Submitted to:

THE KLAMATH TRIBES
KLAMATH - MODOC - YAHOOSKIN

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Submitted by:

Watershed Sciences
Applied Remote Sensing & Analysis

June 3, 2005

Draft Report

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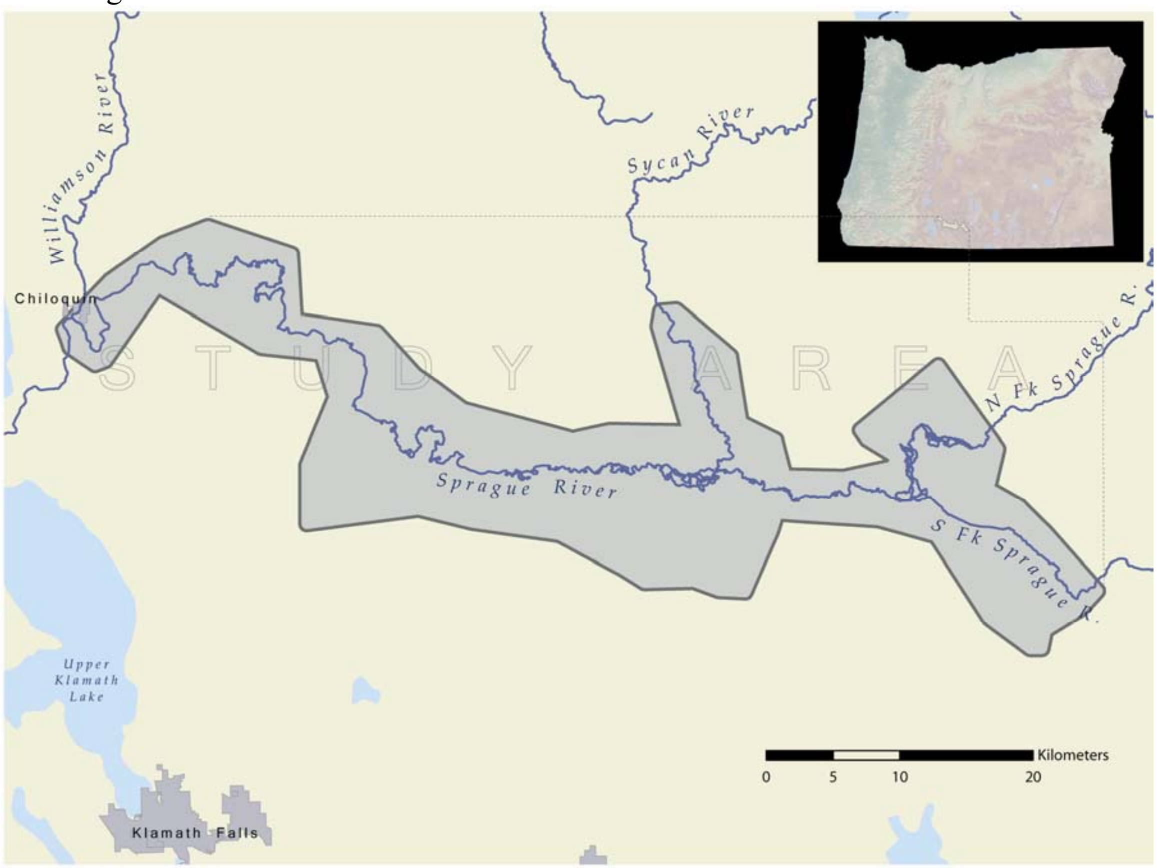
Overview

Watershed Sciences, Inc. (WS) collected Light Detection and Ranging (LiDAR) data for the Klamath Tribes over a seven day span in November, 2004. Conditions included leaf off and a normal fall low flow condition. The survey area encompassed the Sprague River, the lower Sycan River, and the lower reaches of the North and South Forks of the Sprague River. The study area was buffered by 500 meters to ensure complete coverage of important areas.

Figure 1. Full Extent of Study Area Buffered by 500 meters covering 185,018 acres. A detail of the bare earth model (second image below) shows where vegetation, structures and bridges are removed.

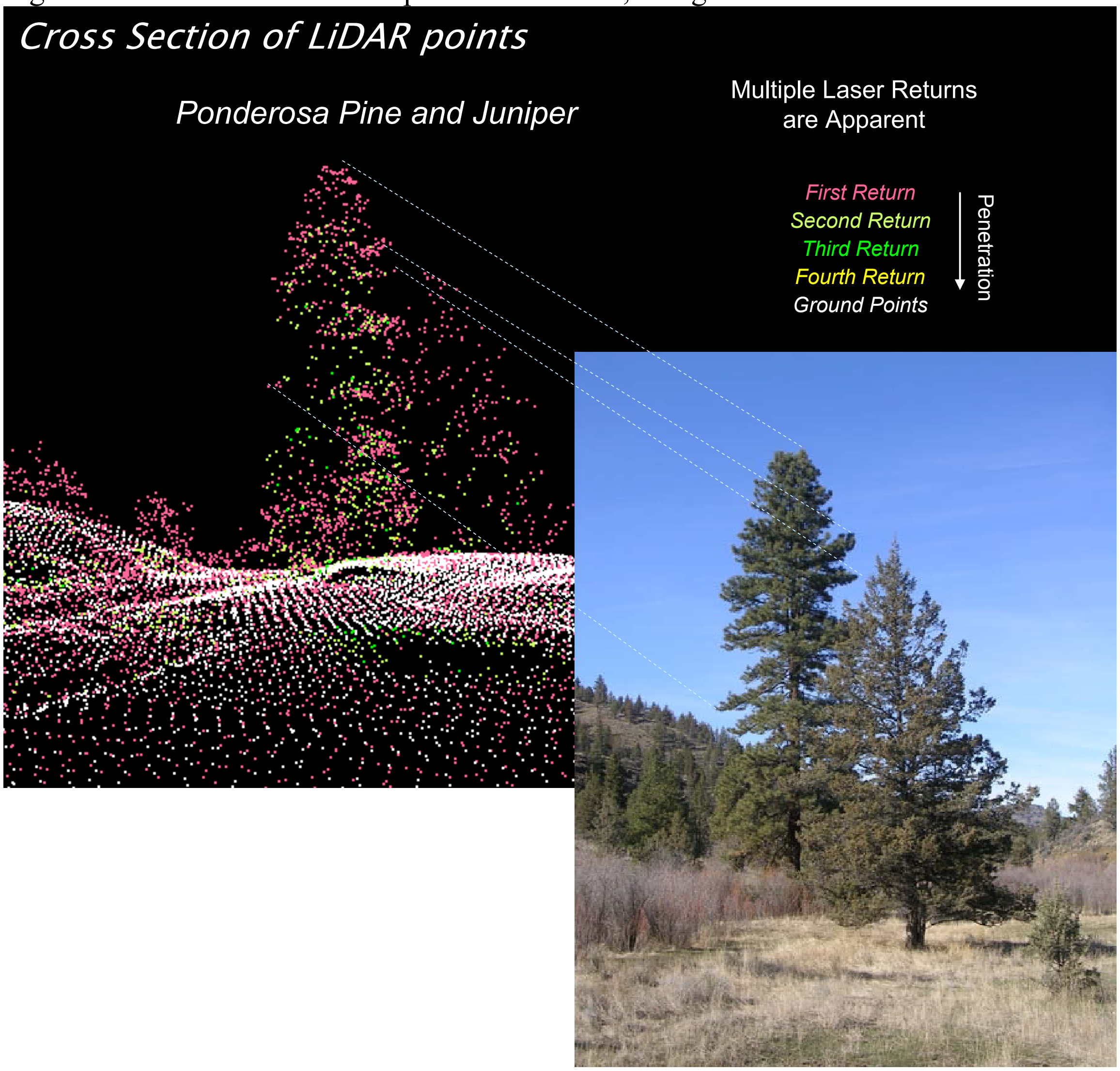


A total of 1,469,351,015 laser points were collected over the study area using an Optech ALTM 3100 LiDAR system set to acquire points at average spacing of less than 0.68 meters (greater than 2 points per square meter). The system also recorded individual return intensities (per laser return) that are used to create combined elevation models that display both elevation and surface reflectivity.

Two Trimble 5700 ground GPS units were deployed and used to process kinematic solutions to the onboard GPS and inertial measurement unit (IMU) using PosPAC v4.1. Points were computed per flight line using the REALM Survey Suite v3.4. 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.

Figure 2. Laser Returns – Multiple Laser Returns, along with Classified Ground Points.



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 967 RTK GPS measurements were compared to ground laser points collected along a variety of surfaces, such as roads, riparian zones, and fields to provide a greater diversity of points for comparison. The deviation RMSE is 0.052 meters, standard deviation is 0.051 meters, with a median (50^{th} percentile) absolute deviation of 0.032 meters and a 95^{th} percentile of 0.1057 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 0.04 – 0.06 meters (measured over known surface and compared to ground survey data).

Technical Approach

Data Collection

Our LiDAR system is mounted in the belly of a Cessna Caravan 208 (Figure 3). Quality control (QC) 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 50kHz laser repetition rate and flown at 1,000 meters AGL, capturing a 36^{o} scan width (18 ^{o} from NADIR). These settings yielded points with an average spacing of less than 0.68 meters (greater than 2 points per square meter). The entire area was surveyed with opposing flight line overlap of 30% to reduce laser shadowing and increase surface laser painting. While the system allows up to four range measurements per pulse, only the first and last returns were processed in the output. 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, two dual frequency DGPS Trimble 5700 base stations recorded fast static (1 Hz) data. Two stations were located at National Geodetic Survey (NGS) monuments in Chiloquin and Bly to minimize kinematic solution baselines and increase GPS data accuracy (Table 1).

A total of 987 quality control real-time kinematic (RTK) GPS data points were collected within the project area using a Trimble 5700 ground based DGPS station. Data collected were then compared to the processed LiDAR data to ensure accuracies across the project area.

Figure 3. The Cessna Caravan 208 - A removable composite cargo pod provides housing for GPS equipment and the LiDAR system and other remote sensing sensors.

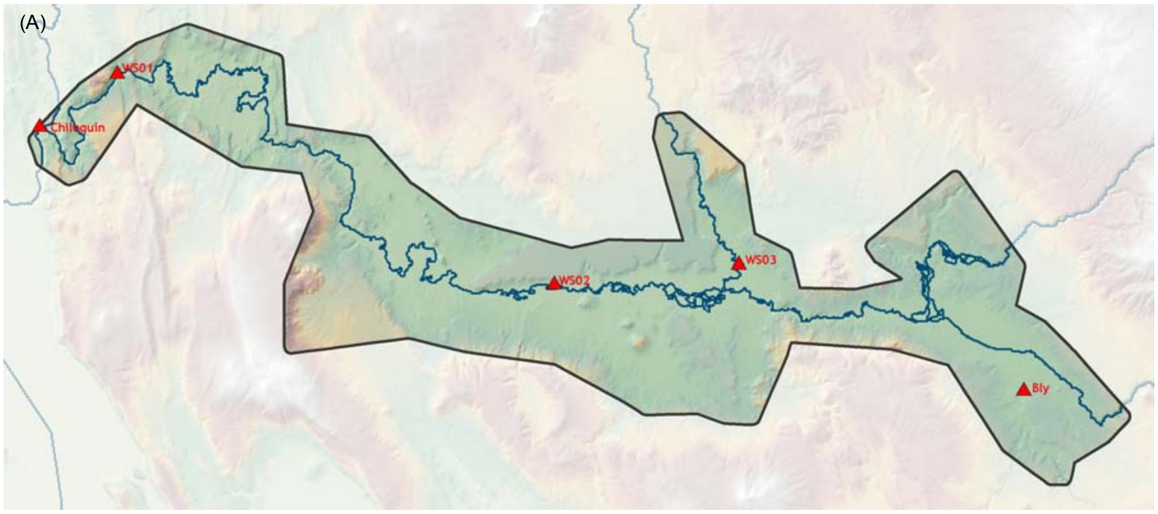
Flight Parameters

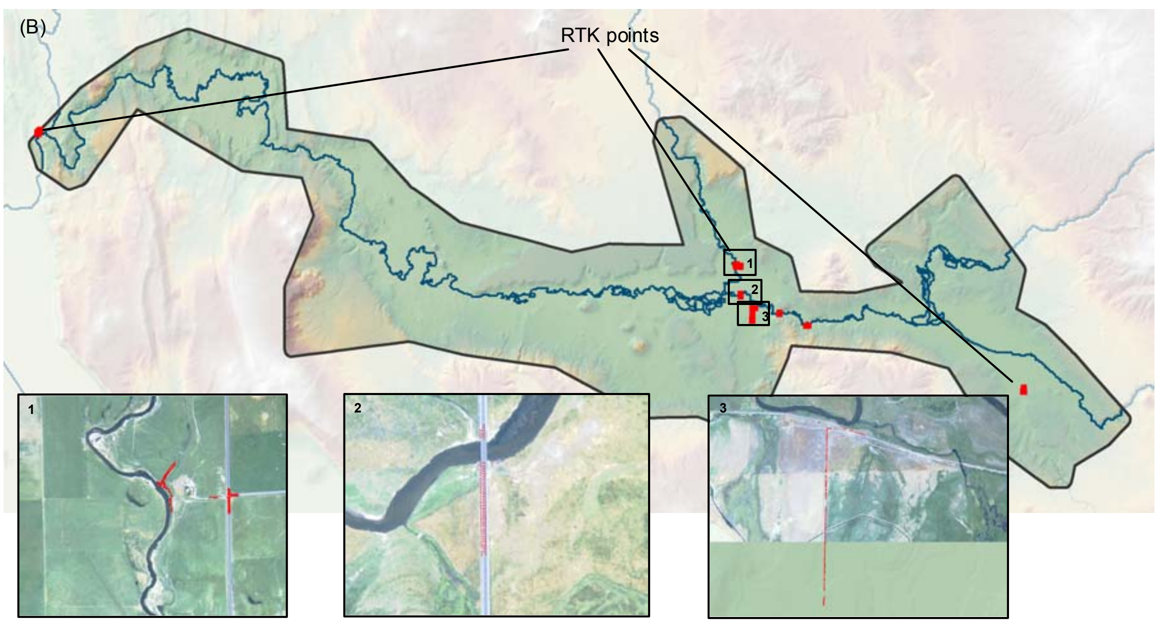
System:	Optech 3100
Flight AGL (m):	1,000 m
Flight Speed:	105 knots
Scan Width:	36° (18 ° from NADIR)
Scan Pulse Repetition Frequency (PRF):	50,000 pulses per second (50kHz)

Table 1. Base Station Surveyed Coordinates and Calculated Errors

			NAD83 NAVD88			
Point ID	***Latitude (North)***	***Error (m)***	***Longitude (West)***	***Error (m)***	***Ellipsoid Height (m)***	***Error (m)***
NY0503 Chiloquin	42°34'25.40452"	N/A	121°52'39.17350"	N/A	1251.65	N/A
NY0304 Bly	42°23'35.02732"	N/A	121°01'37.15389"	N/A	1319.57	N/A
WS 01	42°36'25.69739"	0.010m	121°48'33.34223"	0.010m	1275.080	0.014m
WS 02	42°28'03.11552"	0.013m	121°25'57.36710"	0.013m	1305.011	0.026m
WS 03	42°28'40.84468"	0.012m	121°16'18.31816"	0.012m	1294.700	0.023m

Figure 4. GPS Monuments and Ground Survey Points. (A) NGS monuments were used to survey fast static (1 Hz) data during the LiDAR survey. (B) A total of 967 ground survey points (RTK) were collected throughout the study area. These RTK points are used to assess data quality and accuracy.





Data Gaps: The study area was buffered by five hundred meters to ensure complete coverage. While there may be the appearance of data gaps, these are limited to areas under large buildings or over very still/calm water surface (ponds, pools, etc.) where the bare ground model required greater than 25 meters to build a triangle. In these cases, the models recorded no data.

The GRID data are furnished as total area flow and a shapefile mask is provided to denote the area where all survey parameters (flight line overlap and point density) are met. Recall that the are was over-flown, and areas outside of the original survey area are included. The GRID is not clipped due to the varied interests and applications of user in the in the Sprague watershed. Some may find the upland (and outside of study area) data useful. The mission specifications and reported accuracy of the data apply only to those data within the study area.

Data Processing

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 v4.1. Flight lines and LiDAR data were reviewed to insure complete coverage of the study area and positional accuracy of the laser points.

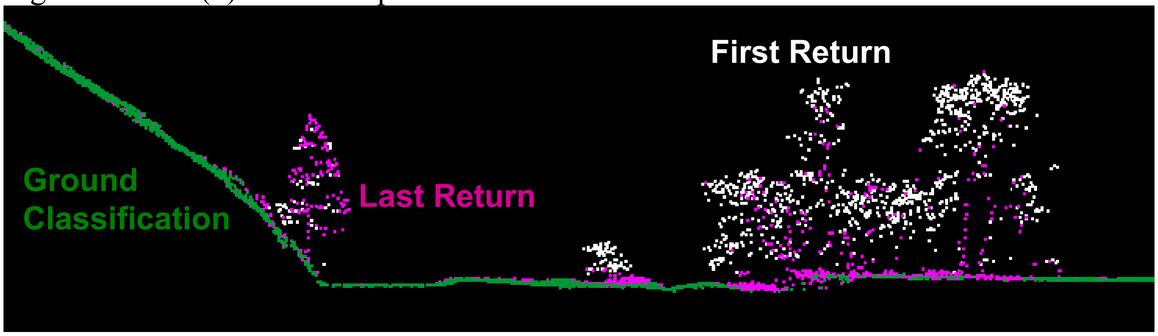
TerraScan Processing

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 465 individual bins with a maximum size of 2.25 km^2 (see Figure 6), capturing all 111 flight lines (see Figure 6).

Laser point returns (first and last) are assigned an associated (x, y, z) coordinate, along with unique intensity values. The raw LiDAR points were 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 laser points.

The TerraScan software suite is designed specifically for developing a standard bare earth model to remove buildings, vegetation, and other features. The initial bare earth model retains bridges and overpasses, and these artifacts are removed manually. 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 was only done in areas with known ground modeling deficiencies, such as: bedrock outcrops, cliffs, deeply incised stream banks, and dense vegetation.

