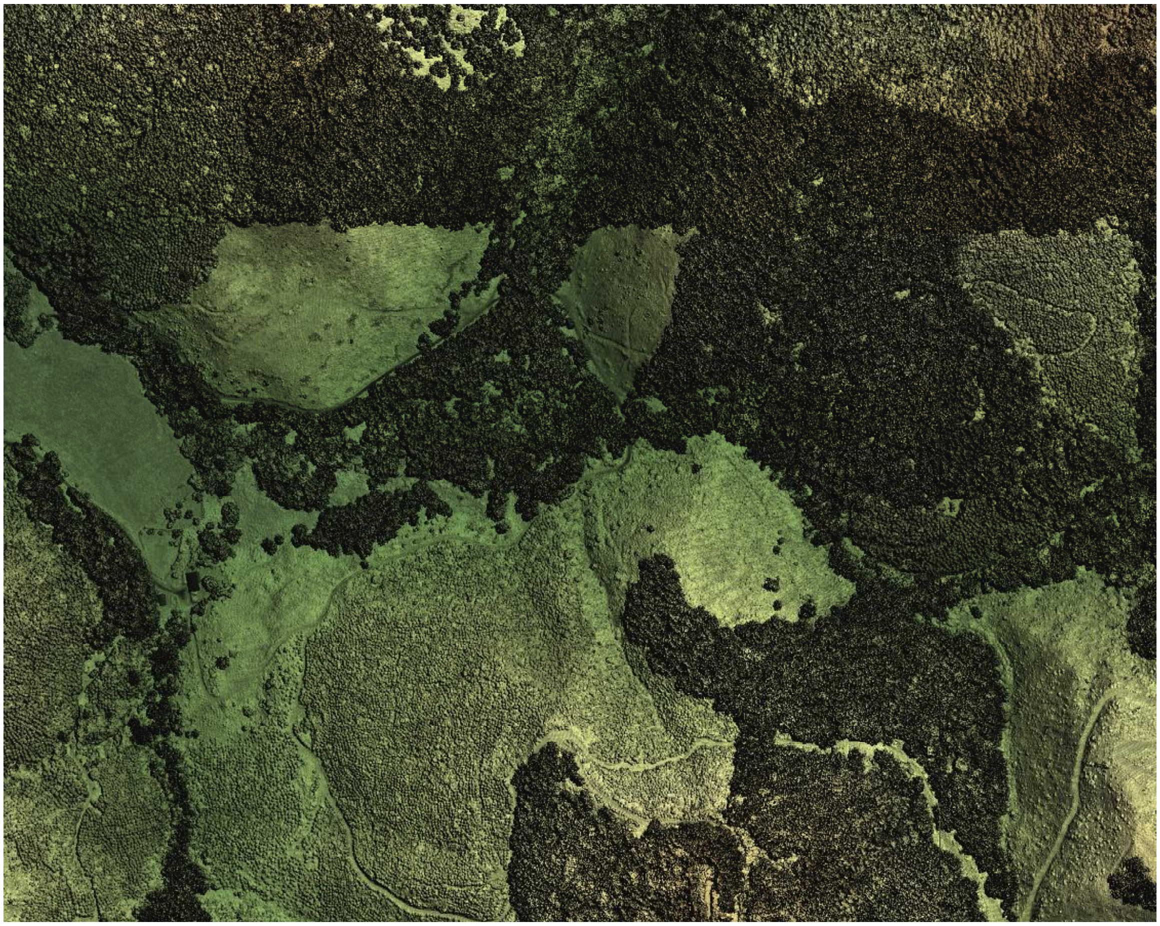
LiDAR Remote Sensing Data Collection:
Yaquina and Elk Creek Watershed, Leaf-On Acquisition



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Light Detection and Ranging (LiDAR)

