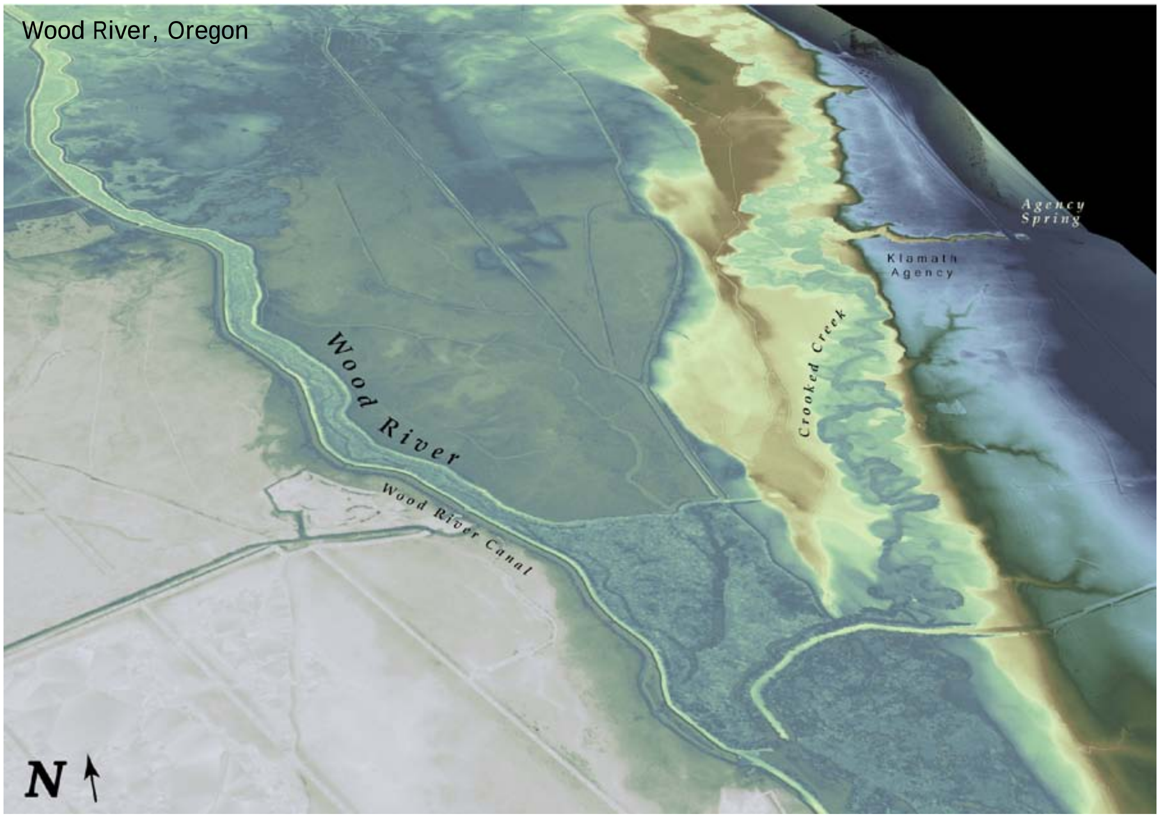
LiDAR Remote Sensing Data Collection: Wood River, Oregon