Figure 5. Five (5) meter Deep Cross-Section of LiDAR Points



Description of Processing Steps:

Units: Meters
Projection: UTM Zone 10, NAD83 NAVD88, Geoid03

1. Import point data into 465 bins
2. Perform relative accuracy testing.
3. Removing False LiDAR Points: False high and low points were 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 88^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 bridges and highway spans.
6. Generate TINs within all bins (including points 100 m outside) and export ASCII lattice files for first return and ground points.
7. 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.
8. Create ESRI 1 meter GRIDs
9. Create ½ meter QTViewer GRIDs and point data.

Figure 6. Processing Bins – 465 Total Bins with maximum size of 2.25 km^2 (1.5 km x 1.5 km)

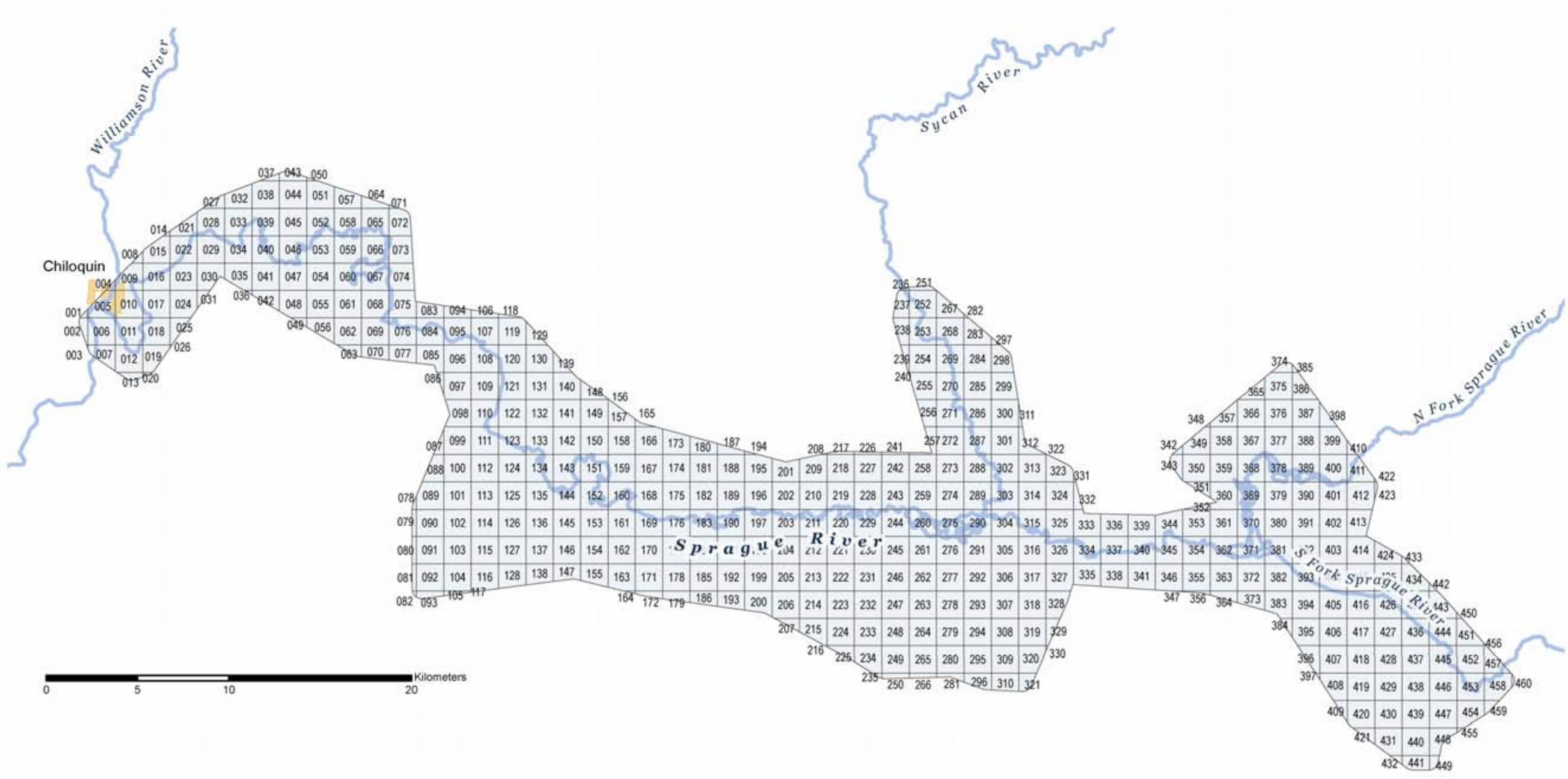
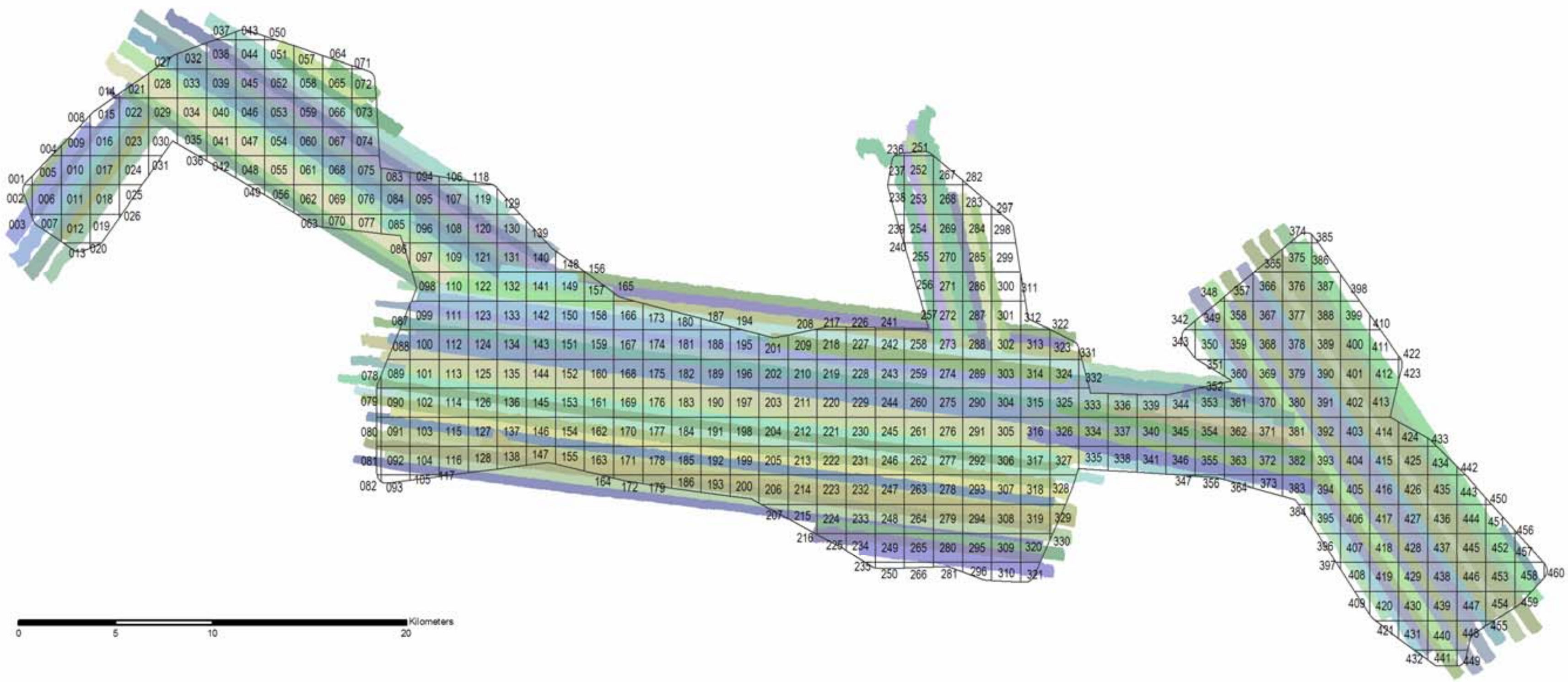


Figure 7. Survey Flight Lines (111 Total Lines), 30% overlap on each side (60% total overlap) and Scan Width of Each Flight Line (643 meters). Each color is an individual flight line.



Statement of Accuracy

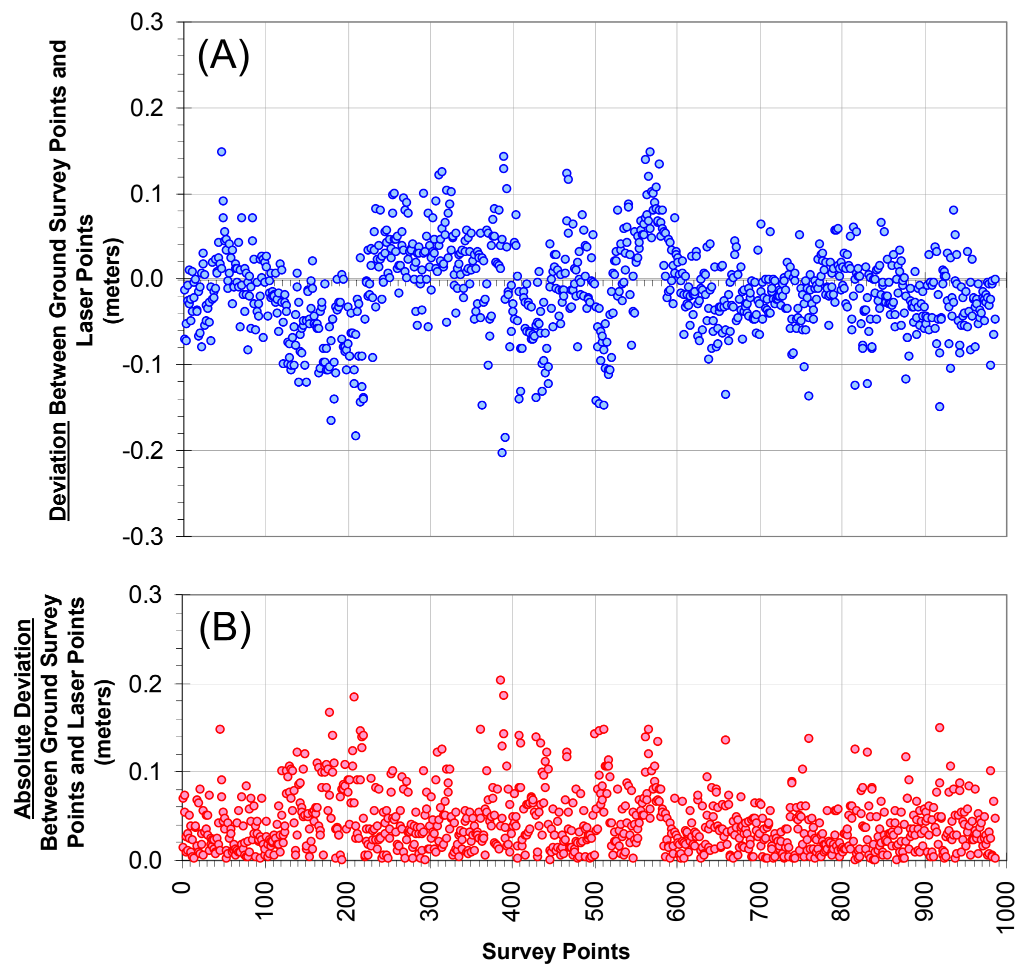
Absolute Accuracy – Divergence between laser points and survey points.

Figure 8. Point Divergence Statistics (Watershed Sciences Real Time Kinematic Survey Points)

Laser Points compared to Watershed Sciences Real Time Kinematic Survey Points

Standard Deviation:	0.051 m	5th Percentile:	0.003 m
RMSE:	0.052 m	25th Percentile:	0.016 m
n:	987	50th Percentile:	0.032 m
Minimum Δz:	-0.203	75th Percentile:	0.056 m
Maximum Δz:	0.147	95th Percentile:	0.106 m
Average Magnitude:	-0.013 m		

(A) Ground survey point deviation from laser points
(B) Absolute deviation from laser points

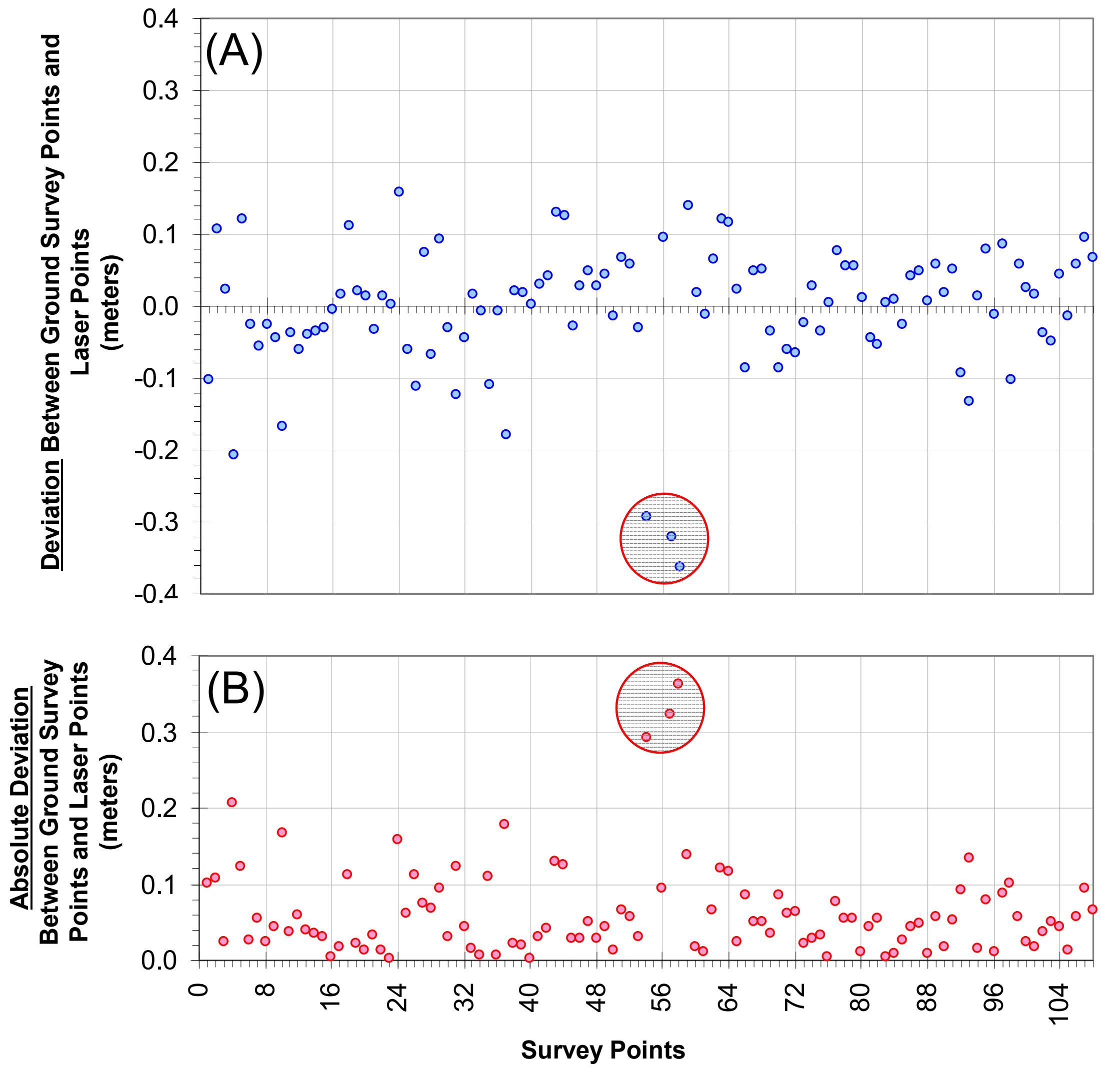


Ground survey points were collected with GPS Real Time Kinematic (RTK) corrections and are accurate to ≤ 2 cm.

Figure 9. Point Divergence Statistics (USFWS Survey Control Points)

Laser Points compared to USFWS Survey Control Points

Standard Deviation:	0.098 m	5th Percentile:	0.007 m
RMSE:	0.098 m	25th Percentile:	0.024 m
n:	108	50th Percentile:	0.047 m
Minimum Δz:	-0.453	75th Percentile:	0.086 m
Maximum Δz:	0.158	95th Percentile:	0.175 m
Average Magnitude:	-0.067 m		



Note that three survey points have roughly twice the inaccuracy as the other points. One of these point is within the Sycan River active channel and the other two are located on a upper bench above the floodplain.

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 that 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 30% side over-lap 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.