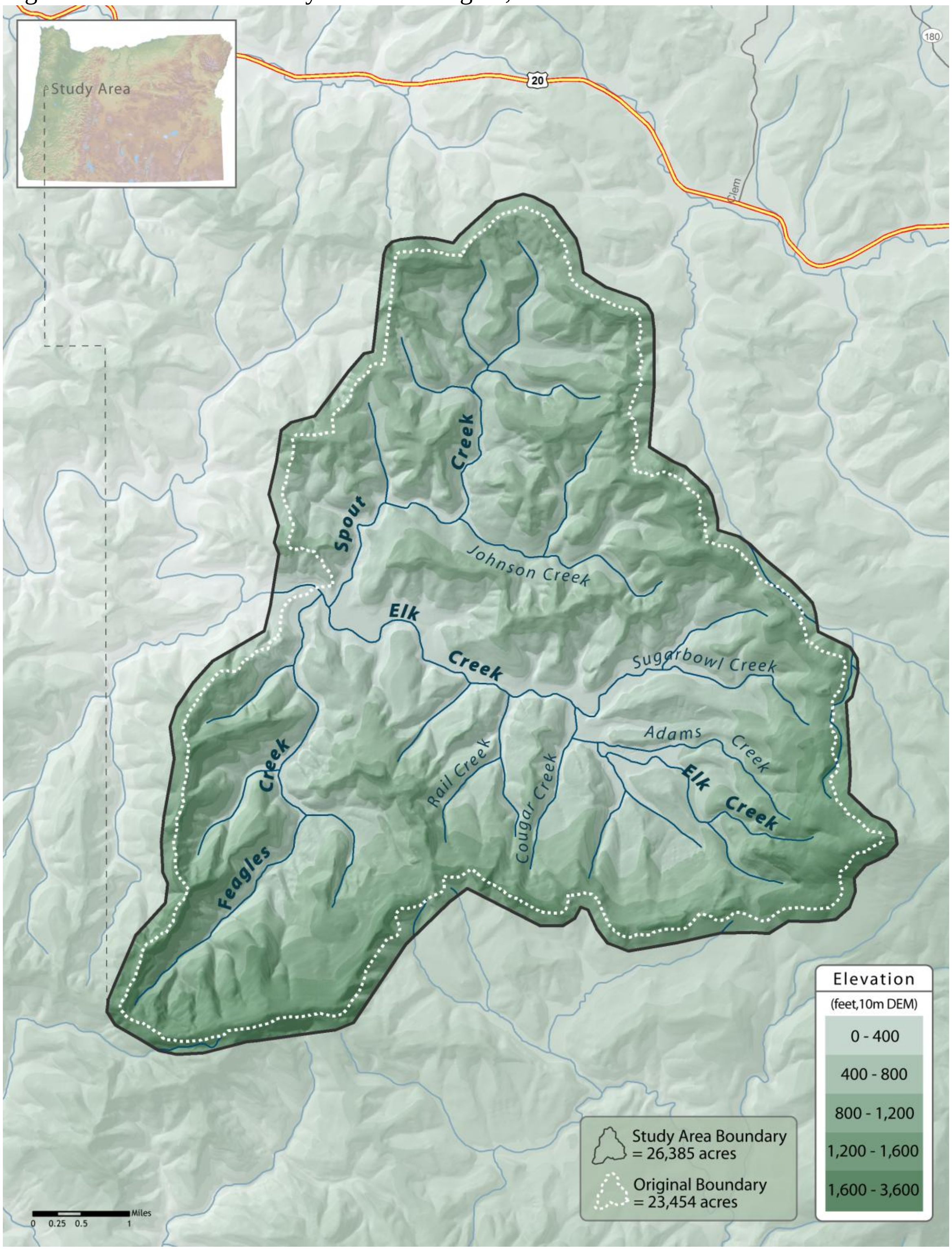
Overview

Watershed Sciences, Inc. (WS) collected Light Detection and Ranging (LiDAR) data for the United States Forest Service (USFS) in the Elk Creek watershed between July 13-15, 2005. The survey area is located inside the Siuslaw National Forest and encompasses all of Spout Creek (northern extent), Feagles Creek (southern extent), the confluence of these streams with Elk Creek (western extent), and up the headwaters of Elk Creek (eastern extent). The initial study area (~23,454 acres) was buffered by 200 meters, extending the contracted survey area to 26,385 acres.

Laser points were collected over the study area using an Optech ALTM 3100 LiDAR system set to acquire points at an average spacing of >8 points per square meter. The system also recorded individual return intensities (per laser return) that are used to create models that display surface reflectivity.

Two differential GPS units were 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 returns, vegetation and ground models.

Figure 1. Full extent of Study Area covering 26,385 acres.



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 354 RTK GPS measurements were compared to ground laser points collected for comparison with the LiDAR point data. The deviation RMSE is 0.054 meters and the standard deviation is 0.053 meters, with a median (50^{th} percentile) absolute deviation of 0.036 meters and a 95^{th} percentile of 0.102 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 0.040 - 0.070 meters.

Technical Approach

Data Collection

Our LiDAR system is mounted in the belly of a Cessna Caravan 208. 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 1,000 meters above ground level (AGL), capturing a 20^{o} scan width (10^{o} from NADIR). These settings yielded points with an average density of > 8.0 per square meter, with an average spot spacing of 32cm. The entire area was surveyed with opposing flight line overlap of 50% 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 eastern edge of the study area, near Marys Peak, Oregon.