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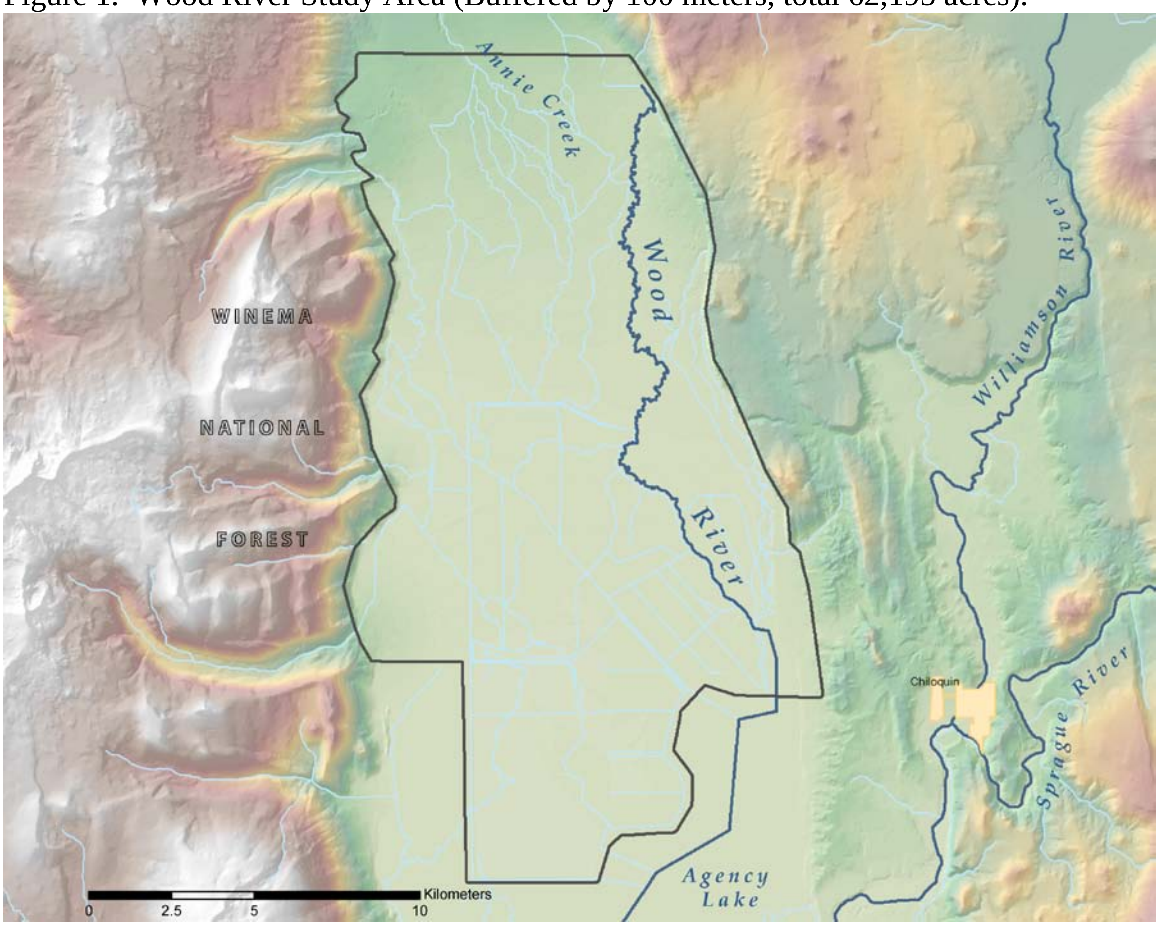
Overview

Watershed Sciences, Inc. (WS) collected Light Detection and Ranging (LiDAR) data for the Klamath Basin Rangeland Trust on September 26th and 27th, 2004.

The survey area encompassed the Wood River floodplain from Agency Lake at the southern edge to Annie Creek in the north (Figure 1). The data were collected using an Optech ALTM 3100 LiDAR system set to acquire points at average spacing of 8 points per square meter for parallel overlapping areas. The system also recorded individual return intensities that are used to create combined elevation models. 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 1 meter mosaics of first and ground models.

Figure 1. Wood River Study Area (Buffered by 100 meters, total 62,195 acres).



Laser point absolute accuracy is largely a function of internal consistency and laser noise[1]:

- **Absolute Accuracy**: The comparison of laser points to real time kinematic (RTK) ground level survey data. A total of 263 RTK GPS measurements were compared to ground laser points along road grades in three sections of the study area. The deviation RMSE and standard deviation are both 0.07 meters, with a median (50^{th} percentile) absolute deviation of 0.047 meters and a 95^{th} percentile of 0.134 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 flight lines and qualitative divergence testing.

  Internal consistency is performed before processing and involves making slight changes to the pitch, roll and yaw of the system. The changes are slight and used only fine tune the standard calibration (Latypov and Zosse, 2002). Opposing flight lines allow testing at known breaks in terrain or buildings to resolve pitch and yaw displacements. Across flat surfaces, a roll displacement can be resolved in a similar fashion. These refinements are beyond “normal” LiDAR processing and are used to zero in the system. It is a relatively subjective test, meaning there are no hard results (statistics), other than measuring displacements below the reported internal accuracy of the sensor specification (i.e., 1/2,000 of flight altitude AGL).

- **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 - 0.09 meters, based upon calibration data.

[1] (Optech, Personal Communication)

Technical Approach

Data Collection

Our LiDAR system is mounted in the belly of a Cessna Caravan 208 (Figure 2). 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.