Deliverables

- Point data provided in ascii format
- 1 meter ESRI GRIDs (bare earth and first return)
- ½ meter QTViewer GRIDs (bare earth and first return) and point data
- Metadata and accuracy reporting

All data reported in:

Units: Meters

Projection: UTM Zone 10, NAD83 NAVD88, Geoid03

Selected Images

Figure 10. Upper Sprague River 1 meter ESRI GRID data

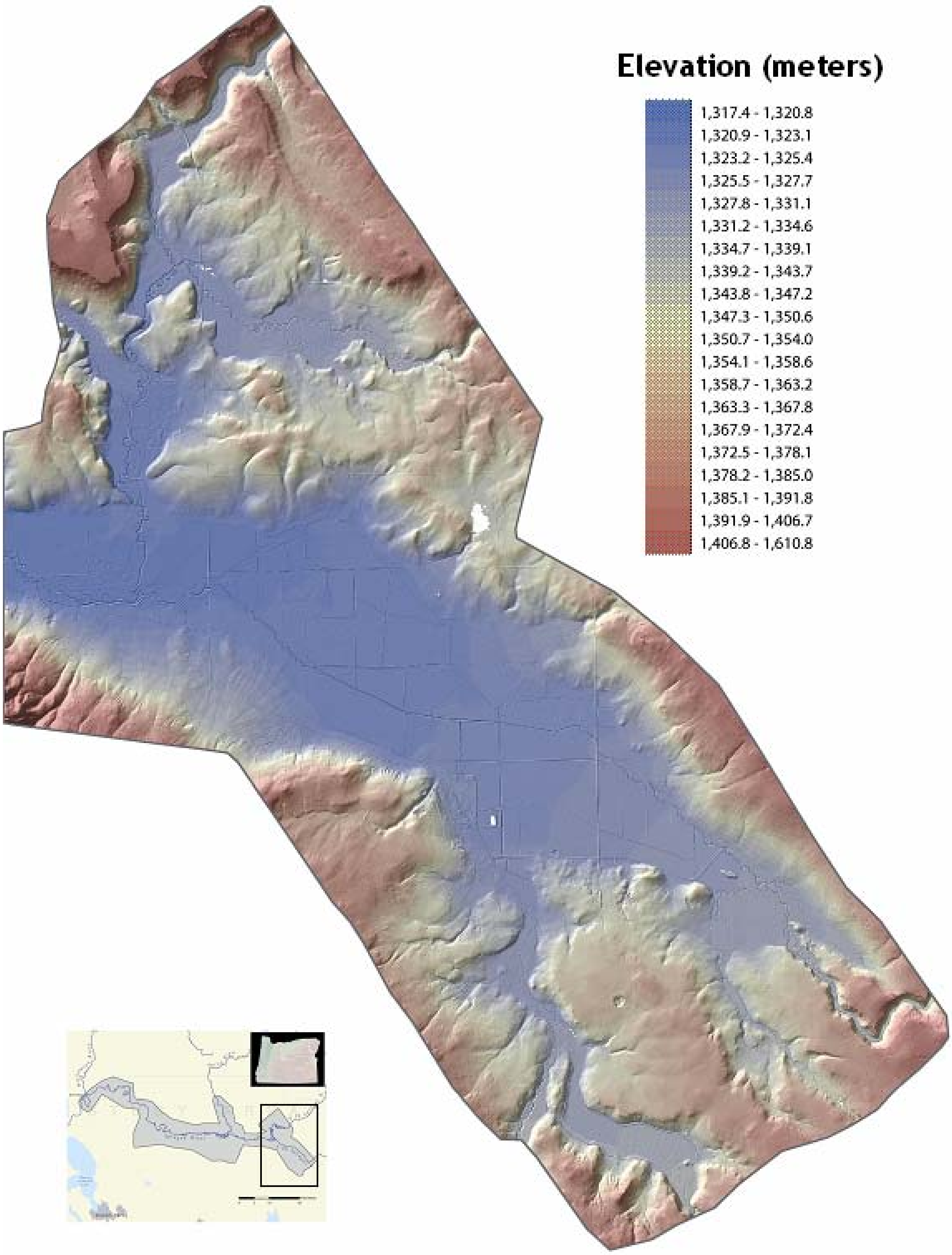


Figure 11. Extent of Study Area Showing Locations of Modeled Details