Data Acquisition Specifications

LiDAR Data Acquisition Feature	***Specification***
Laser Pulse Repetition Frequency	71 kHz
Laser Pulse Repetition Rate	≤71,000 pulses/sec
Operating Altitude	1,000 m AGL
Scan Frequency	≤52 Hz
Scan Angle	20^{o} ($+10^{o}$ to -10^{o} from Nadir)
Scan Pattern	Sawtooth
Laser Footprint Diameter on Ground (at 1,000 m AGL)	30-33 cm
Number of Returns Collected Per Laser Pulse	4
Multi-Swath Pulse Density	≥8 pulse/m^2
Intensity Range	8 bits
Minimum Resolvable Distance Between Returns	2.5 cm
Swath Width	352 m
Adjacent Swath Overlap (Side-Lap)	≥50%
Laser Spot Spacing (Cross Track = Along Track)	Single Swath: ≤0.52 m (≥2 pts/m^2) Multi Swath: ≤0.26 m (≥8 pts/m^2)
Vertical RMSE of LiDAR Survey	0.053 m
Number of GPS Base Stations Used	1
Maximum Distance From Airborne to Ground GPS	15 km (9.5 miles)
GPS PDOP During Acquisition	≤3.5, preferably ≤3.0
GPS Satellite Constellation During Acquisition	≥6
RTK Quality Control Data Points Collected	354
RTK Data RMSE	≤2.0 cm

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

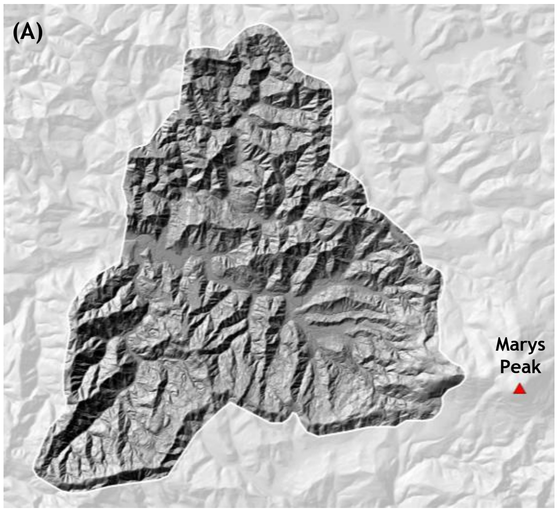
System:	Optech 3100
Flight AGL (m):	1,000 m
Flight Speed:	105 knots
Scan Width:	20° (10° from NADIR)
Scan Pulse Repetition Frequency (PRF):	71,000 pulses per second (71kHz)

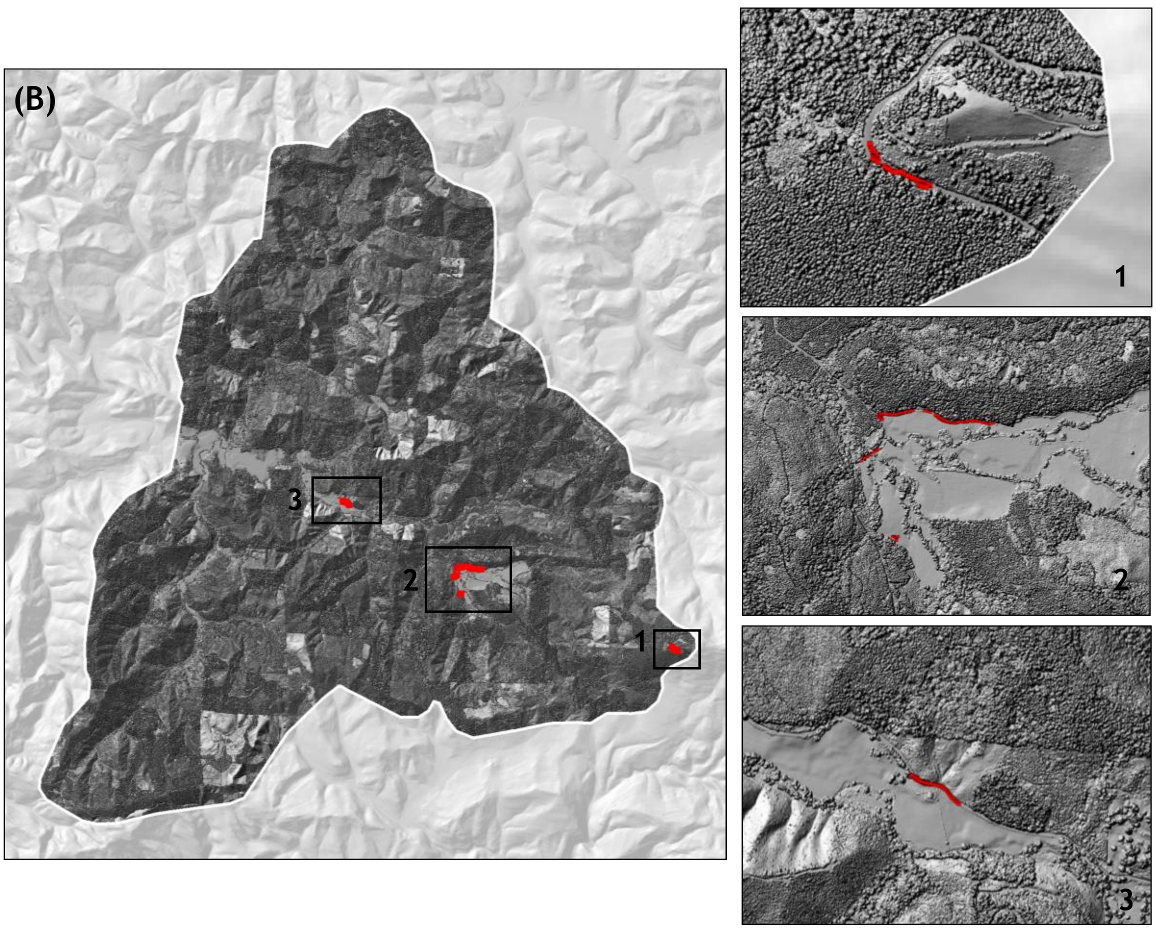
A total of 354 quality control real-time kinematic (RTK) GPS data points were collected within the project area using a ground based DGPS station. Data collected were then compared to the processed LiDAR data to ensure accuracies across the project area.