Figure 2. Sky Research Cessna Caravan 208 is a non-pressurized, high-wing, single-engine turbo prop, with fixed gear designed for general utility purposes. 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^{o} (18^{o} from NADIR)
Scan PRF:	100,000 pulses per second (100kHz)

The Optech 3100 system was set to a 100kHz laser repetition rate and flown at 1,000 meters AGL, capturing a 36^{o} scan width (18^{o} from NADIR). These settings yielded an average spacing of 8 points per square meter. The entire area was surveyed with opposing flight line overlap, to reduce laser shadowing and increase surface laser painting. A section was flown with both opposing flight line overlap and orthogonal flight line overlap. 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, 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. To increase GPS data accuracy by minimizing kinematic solution baselines, one station was located in the center of the surveyed in the study area and the other was located in nearby Chiloquin. Table 1 shows the surveyed coordinates and corresponding error values.

Table 1. Base Station Surveyed Coordinates and Calculated Errors

Point Id	NAD83/96 (HARN) Latitude	Error Uncertainty in Latitude (m)	NAD83/96 (HARN) Longitude	Error Uncertainty in Longitude (m)	NAD83/96 (HARN) Ellipsoid Height (m)	Error Uncertainty in Ellipsoid Height (m)
WSCP1	42°36'25.69739"N	0.010m	121°48'33.34223"W	0.010m	1275.080m	0.014m
Chiloquin	42°34'25.40452"N	N/A	121°52'39.17350"W	N/A	1251.65m	N/A