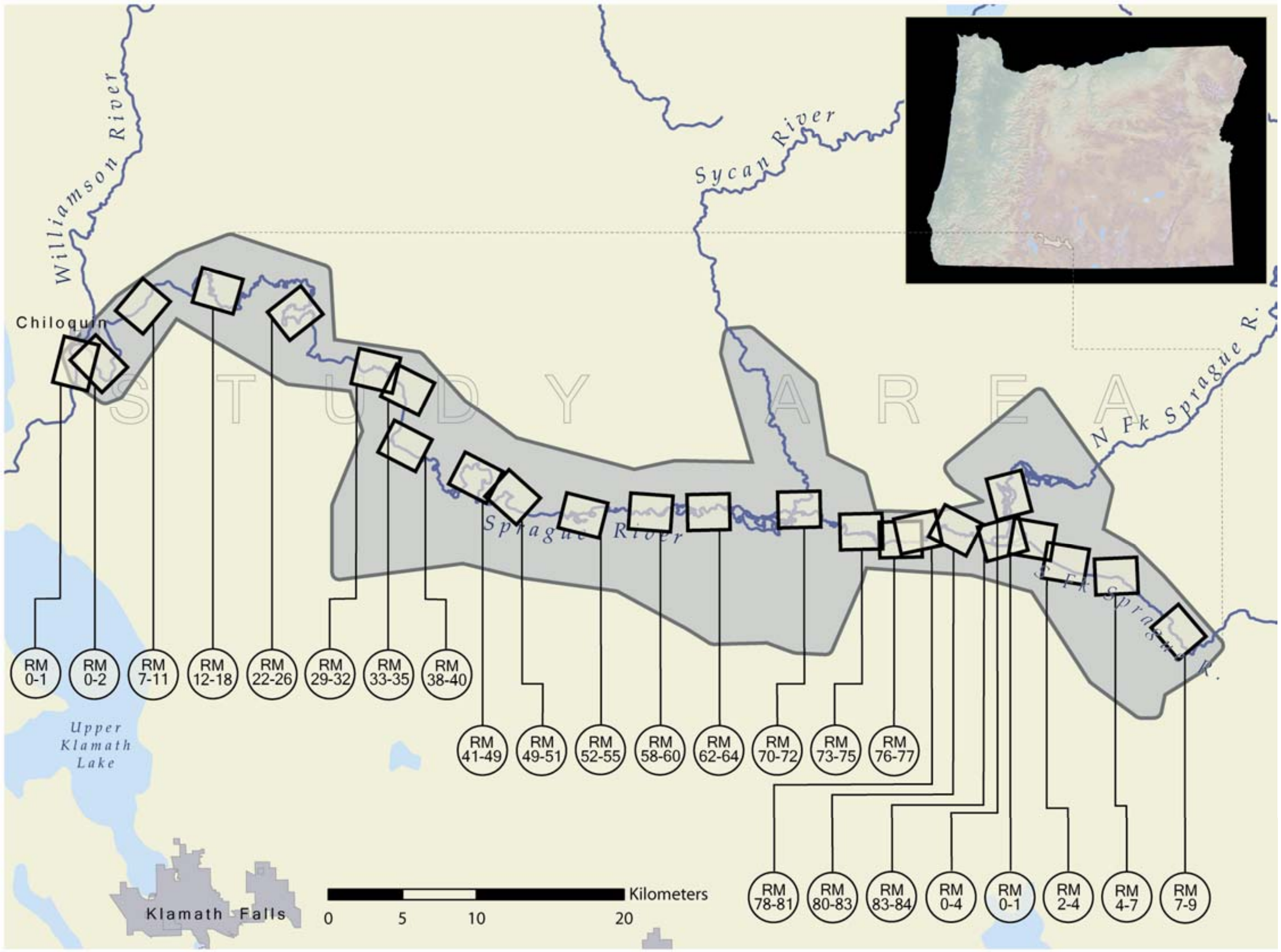


Figure 12. Sprague RM 0-1

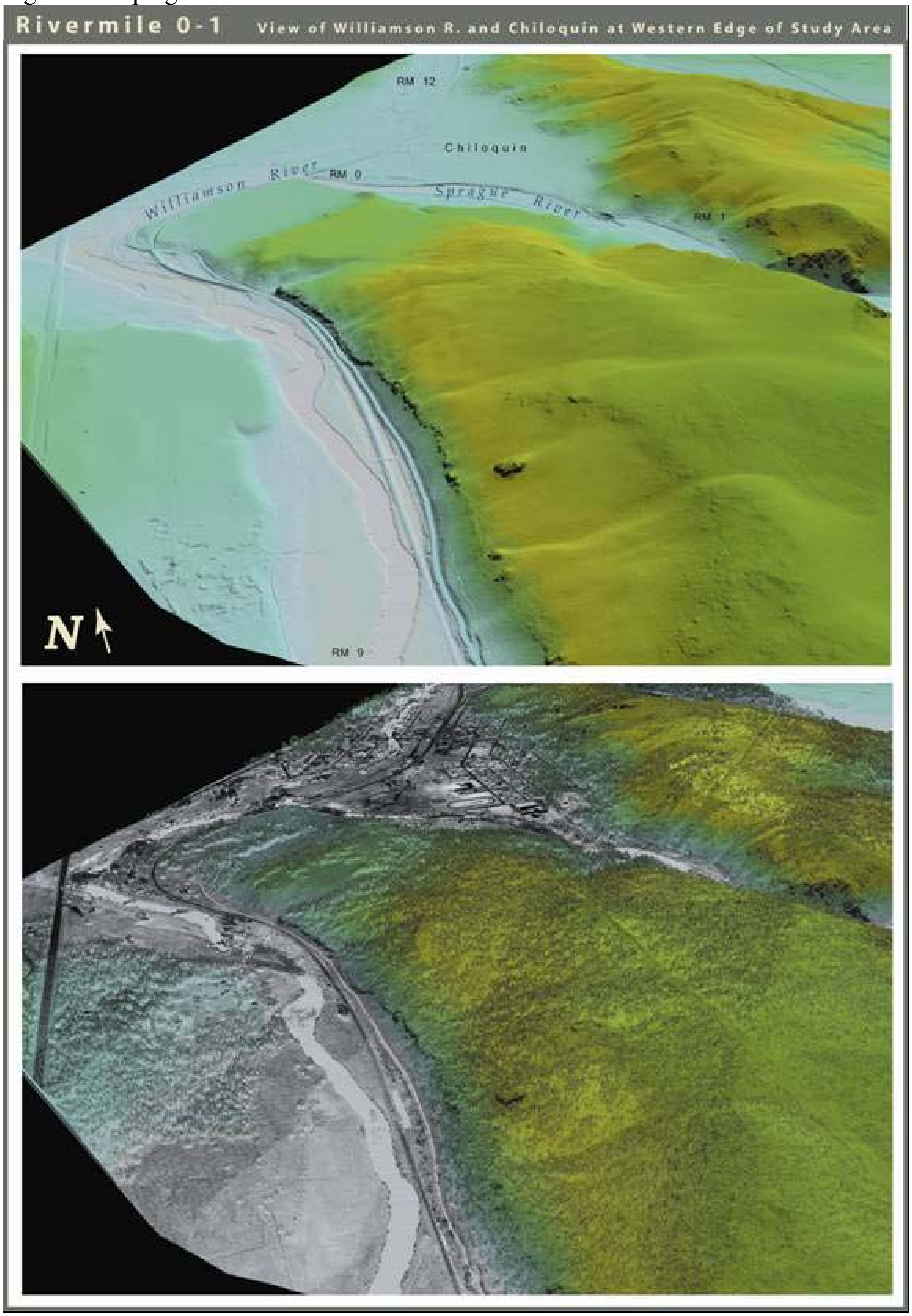


Figure 13. Sprague RM 0-2

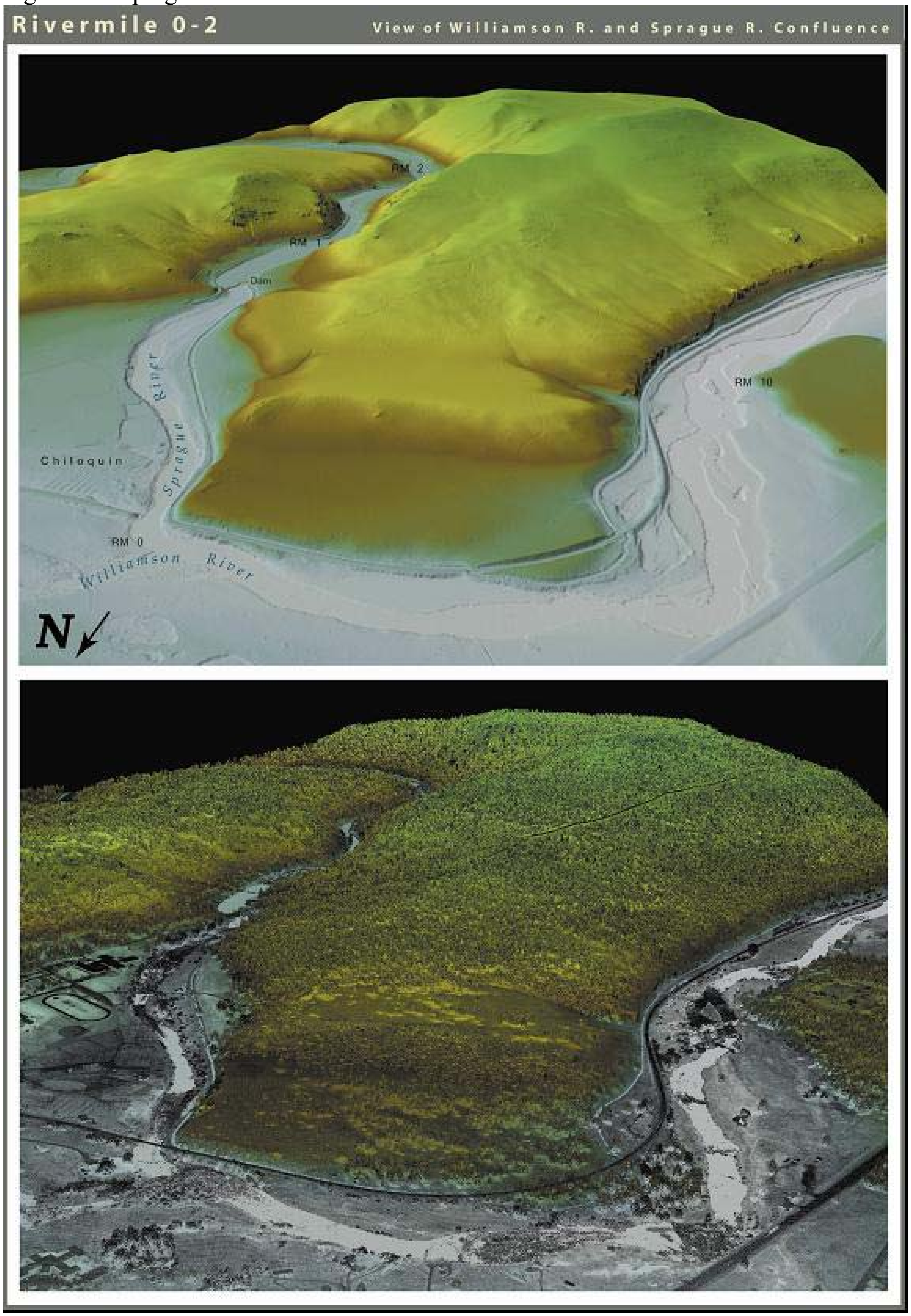


Figure 14. Sprague RM 7-11

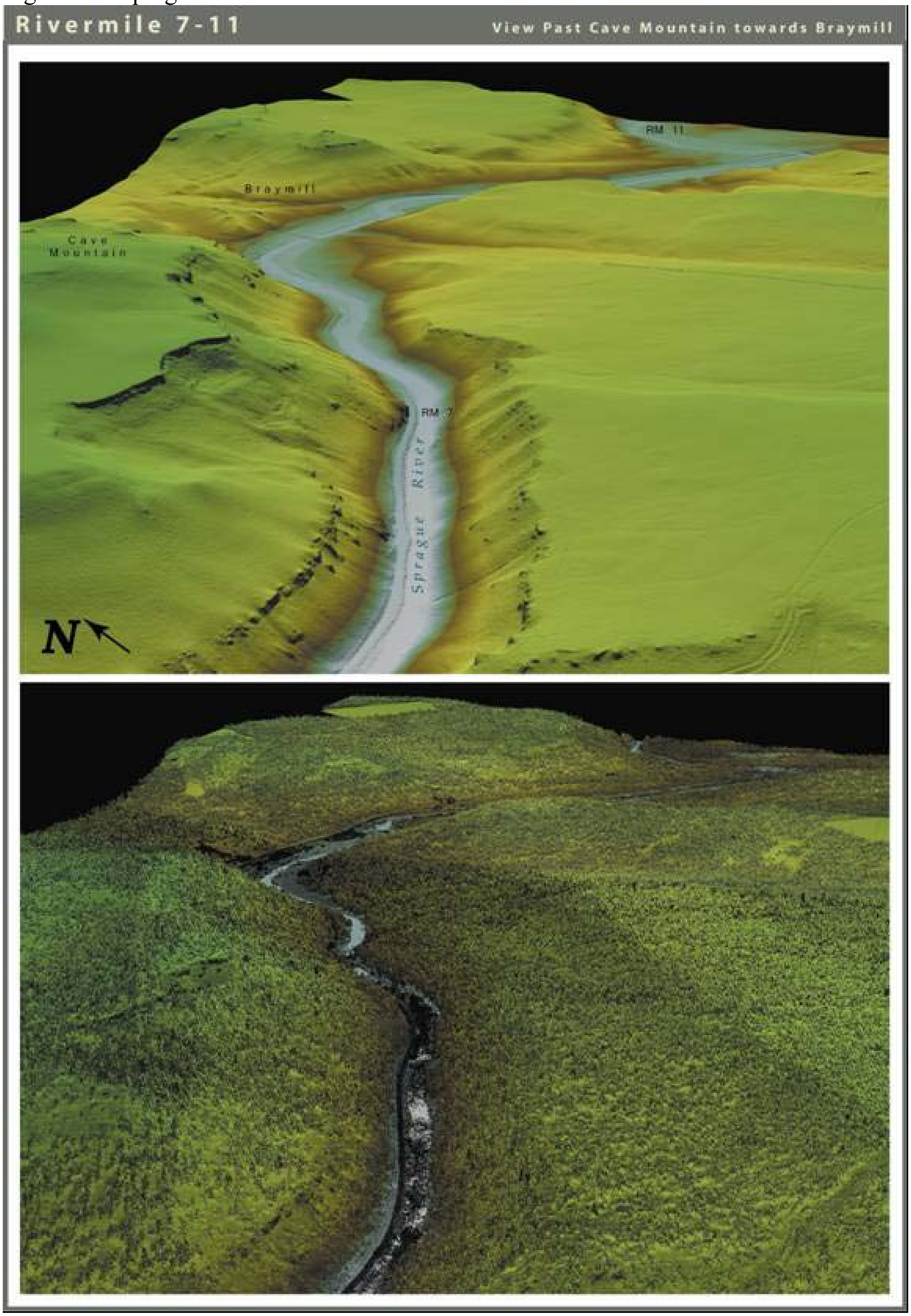


Figure 15. Sprague RM 12-18

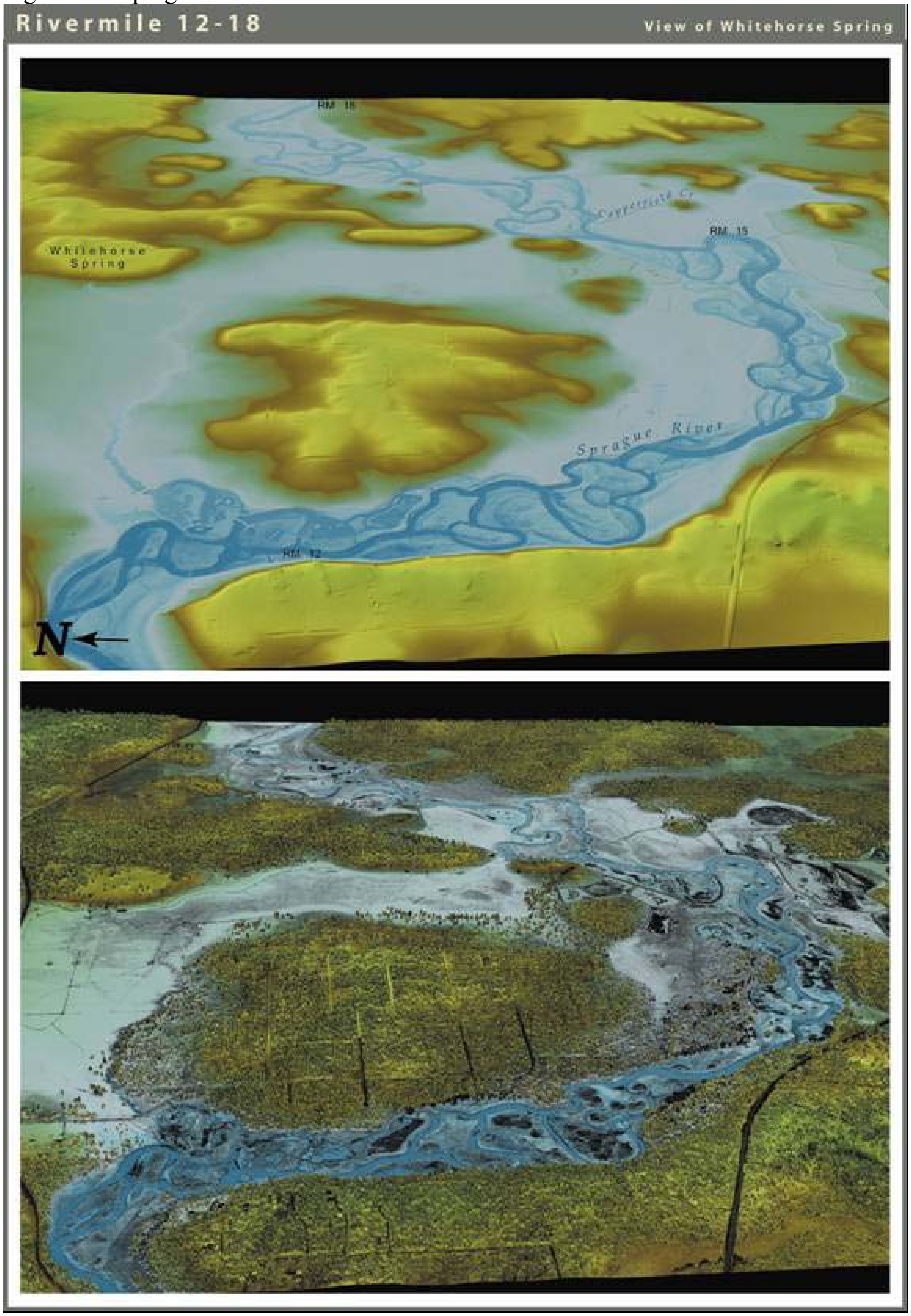


Figure 16. Sprague RM 22-26

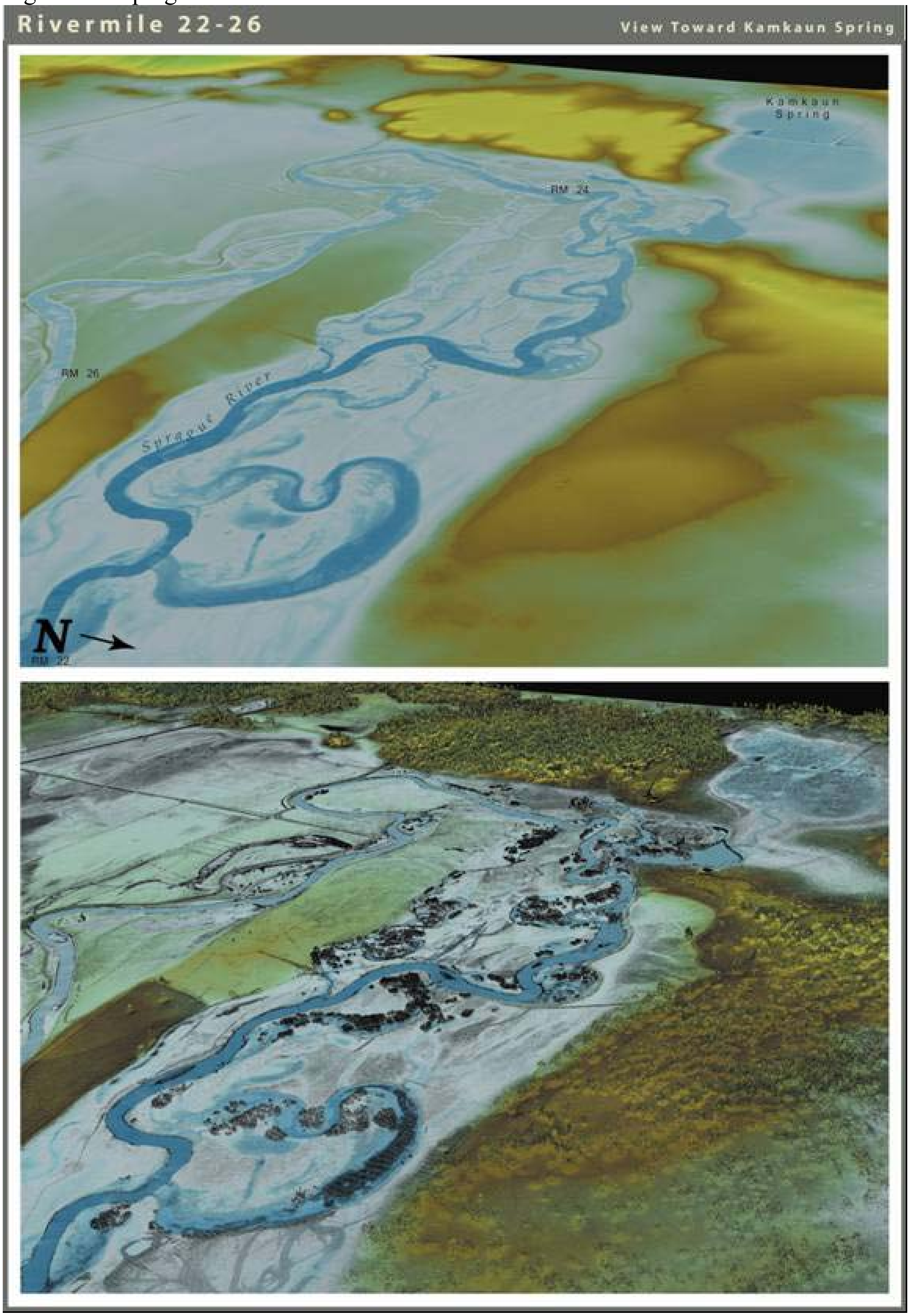


Figure 17. Sprague RM 29-32

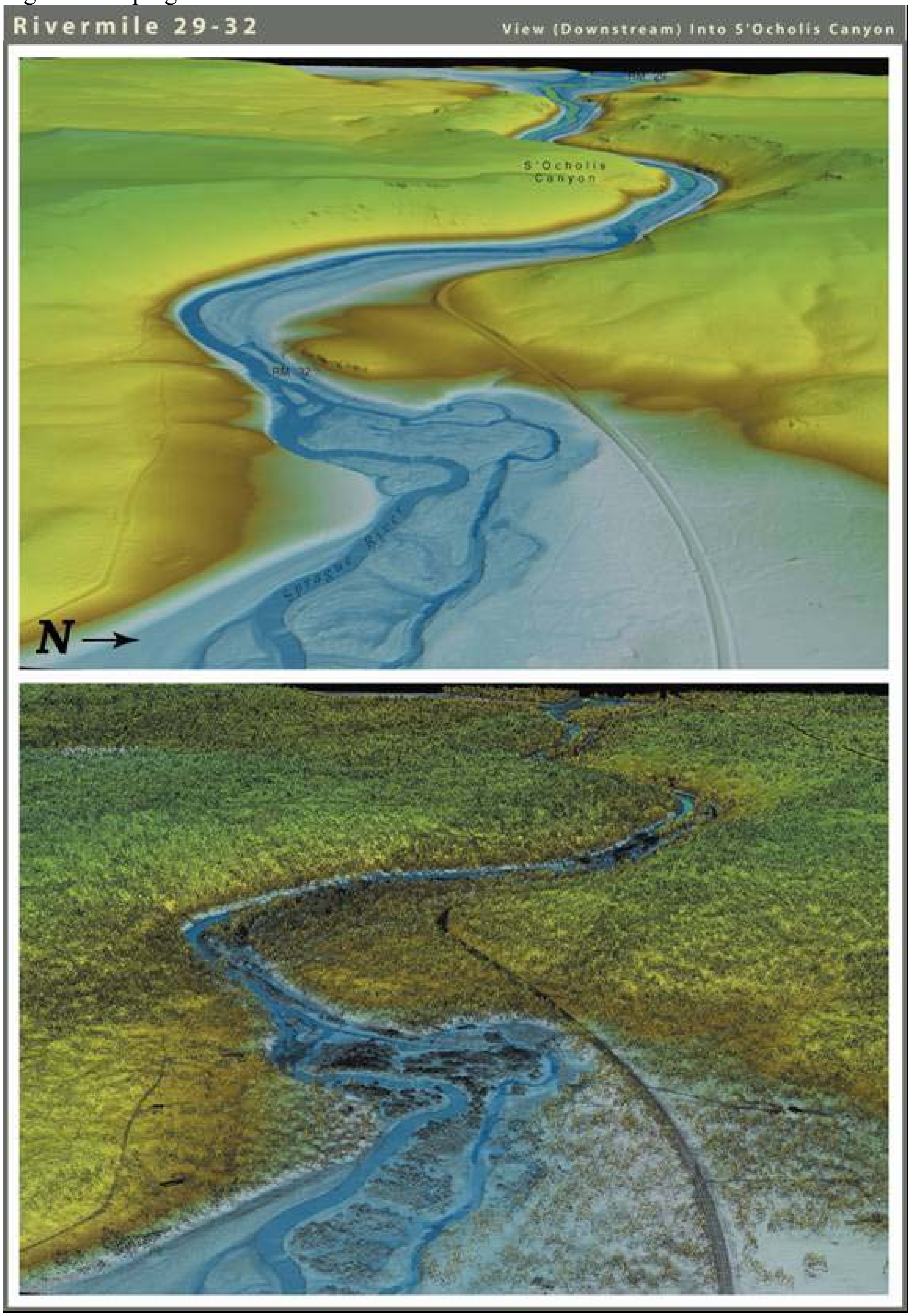


Figure 18. Sprague RM 33-35