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

Point ID	***NAD83NAVD88***		
	Latitude (North)	***Longitude (West)***	***Ellipsoid Height (m)***
QE2316 MARYS PEAK	44°30'16.05270"	123°33'08.19710"	1228.09

Figure 3. GPS Monuments and Ground Survey Points. (A) An NGS monument (Marys Peak) was used to survey fast static (1 Hz) data during the LiDAR survey. (B) A total of 354 ground survey points (RTK) were collected throughout the study area. These RTK points were used to assess data quality and accuracy.





Data Processing

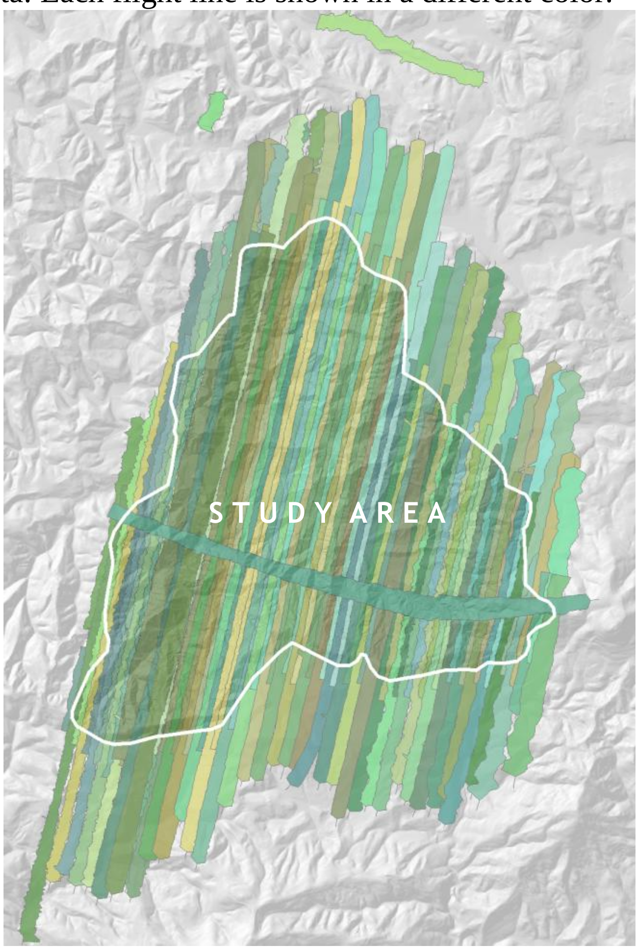
Coordinate System and Units

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 multiple DGPS base stations 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 ensure complete coverage of the study area and positional accuracy of the laser points. The swath data for all three days of acquisition are shown below.