Figure 3. Wood LiDAR Presurveyed Monuments

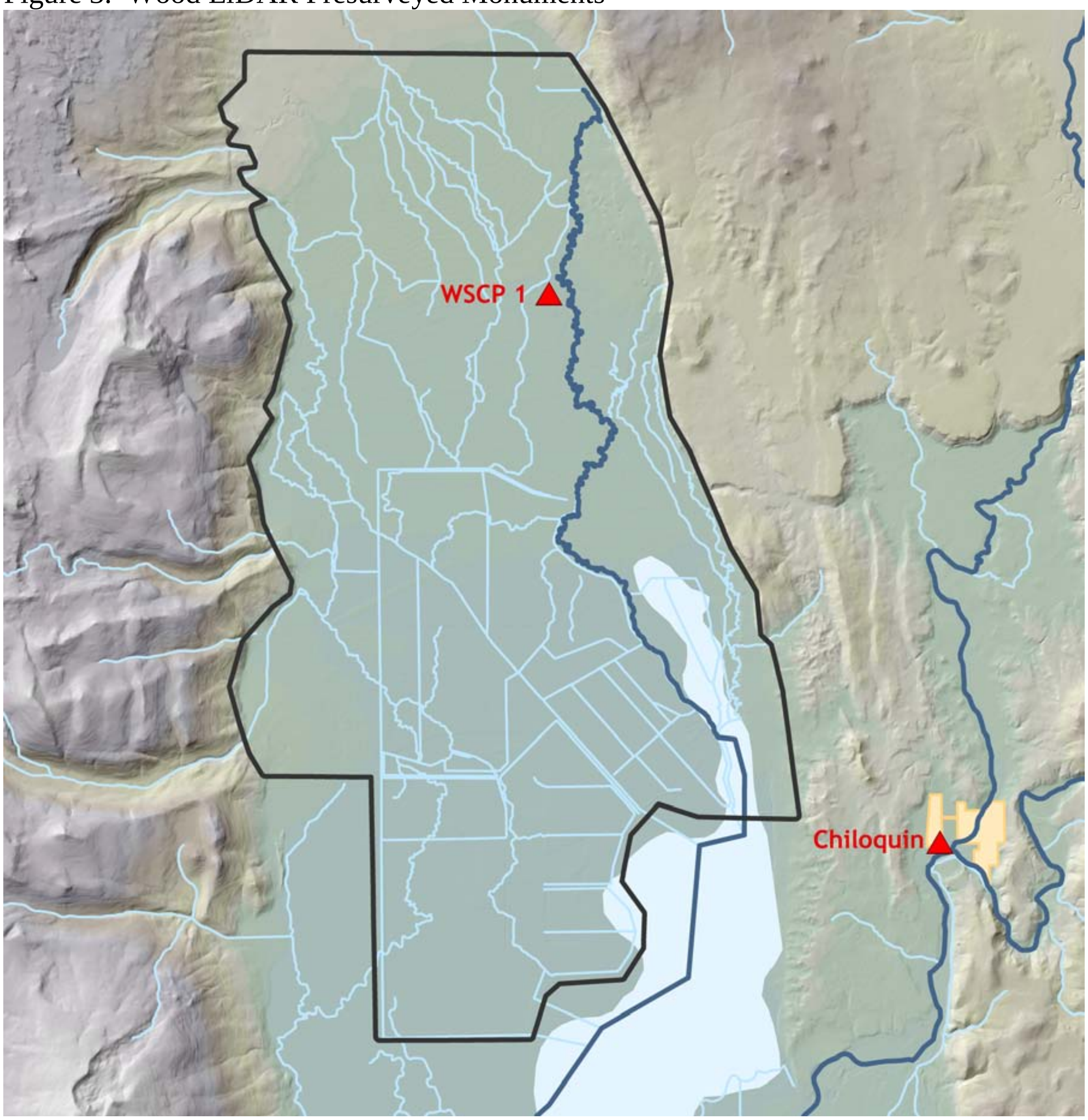
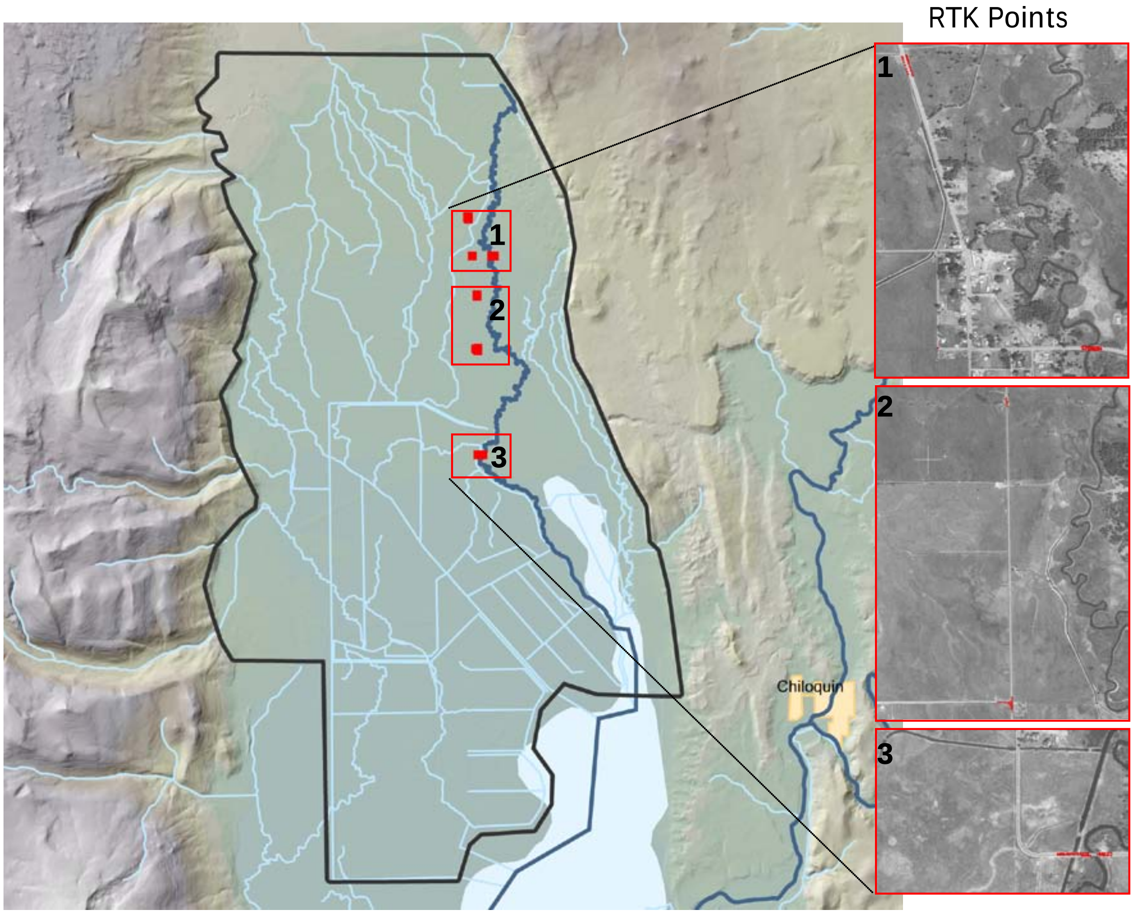