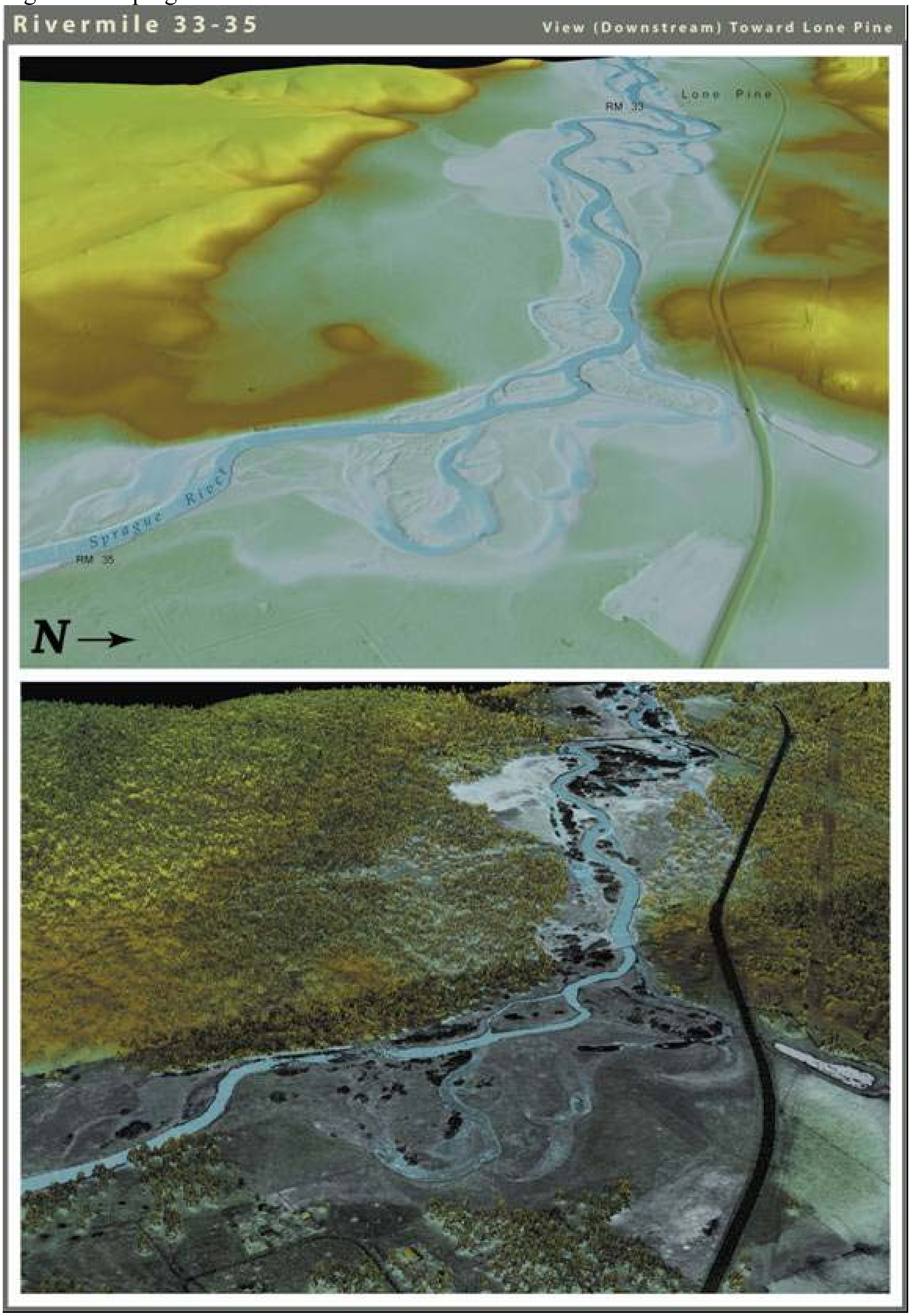


Figure 19. Sprague RM 38-40

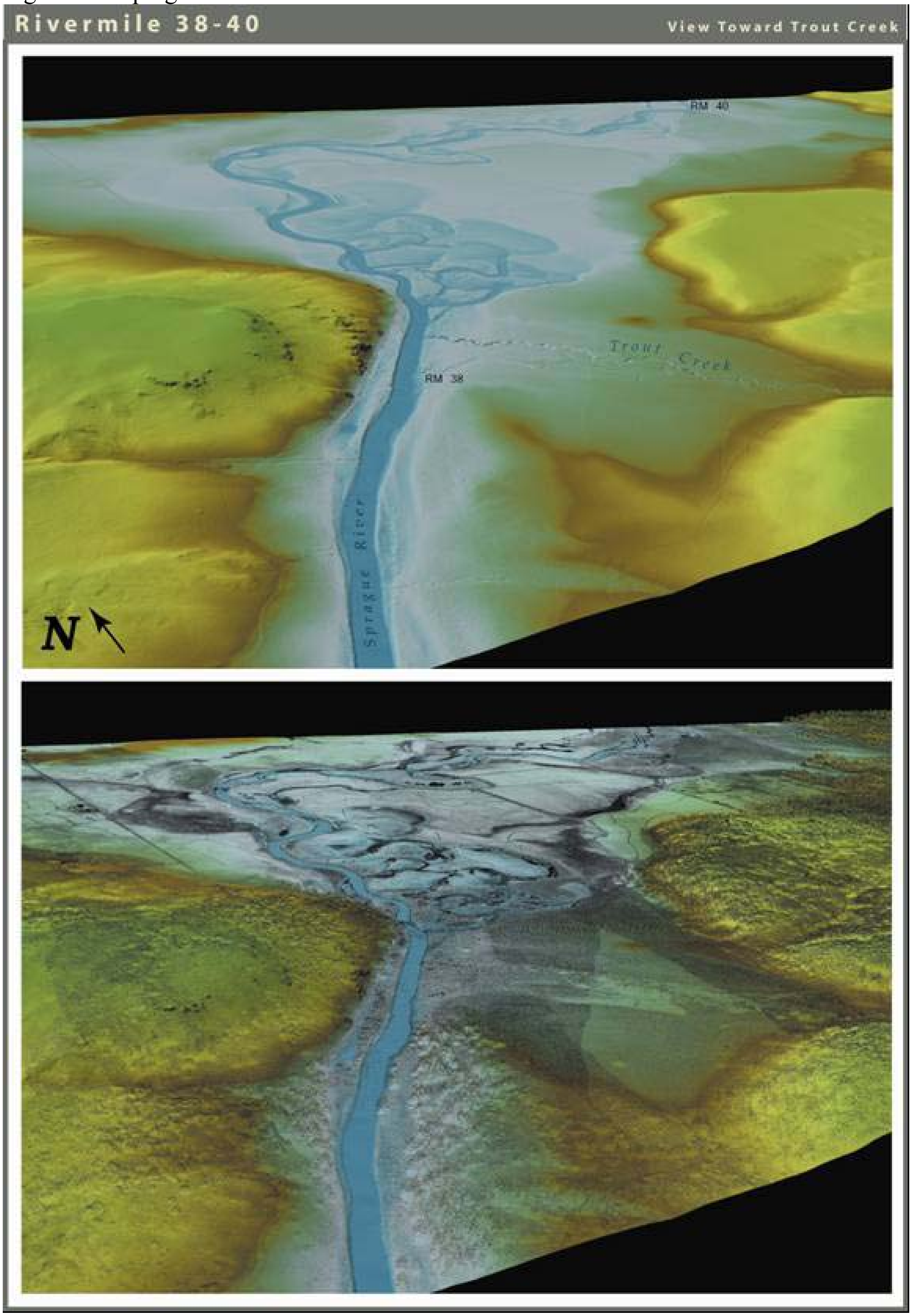


Figure 20. Sprague RM 41-49

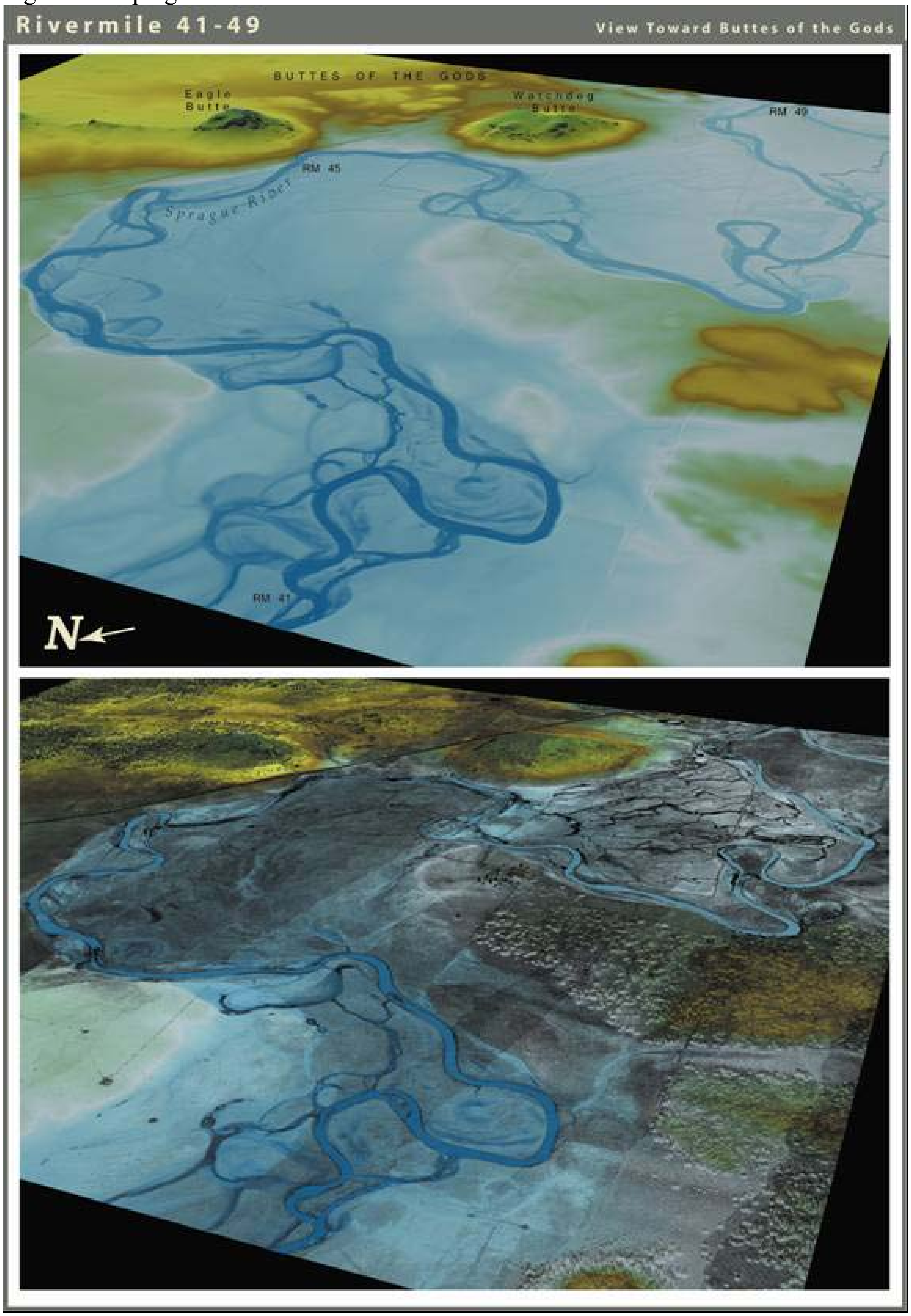


Figure 21. Sprague RM 49-51

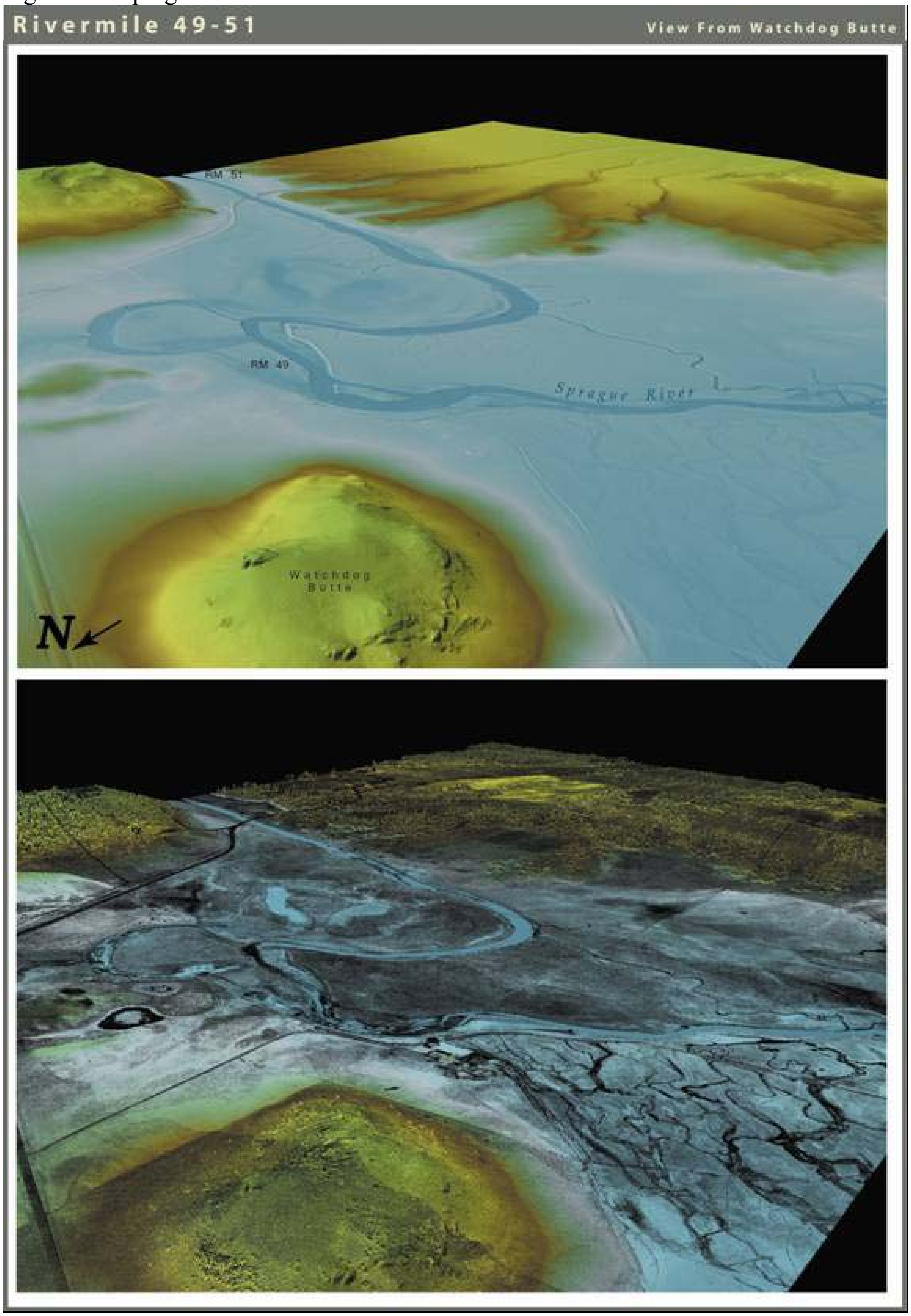


Figure 22. Sprague RM 52-55

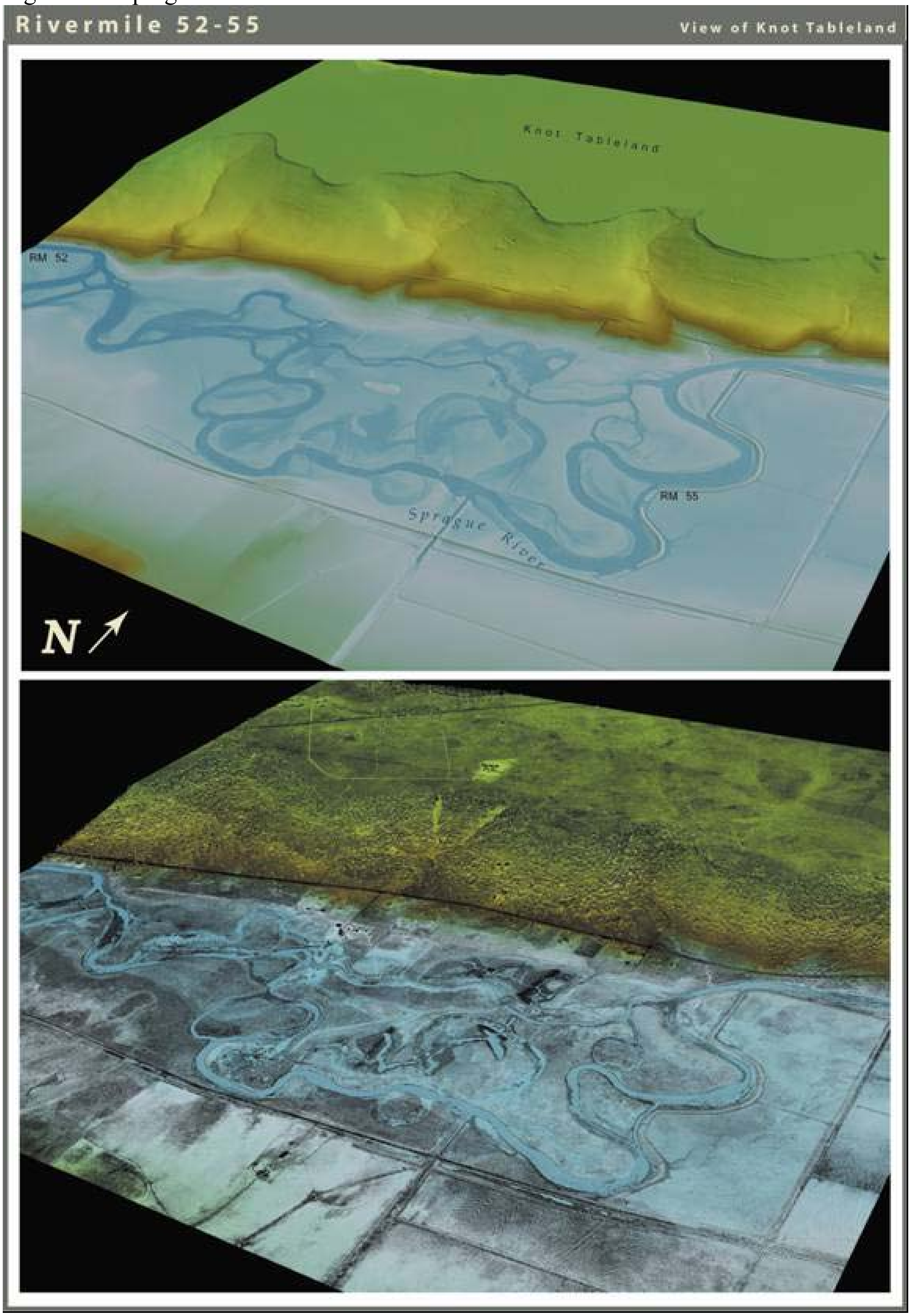


Figure 23. Sprague RM 58-60

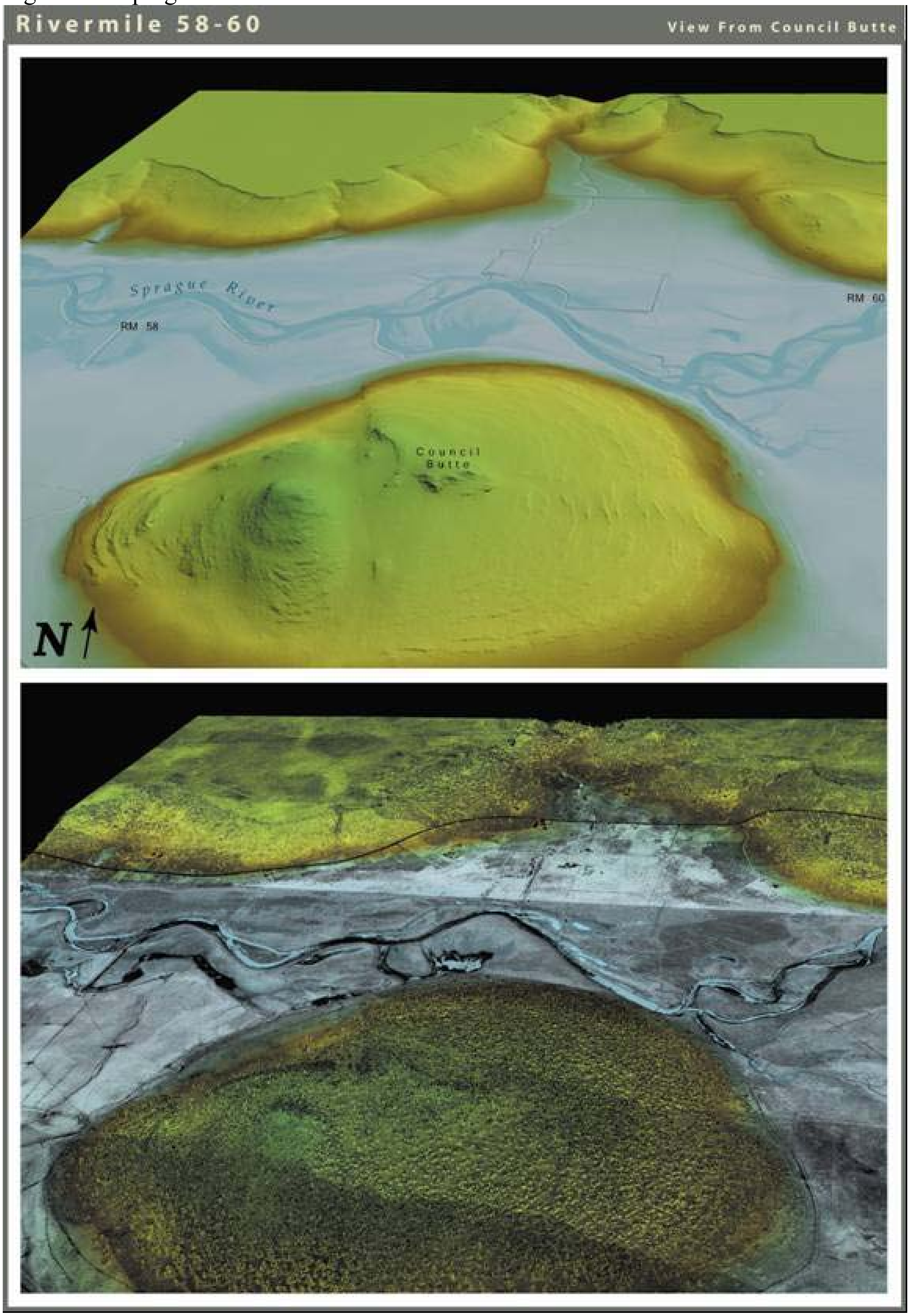


Figure 24. Sprague RM 62-64

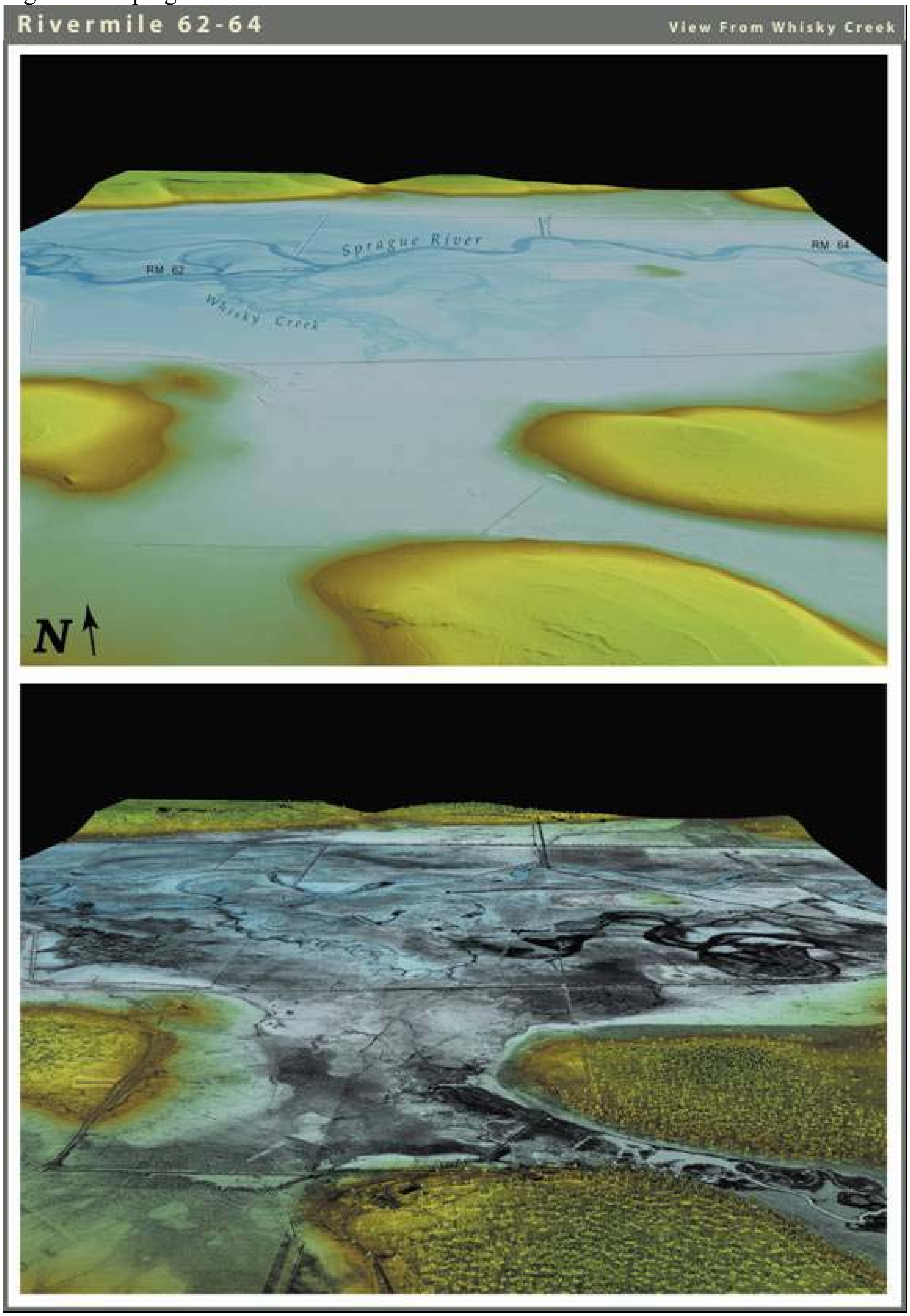


Figure 25. Sprague RM 70-72