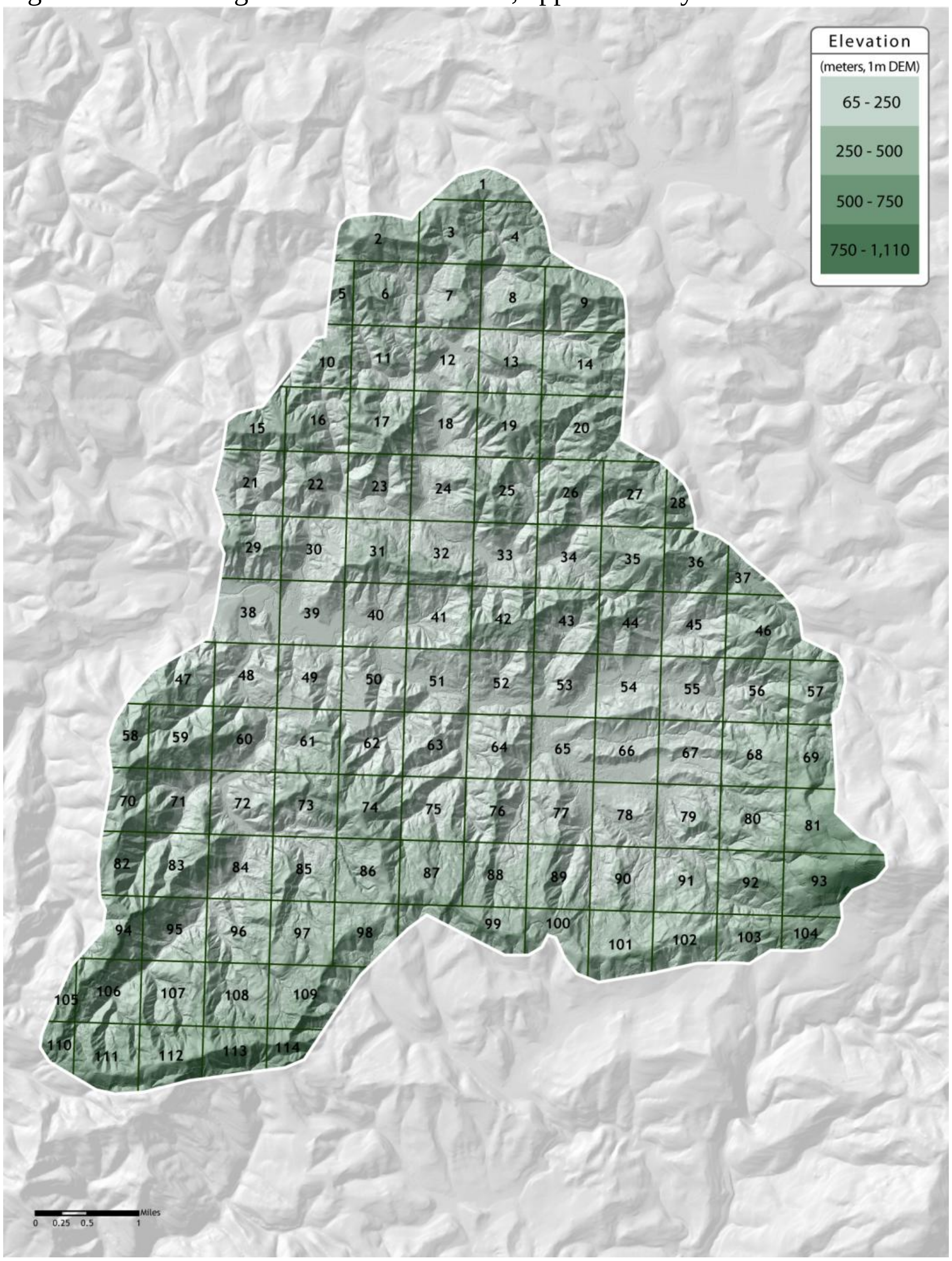
Figure 4. Swath Data: Each flight line is shown in a different color.



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 114 individual bins, approximately 1 km^2 each (see Figure, below).

Figure 5. Processing Bins – 114 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. 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.

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.

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 is 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.

Standard Deviation:	0.053 m	50th Percentile:	0.036 m
RMSE:	0.054 m	67th Percentile:	0.052 m
n:	354	95th Percentile:	0.102 m
Minimum Δz:	-0.192		
Maximum Δz:	0.173		
Average Magnitude:	0.042 m		

Figure 8. Point Divergence Statistics
(A) Ground survey point deviation from laser points
(B) Absolute deviation from laser points, with percentile statistics