Figure 4. Real Time Kinematic (RTK) Survey Points



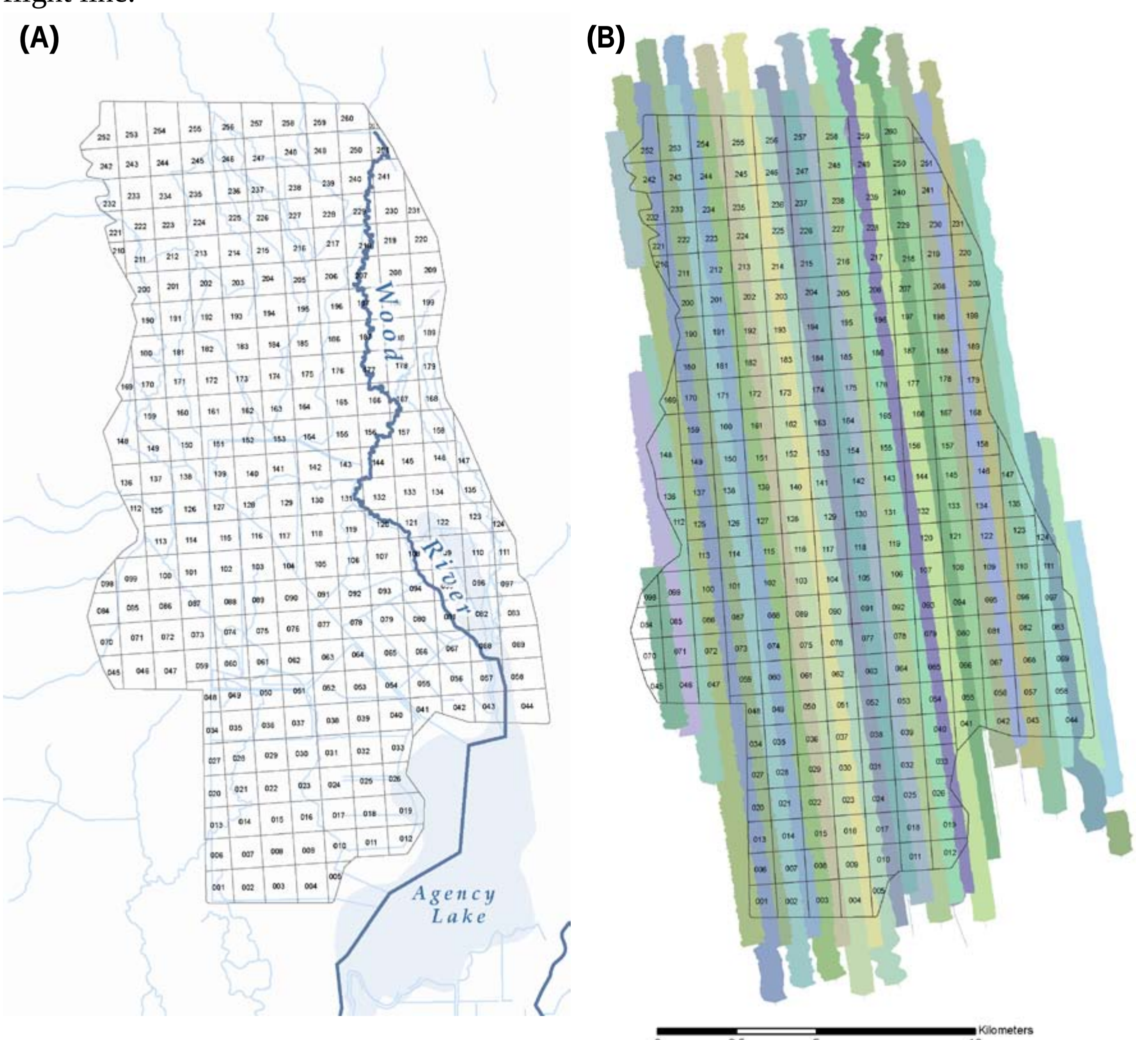
A total of 263 quality control real-time kinematic (RTK) GPS data were collected within the project area using a Trimble 5700 ground based DGPS station. Data collected were then compared to the processed LiDAR data to ensure accuracies across the project area. Although not specified in the contract, the RTK are included as a deliverable.