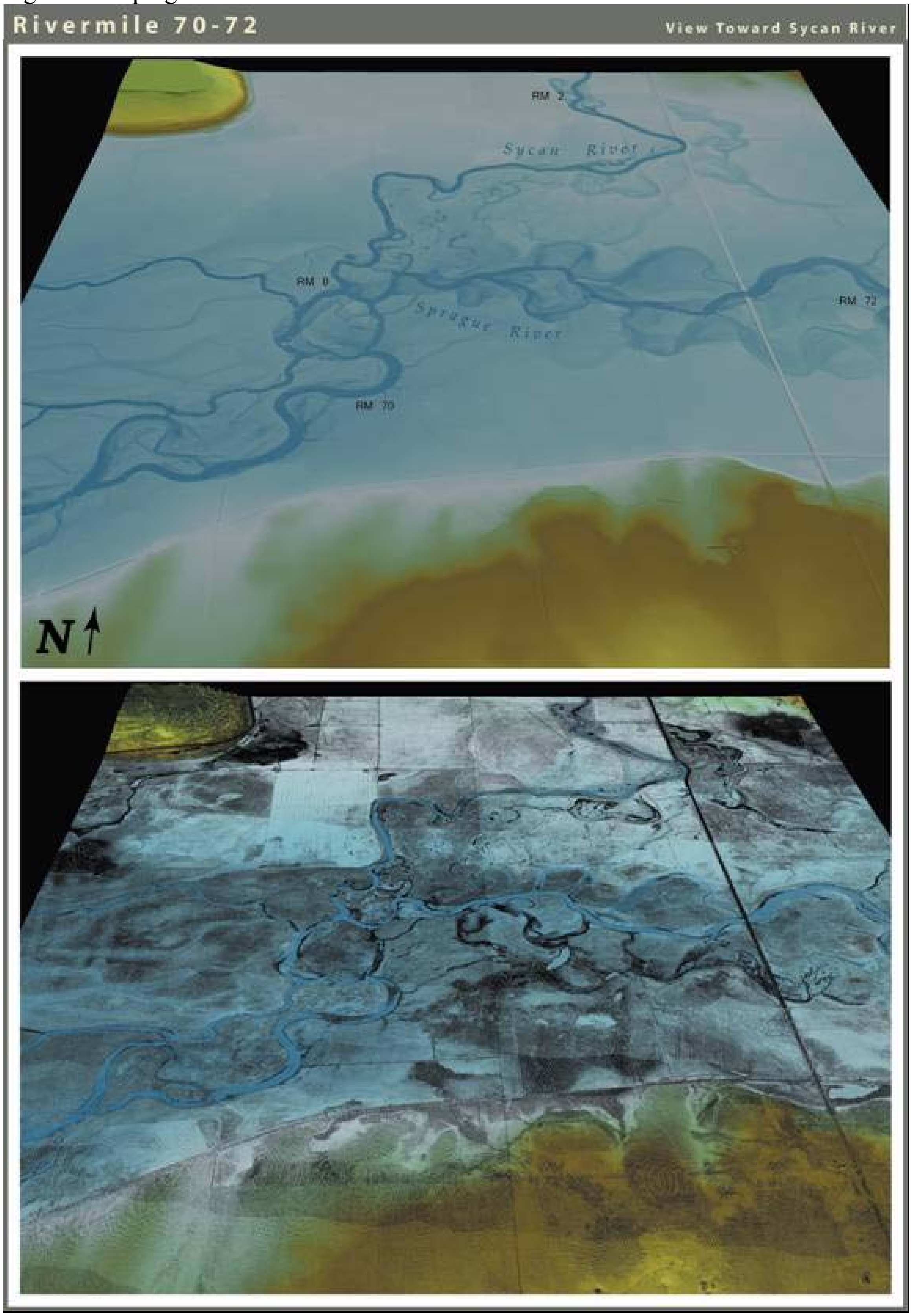


Figure 26. Sprague RM 73-75

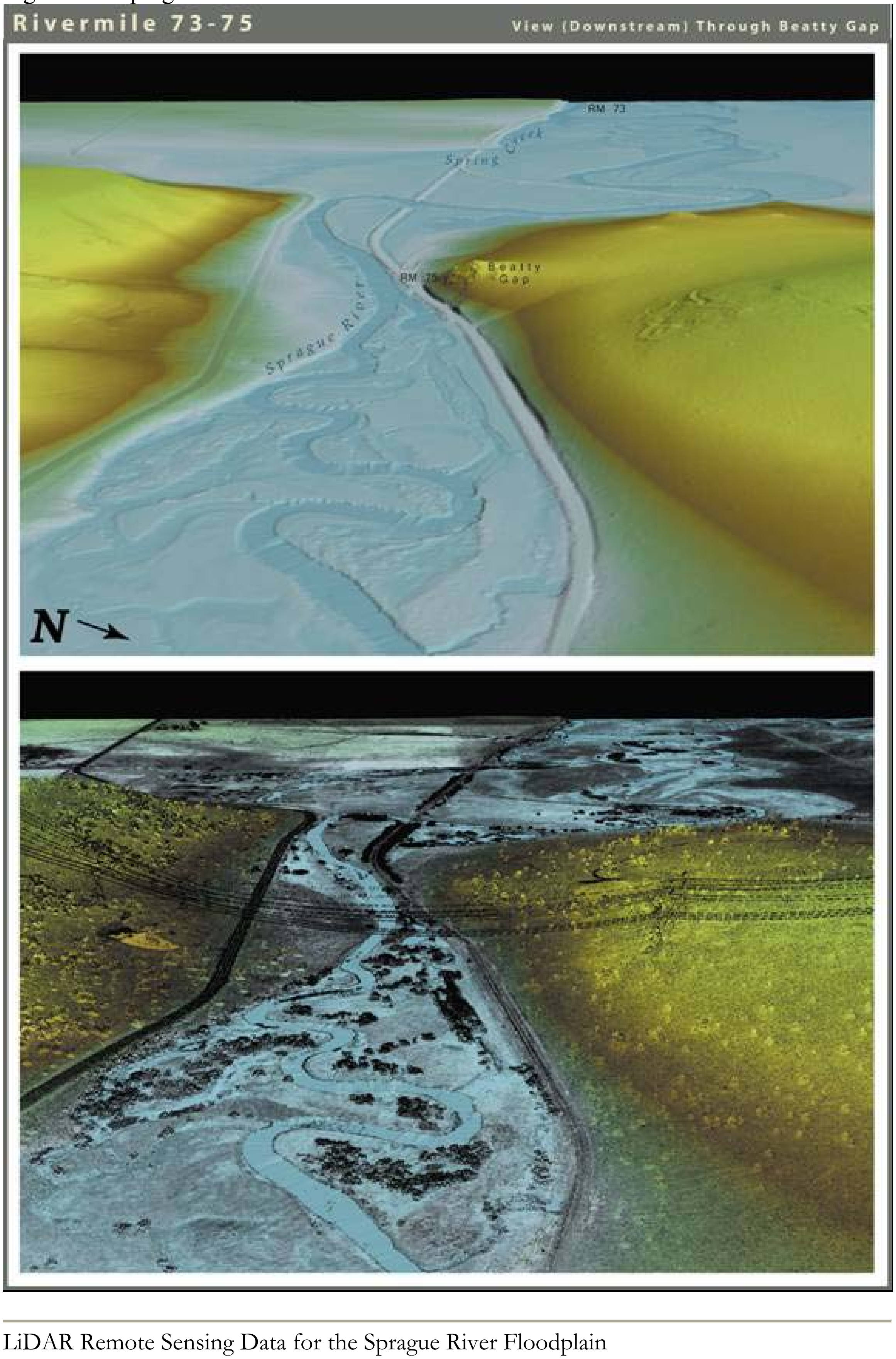


Figure 27. Sprague RM 76-77

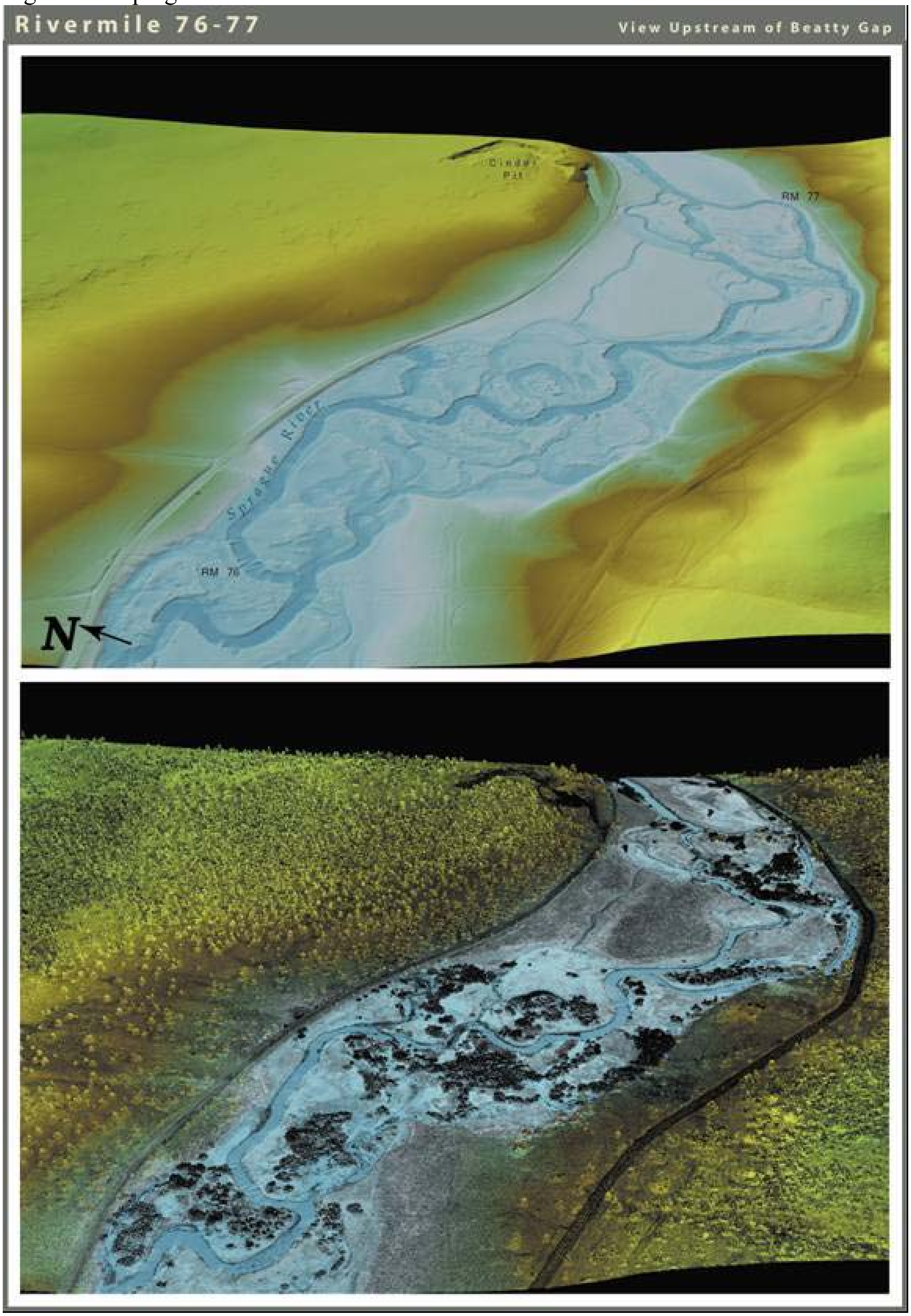


Figure 28. Sprague RM 78-81

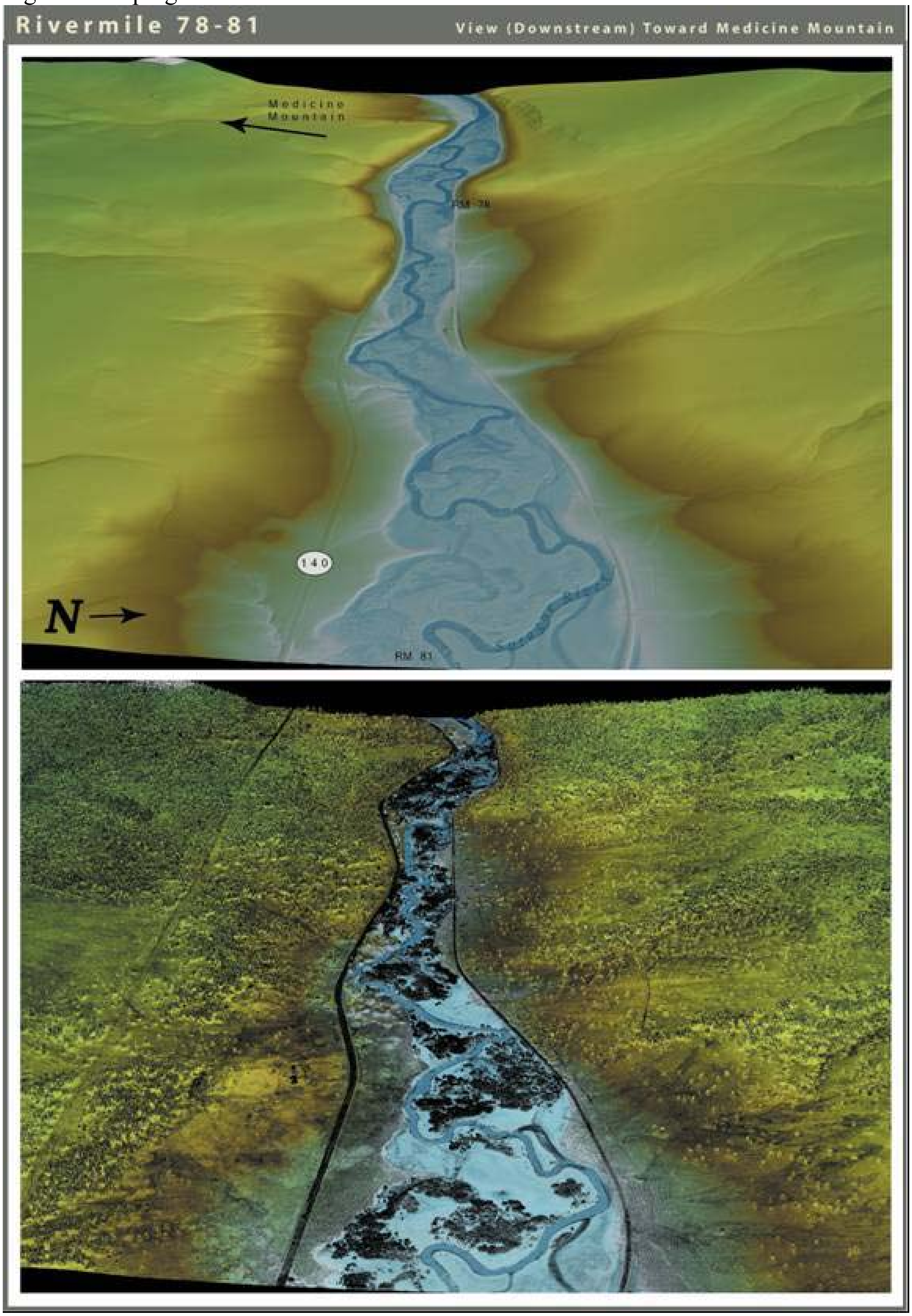


Figure 29. Sprague RM 80-83

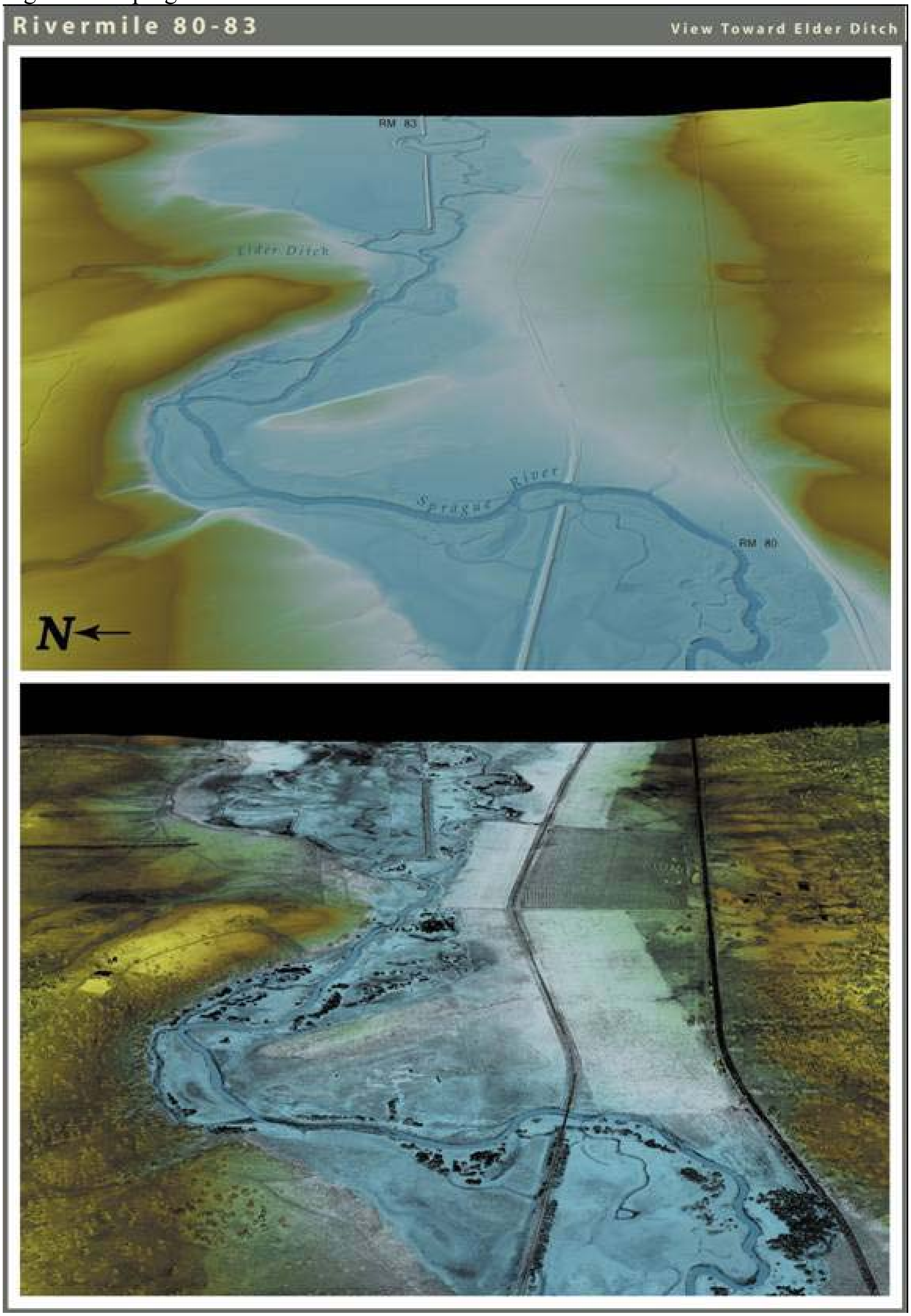


Figure 30. Sprague RM 83-84.6

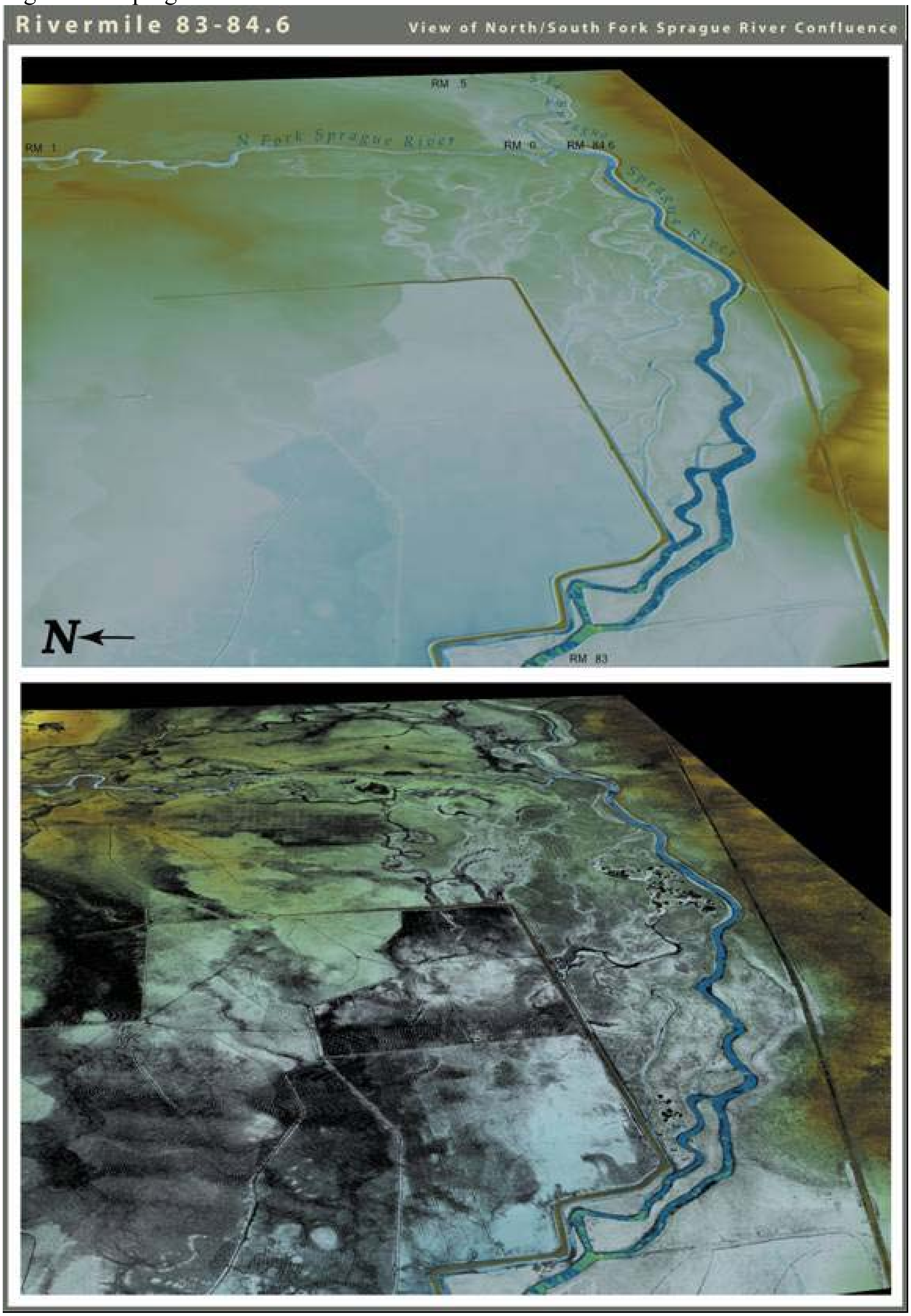


Figure 31. North Fork Sprague RM 0-4

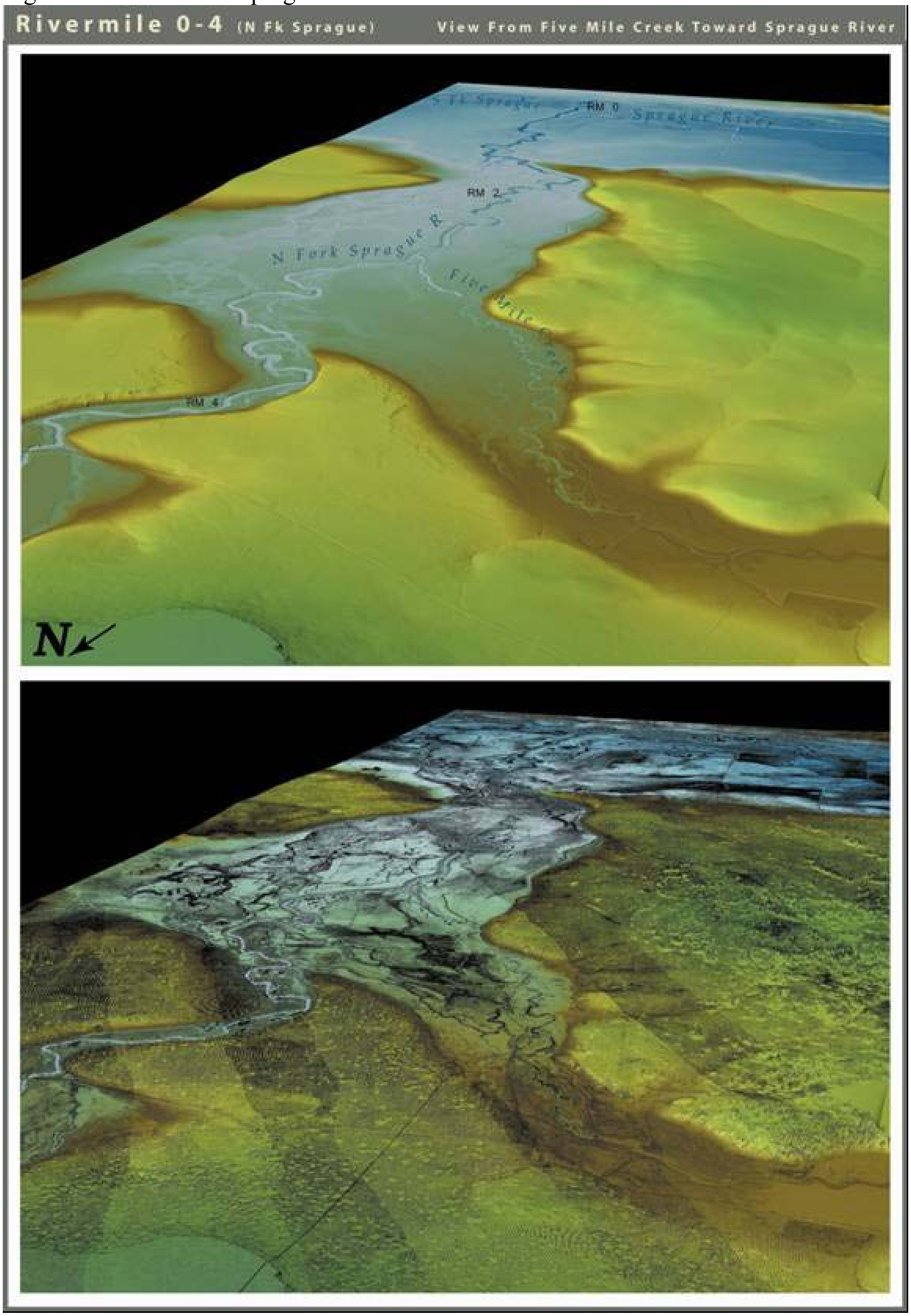