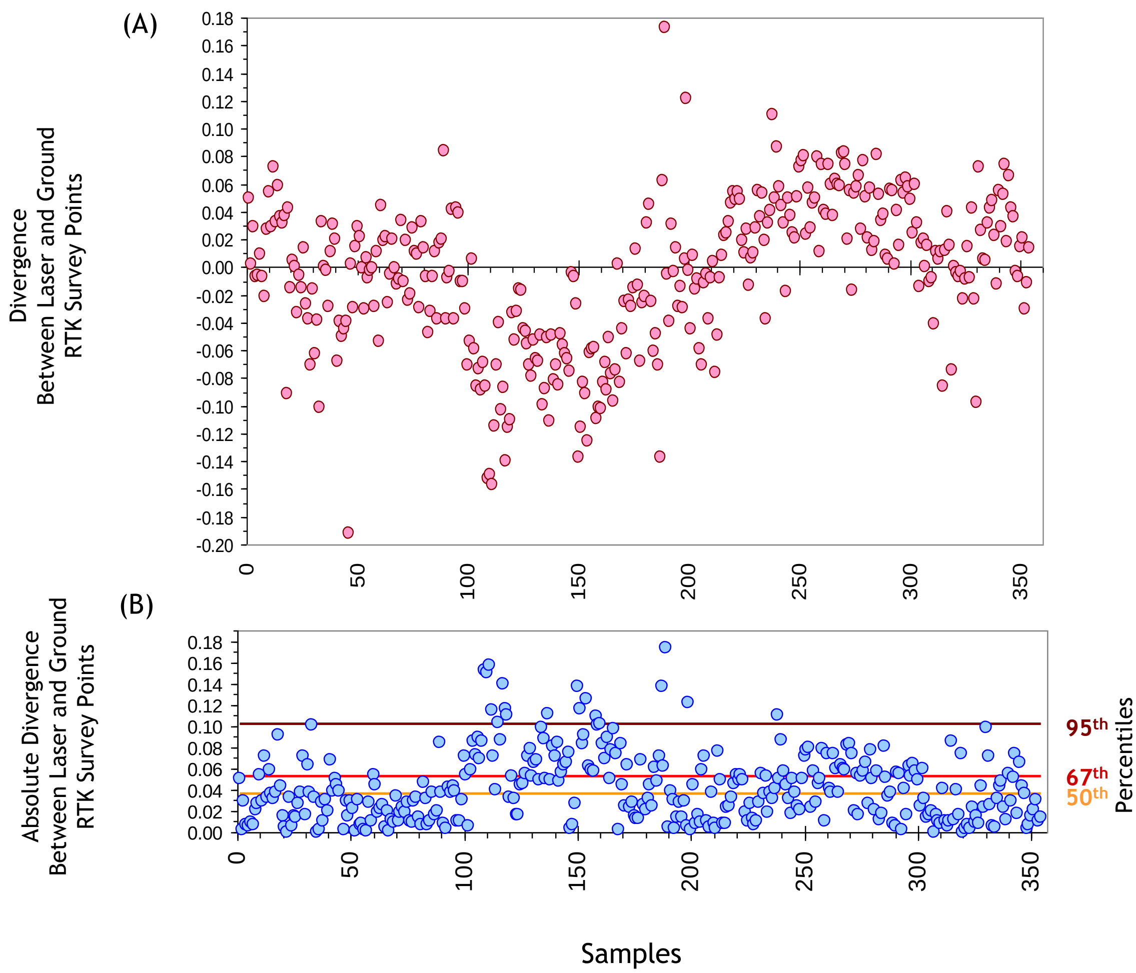


Table 3. LiDAR accuracy is a combination of several sources of error. These sources of error are cumulative. Some error sources that are biased and act in a patterned displacement can be resolved in post processing.

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 50% side over-lap during acquisition is designed to eliminate missing coverage and ensure laser painting of multiple sides of surfaces. Over areas with significant topographic relief, additional lines were flown to ensure complete and consistent overlap. The quality of the GPS signal (or PDOP) is recorded throughout the flight and only PDOP values less than 3.0 are accepted.

Deliverables

Data Report

Points

- LAS: all returns

Rasters

- **TIFFs**
  GEOTIFFs of all returns shaded by intensity, per bin.

- **Bare Earth**
  1.0 meter resolution mosaic

- **Vegetation**

  Highest Hit Model:
  1.0 meter resolution mosaic

Selected Images

Figure 6. Laser points penetrate the forest canopy to cover tree trunks.