Data Gaps: The study area was buffered by 100 meters to ensure complete coverage. While there may be the appearance of data gaps (outside on the known survey gaps), these are limited to areas under buildings or over very still/calm water surface (ponds, pools, etc.) where the bare ground model required greater than 10 meters to build a triangle. In these cases, the models recorded no data. The GRID data are an average value that fits triangles within a specified area (1 m^2). By setting distance limits to triangle length, longer interpolations are avoided for areas with low point density where laser pulses are obstructed or absorbed. It is more typical for commercial LiDAR providers to deliver data sets that allow long triangle lengths to prevent any gaps in the resulting GRID data sets. However, such interpolation of the data may provide a false sense that data are continuous throughout the study area, when in fact, they are not. In the final processing we tend to limit triangle to explicitly demonstrate absence of laser return length and thus allow data gaps where data densities are insufficient to adequately characterize surfaces. This method also effectively displays laser return gaps.

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) (Optech, 2003a). The inertial measurement data were used to calculate the kinematic corrections for the aircraft trajectories using PosPAC v4.1 (Applanix, 2003a and 2003b). Flight lines and LiDAR data were reviewed to insure complete coverage of the study area and positional accuracy of the laser points.

Figure 5. Processing Bins (A) Survey Flight Lines (261 Total Lines), 30% overlap on each side and Scan Width of Each Flight Line (B). Each color represents an individual flight line.



TerraScan Processing

To facilitate laser point processing, the first step is to create bins (polygons) that divide the data set into manageable sizes. Typically, a bin should occupy an area with $5 \cdot 10^6$ to $10 \cdot 10^6$ laser points. Bins are developed by creating a shapefile comprised of 1 km^2 units (developed with an avenue script) that exceeds the entire buffered study area. This 1 km^2

"gridded" shapefile is then clipped by the buffered study area boundaries. The resulting bin layer is imported into Microstation v.8 as a *.dxf layer, where bins are numbered and used for laser point parsing. All processing occurs in individual bins, with a 100 meter overlap from surrounding bins to ensure continuity between bins. The study area encompasses 261 bins that capture all 31 flight line of LiDAR points.

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 after *screening for absolute elevation limits* isolated points and height above ground.

Filtering steps are as follows:

1. Points below 1,200 meters (elliptical height) are classified as artificial pits (classification #5)
2. Points above 1,425 meters (elliptical height) are classified as artificial birds (classification #6)

The filtered and differentially corrected return layers are provided in ASCII format per flight line and bin as "Unprocessed Data". These data have passed initial screening and are deemed accurate; however, ground modeling processing has not been completed on these laser points.

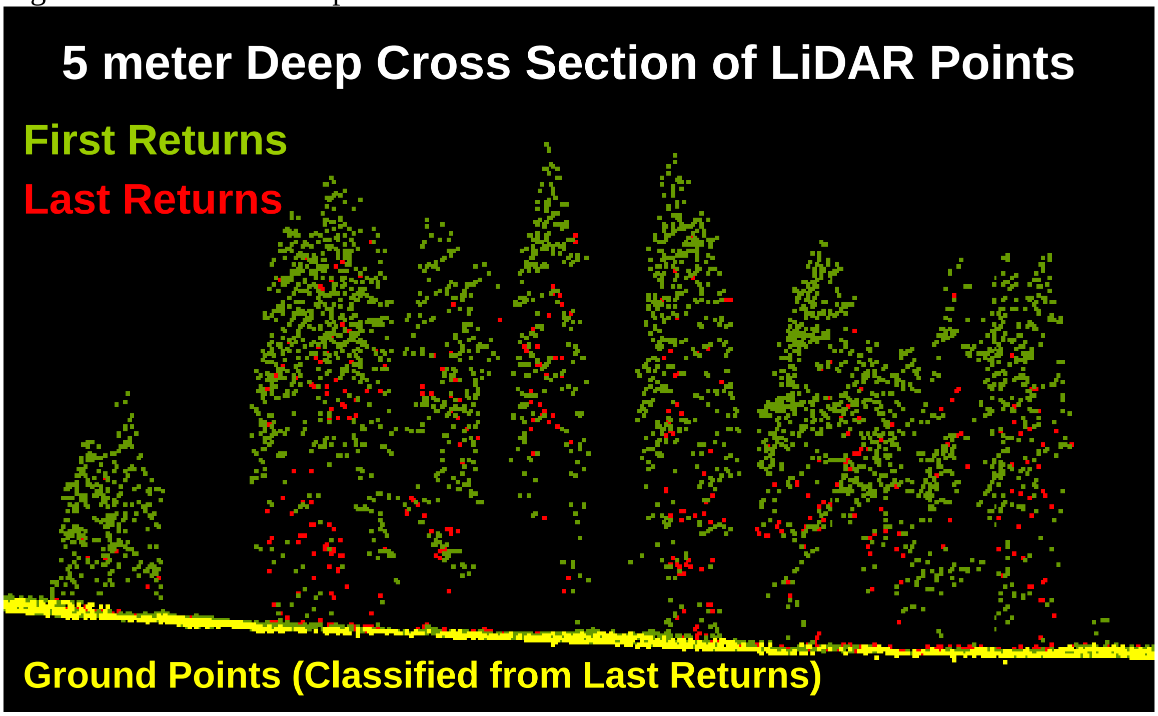
The TerraScan (Soininen, 2004) software suite is designed specifically for developing a standard bare earth model to remove buildings, vegetation, and other features. The initial bare earth model retains bridges and overpasses, and these artifacts are removed manually. The high point density and multiple 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.