Figure 32. South Fork Sprague RM 0-1

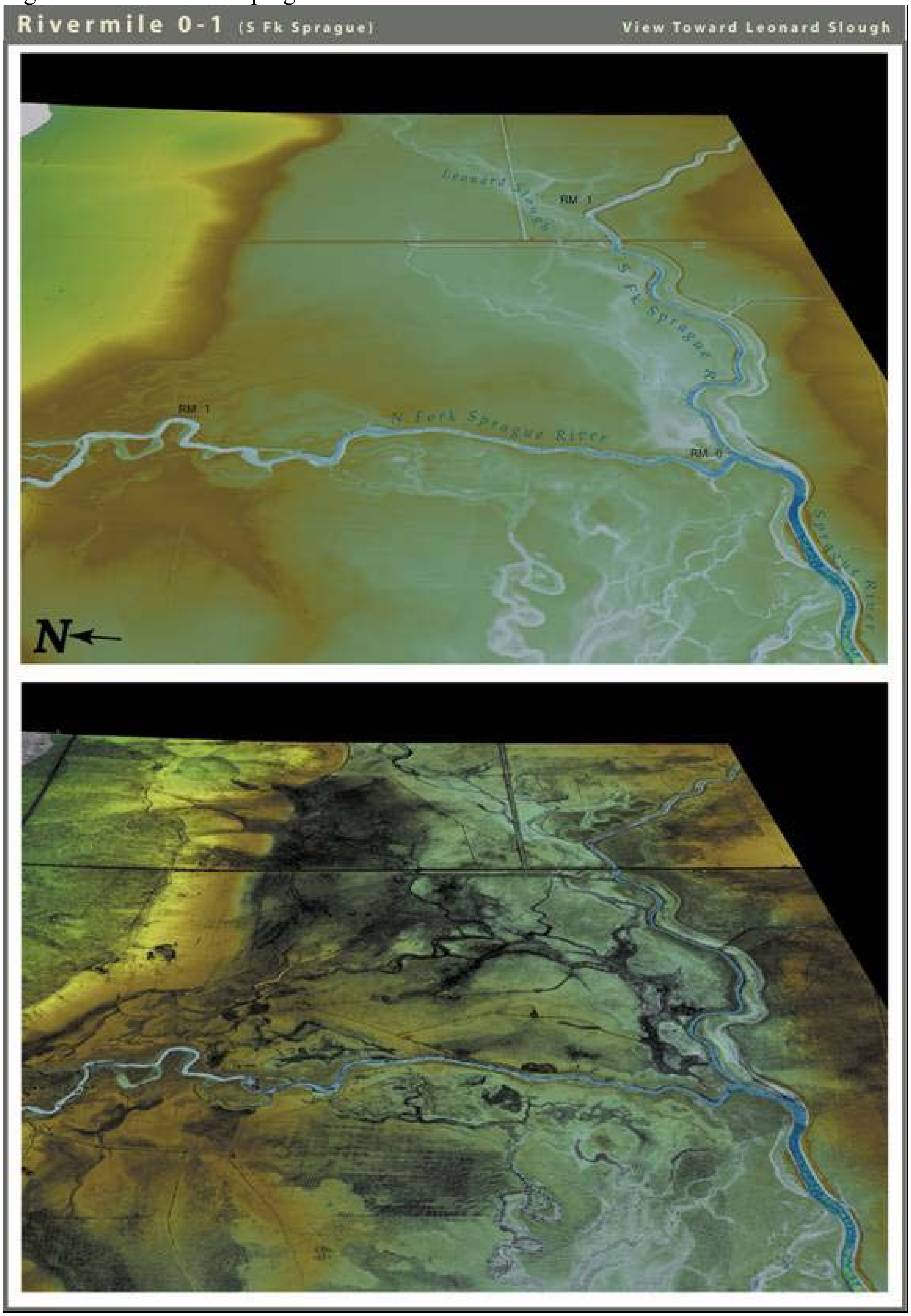


Figure 33. South Fork Sprague RM 2-4

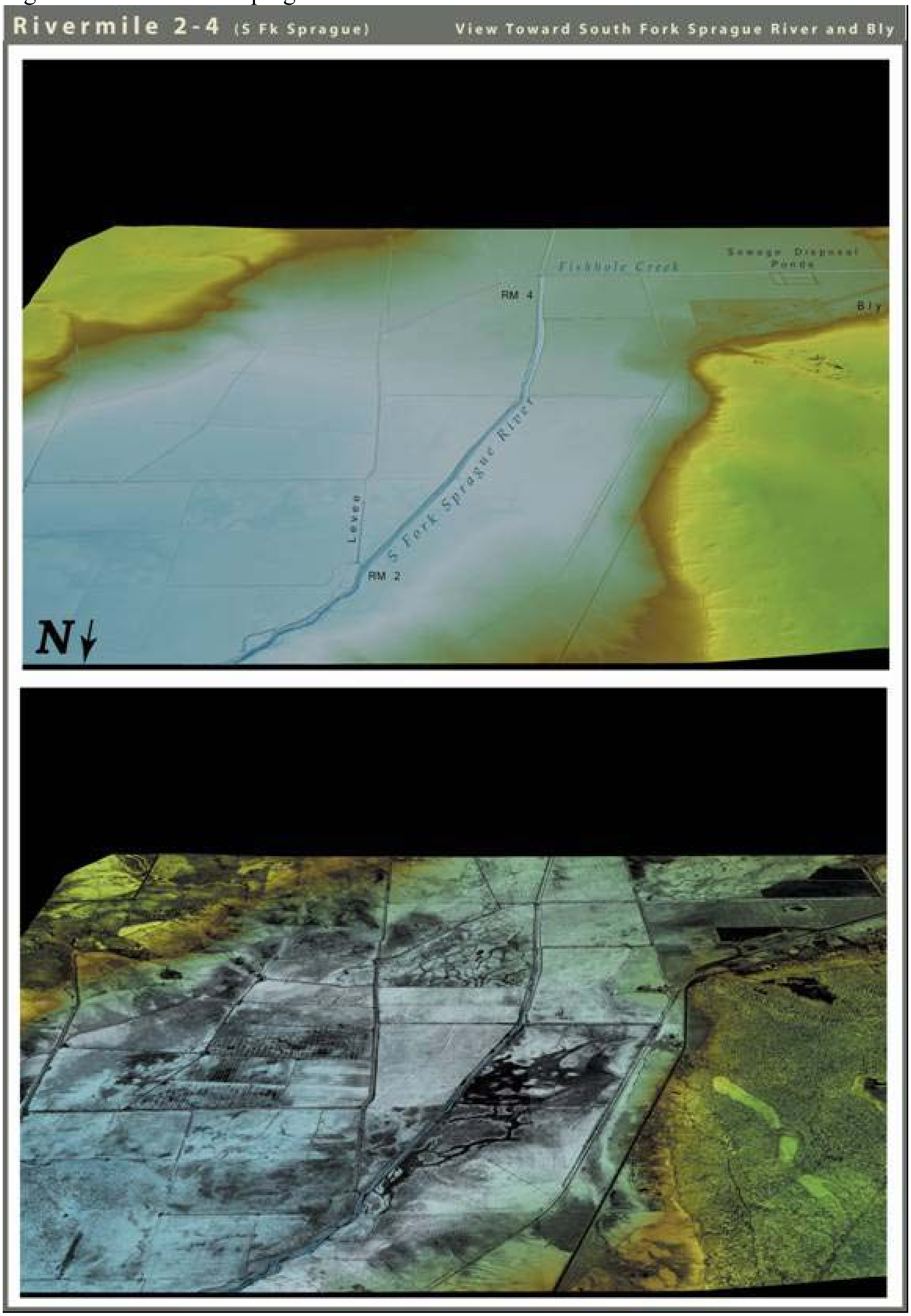


Figure 34. South Fork Sprague RM 4-5

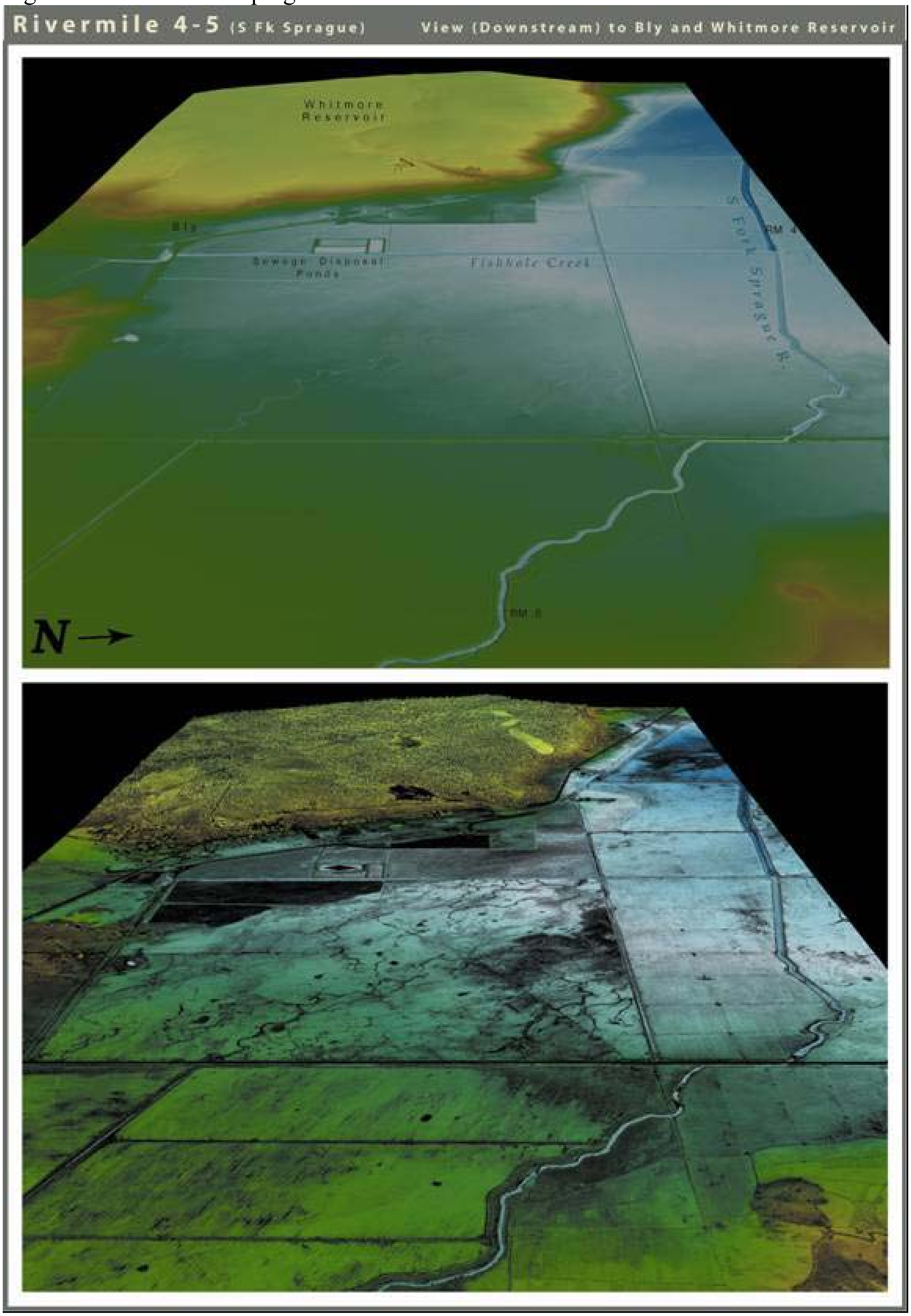


Figure 35. South Fork Sprague RM 7-9

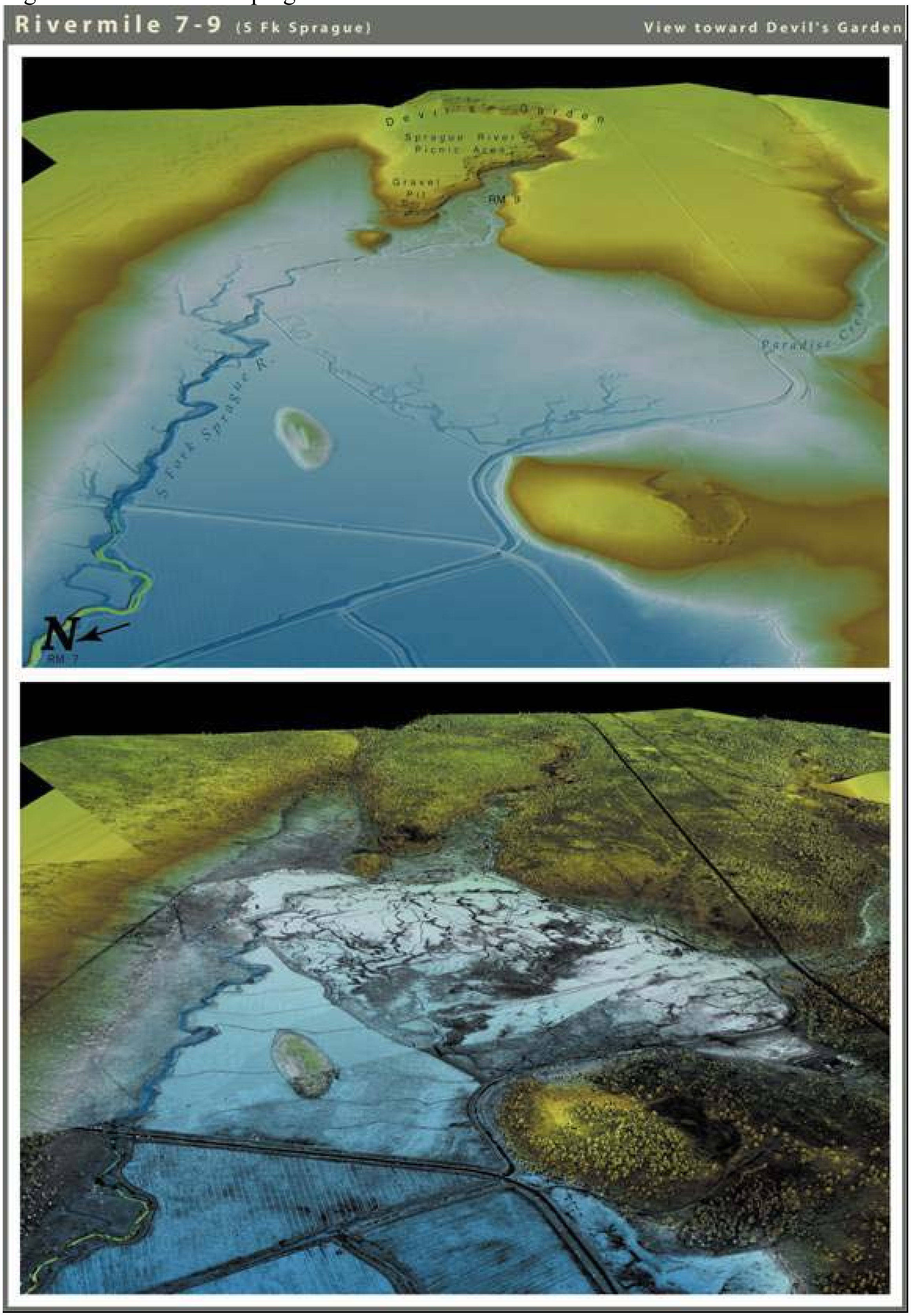


Figure 36. Detail of Sprague and Sycan River Confluence, Bare Earth Model

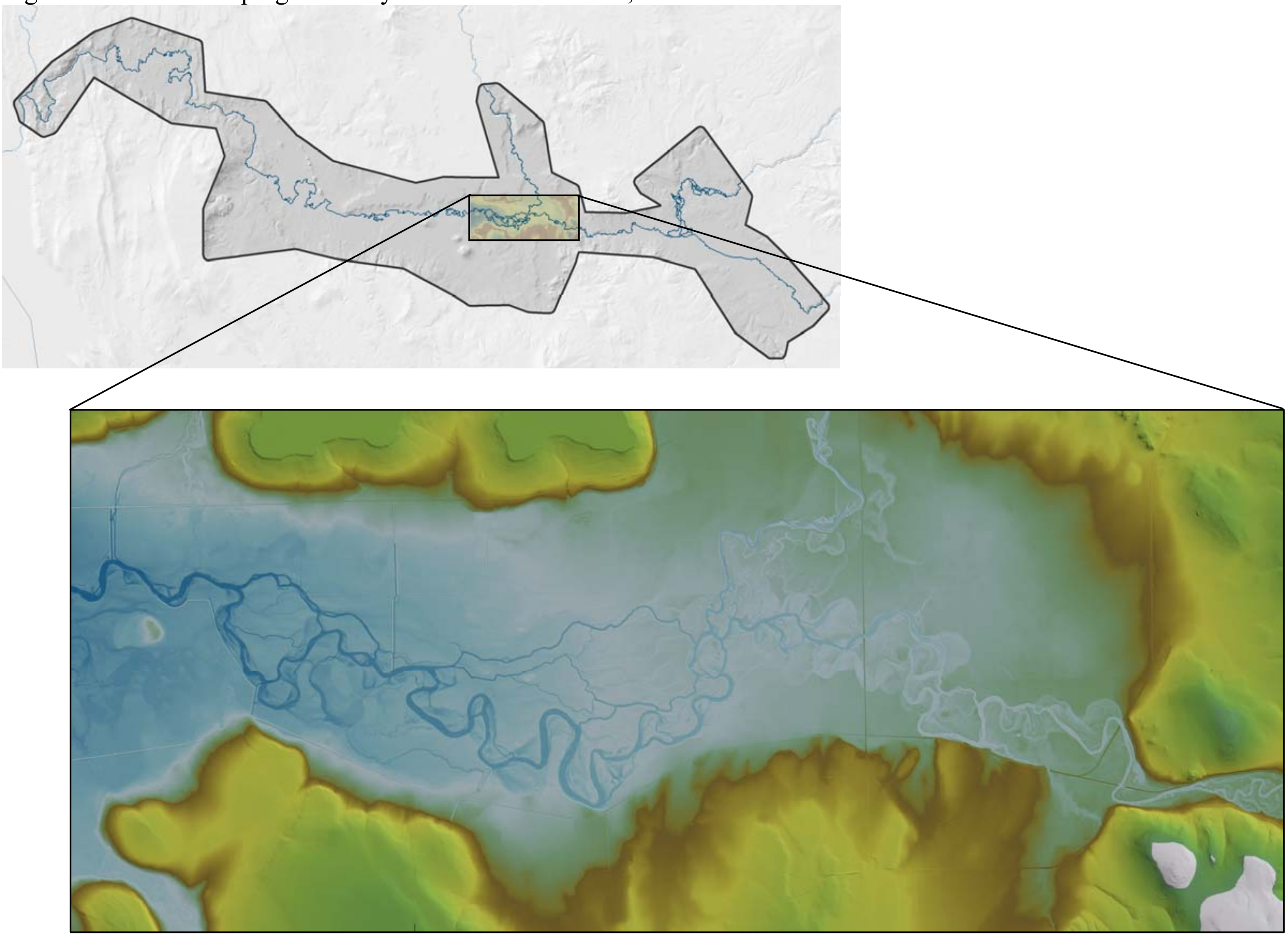


Figure 37. Same Scene Photo and Bare Earth Surfaces