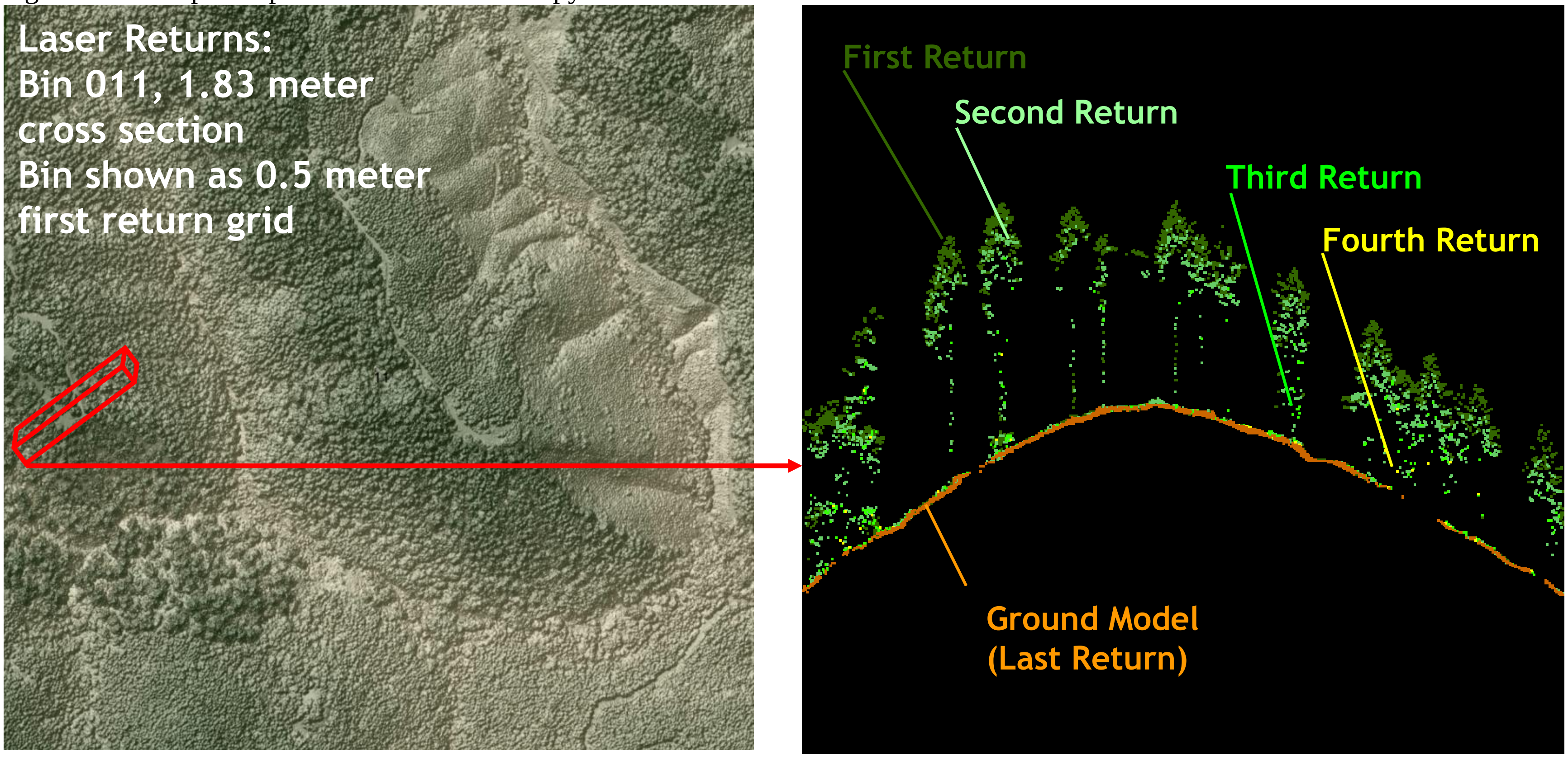


Figure 7. Tree heights can be measured using the laser returns.