A ground classification routine is used that screens last return points with the following criteria for a bare ground point classification:

Maximum Building Size	Maximum Terrain Angle	Maximum Iteration Angle	Maximum Iteration Distance
60 meters	80^o	5^o	1.4 meters

Areas with sheer angles or very steep terrain are nearly impossible to classify as ground, simply because these terrain breaks resemble the walls of buildings or vegetation crowns. This includes bedrock outcrops and cliffs, largely along canyon walls. These areas are limited to local features and are often quite small.

Figure 6. Five meter Deep Cross-Section of LiDAR Points.



Description of Processing Steps:

Units: Meters
Projection: UTM Zone 10, Nad83, NAVD 88, Geoid03,

1. Import point data into 261 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.
   - Points below 1200 meters (elliptical height) are classified as artificial pits (classification #5)
   - Points above 1,425 meters (elliptical height) are classified as artificial birds (classification #6)

4. Write ASCII output files for raw first and last return data (Easting, Northing, Elliptical Height, Intensity)
5. Calculate bare ground model from last return points, with the maximum building size of 60 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 river bed, rocks, macrophytes, etc.

6. Manual removal of bridge spans.
7. Generate TINs within all bins (including points 100 m outside) and export ASCII lattice files for first return, last return and ground points. Creating TINs is simply a direct interpolation between laser points (bare ground and first return). The 1 meter GRID is an average value of triangle elevations with each pixel. TINs are created in TerraScan (Soininen, 2004).
8. 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

Contract Specifications*: The vertical accuracies of the LiDAR data will be the following: At one Sigma (68%) of all points will be within fifteen centimeters (15 cm) or approximately one-half foot (0.5'). The horizontal accuracy will be 1/2000 of the altitude at one Sigma. Areas of high grass, crops, brush lands, low trees and fully covered trees may not meet or exceed the above stated accuracies. The Contractor will do the best of their ability try to determine the accuracy of said areas through the use of kinematic and or static GPS survey methods.*

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

Standard Deviation:	0.07 m	5th Percentile:	0.0061 m
RMSE:	0.07 m	25th Percentile:	0.0195 m
n:	263	50th Percentile:	0.0470 m
Minimum Δz:	-0.2771 m	75th Percentile:	0.0810 m
Maximum Δz:	0.148 m	95th Percentile:	0.1335 m
Average Magnitude:	0.055 m		

