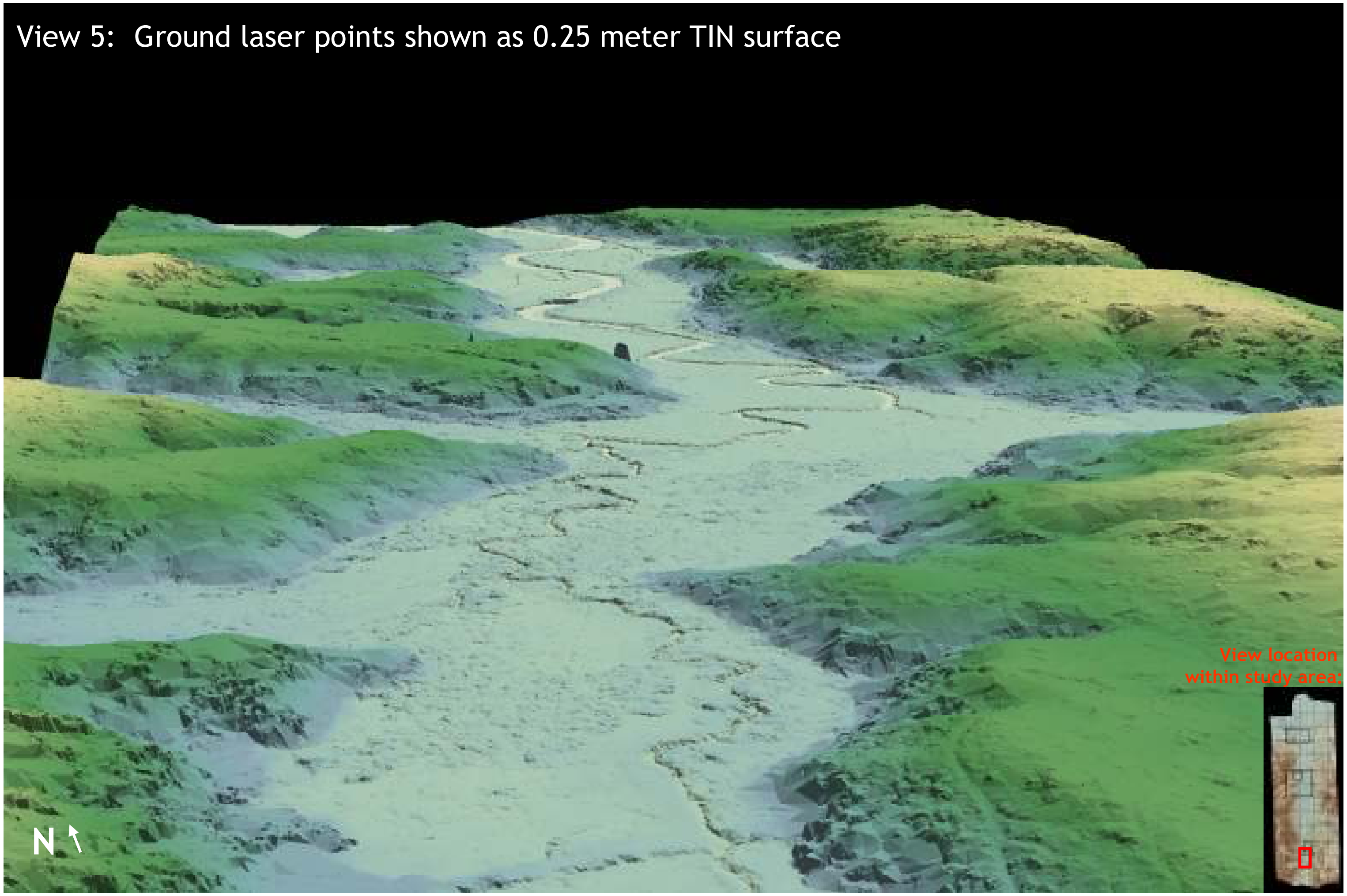
View 5: Ground laser points shown as 0.25 meter TIN surface
View location
within study area:
N