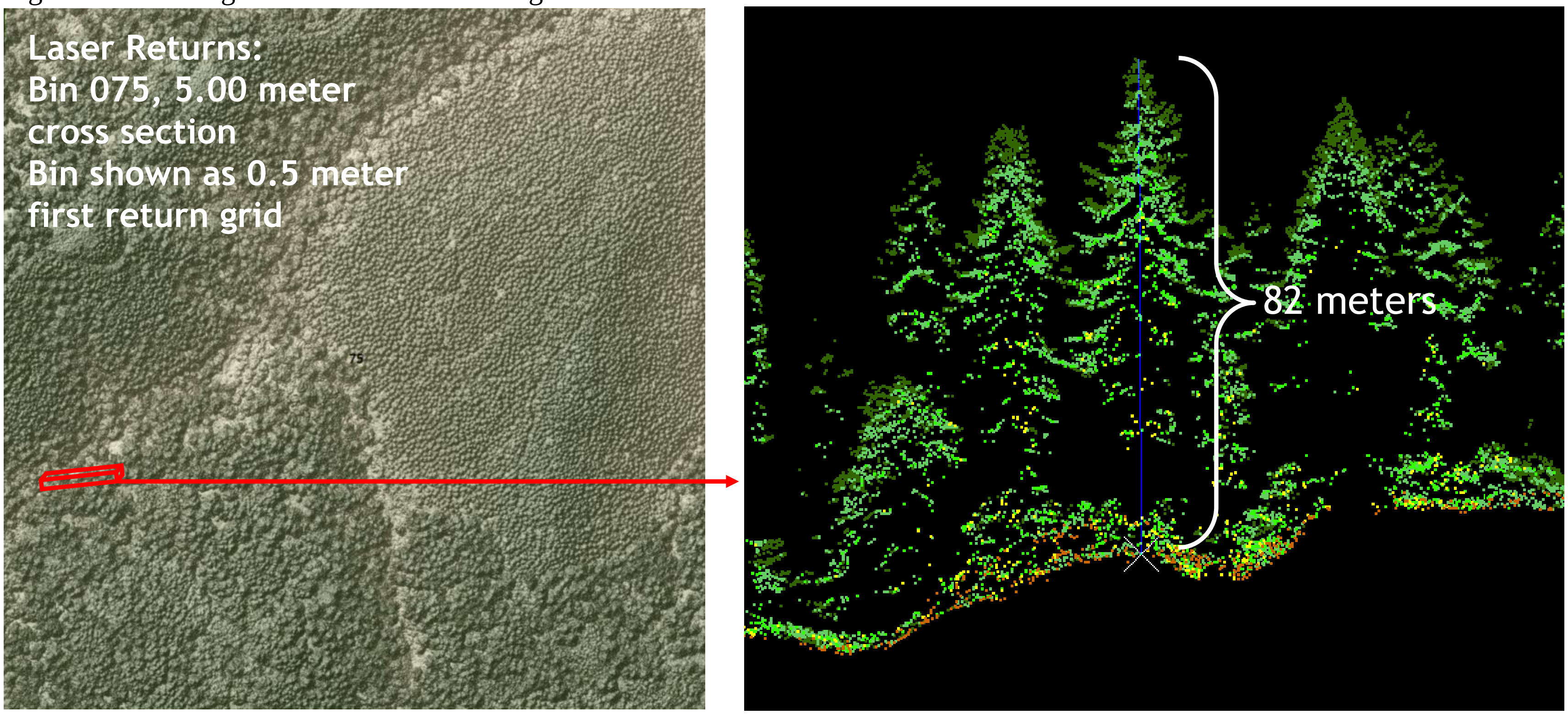


Figure 8. Elk Creek morphology near confluence of Rail Creek.

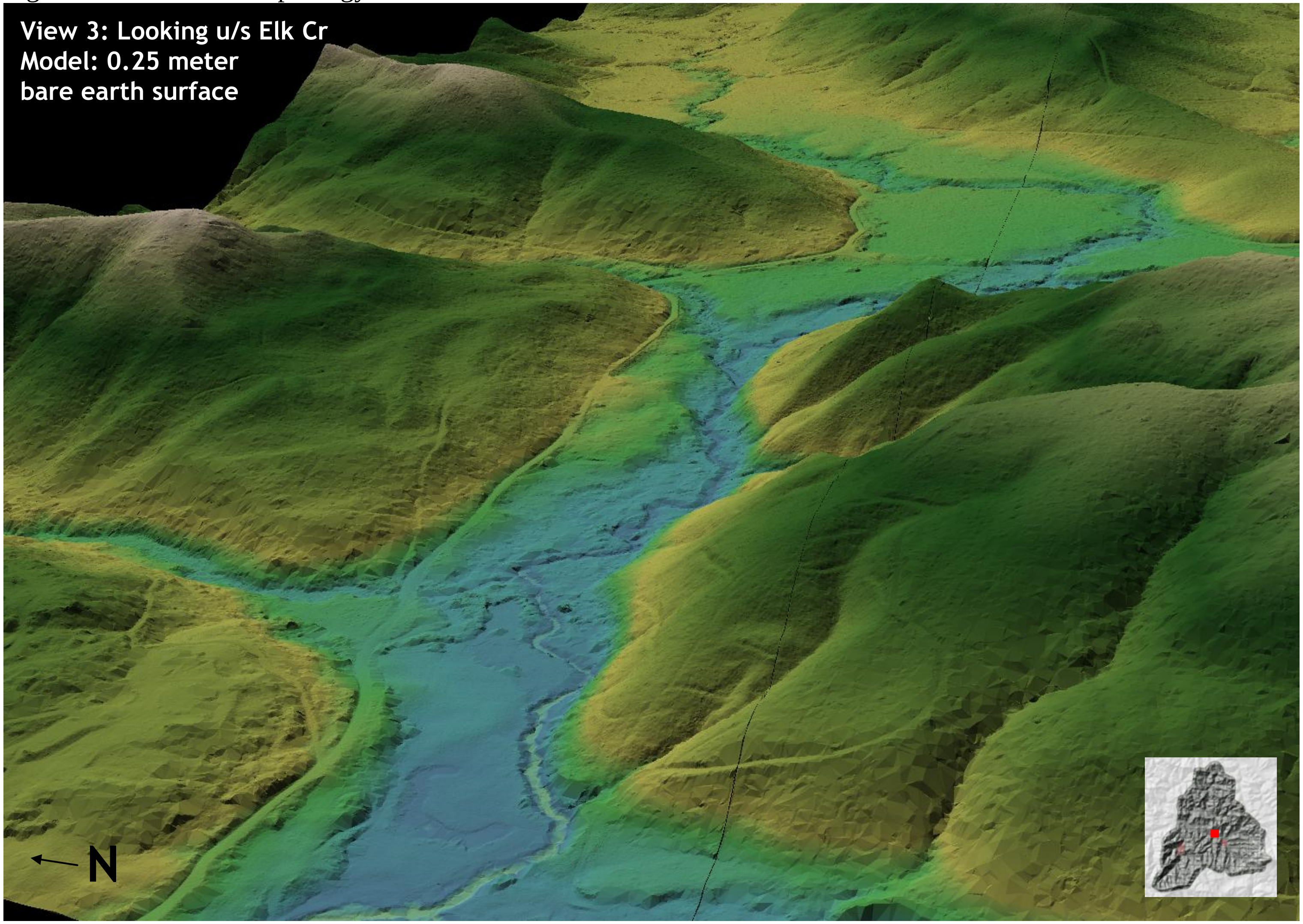


Figure 9. Elk Creek vegetation coverage.