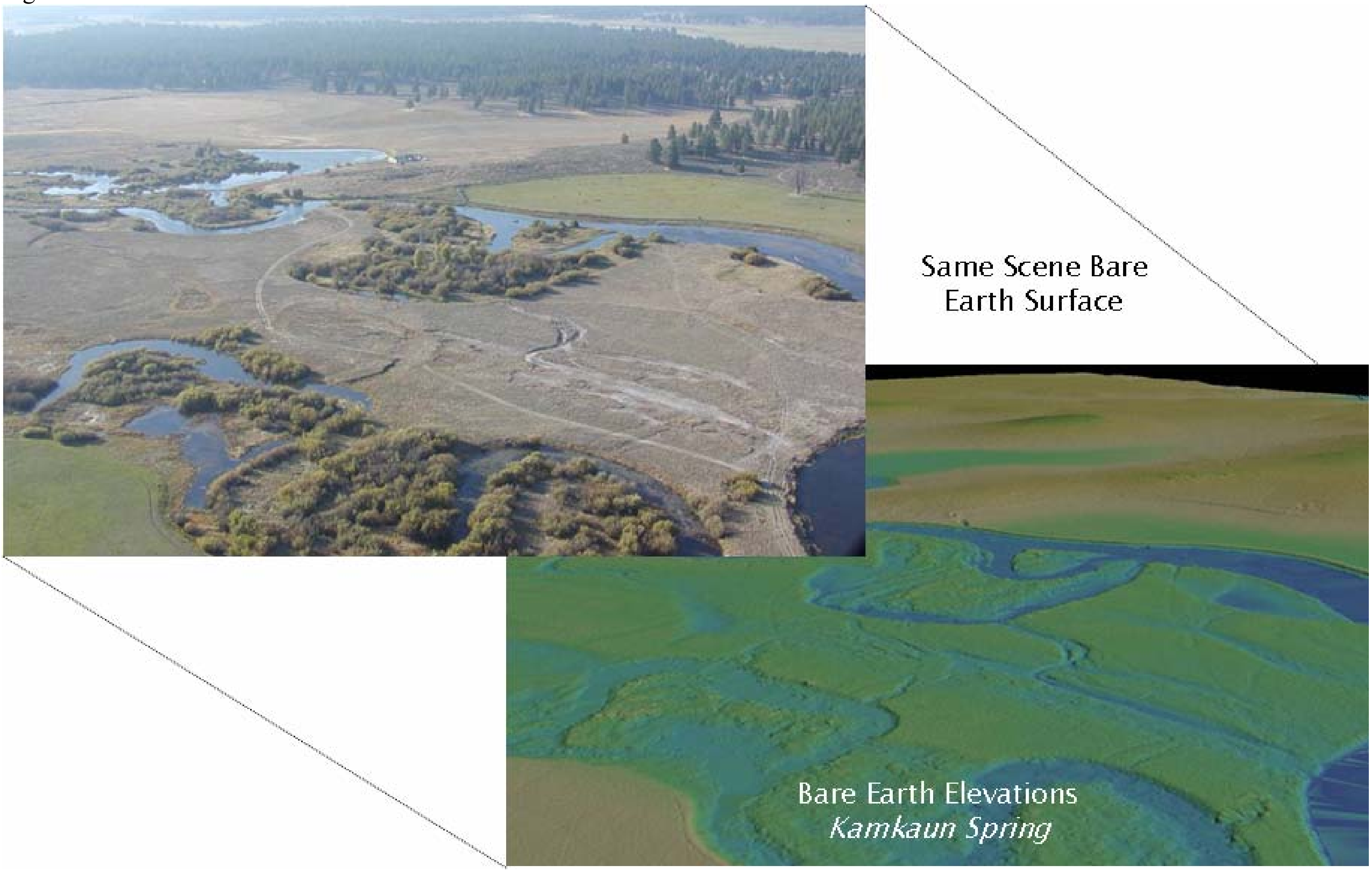
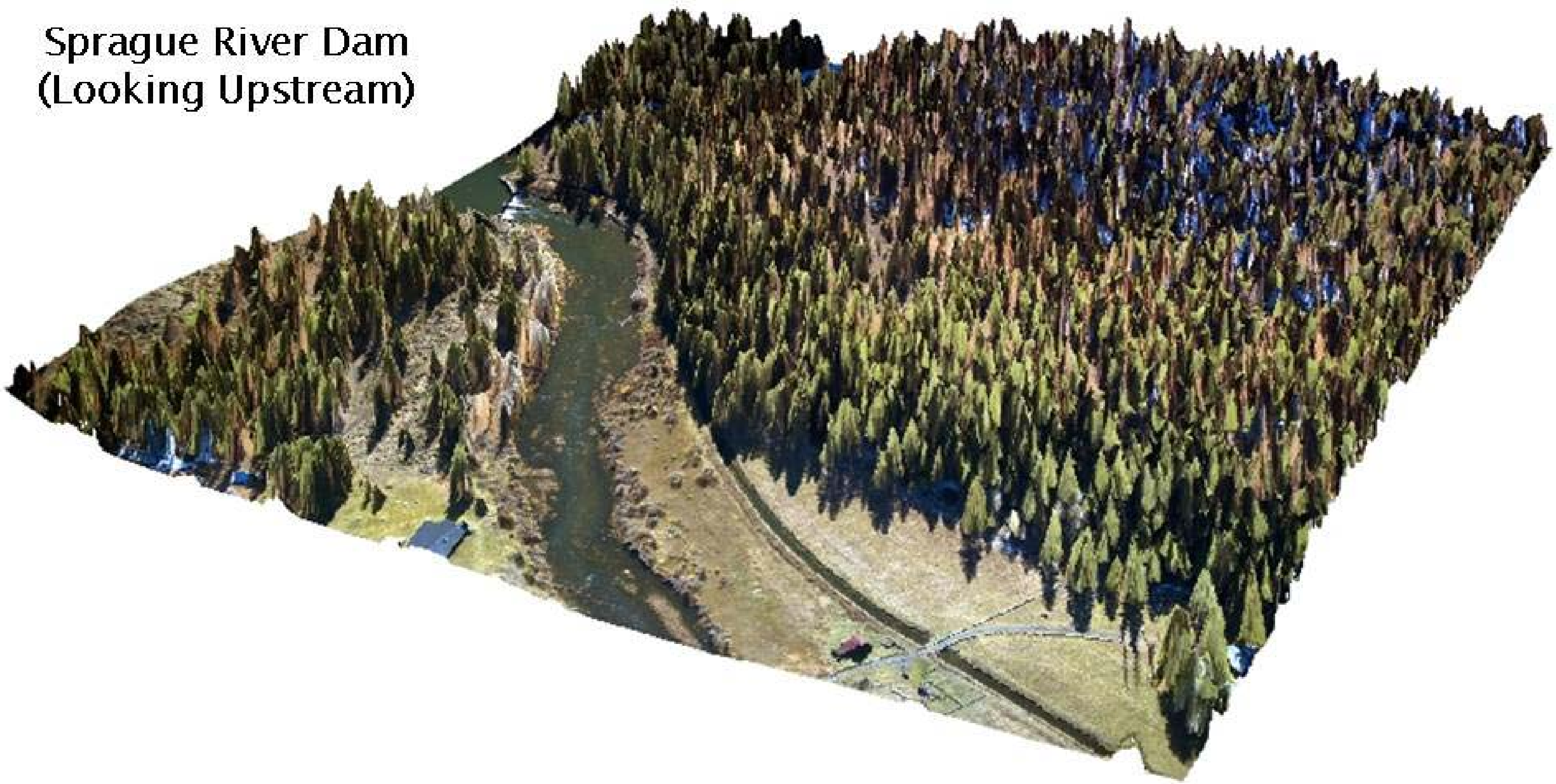


Figure 38. Same Scene Photo, First Retune and Bare Earth LiDAR Data (Downstream Sprague)

Figure 39. First Return Raw Laser Points with Intensity (Sycan River at Mouth)

Figure 40. Bare Earth ½ meter Surface (Sycan River at Mouth) Displaying Alluvial Floodplain

Figure 41. Multispectral Image Co-Registered to LiDAR First Return Data



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