Figure 7. Point Divergence Statistics

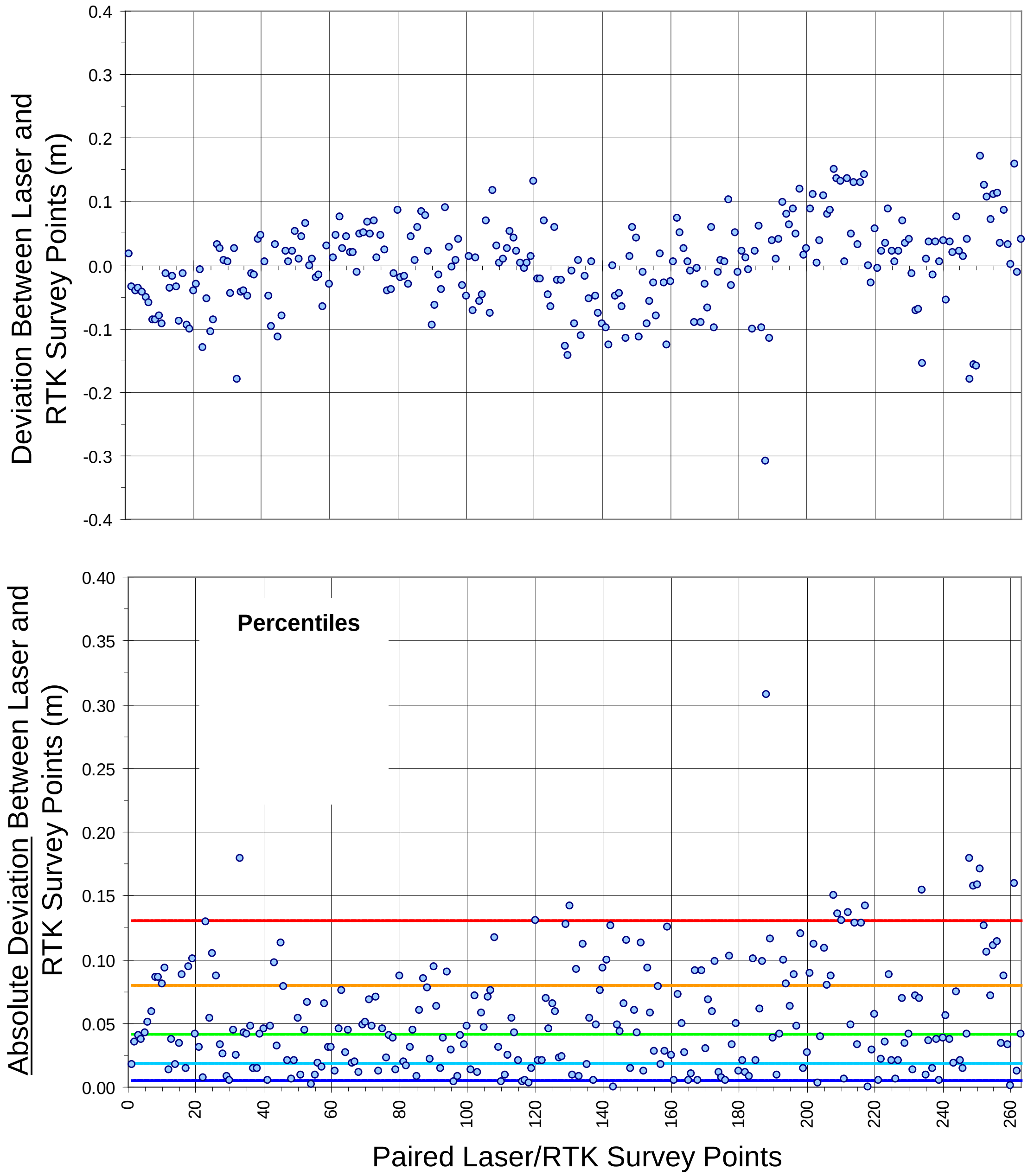


Table 3. LiDAR accuracy is a combination of several sources of error which are cumulative. Some error sources that are biased and act in a patterned displacement can be resolved in post processing. Patterned displacements are system related, and usually reflect alignment or offset errors. The horizontal accuracy specifications of our system (as well as all others) is usually about 1/2000 of flight AGL. We collected data at 1,100 meters AGL, and thus should expect about 55 cm of horizontal error. By reducing internal system errors that result in patterned displacements we expect improvement in horizontal accuracies that are well beyond normal specifications. This emerging trend in post-processing exceeds the manufacturer's system operation is a goal in all our 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	

Internal Consistency – Points from different flight lines should align and provide relative accuracy. Below are points from two flight lines flown in opposite directions.

Laser Noise – Points from the same flight line should have minimal divergence over same target. Laser noise will vary slightly as a function of intensity; surfaces with lower reflectivity will incur more noise (larger data cloud). Common low reflectivity surfaces are roads, calm water, black rooftops, etc.

In-flight 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. The quality of the GPS signal (or PDOP) is recorded throughout the flight and only PDOP values less than 3.0 are accepted.

Deliverables

Units: Meters
Projection: UTM Zone 10, Nad83, NAVD 88, Geoid03

- Raw LiDAR returns in ASCII Format (one layer for each return)
- Bare Earth Files stripped of 90% Vegetation/Features in ASCII format
- LiDAR reflective Surface Models (from First Returns) as Intensity Image in Geotiff Format
- All Laser Points in Ascii Format (zipped text files) (space delimited)

  Ascii Header:
  Easting, Northing, Elevation, Class, Echo Number, Intensity, Flight Line

  Classes:
  1 – Last Return
  2 – First Return
  3 – Ground Return

- A report detailing the mission efforts. The report will include a QA/QC assessment (see this report).

DVD List

DVD 1: Report & Metadata
Coverages (Study Area and Bins)
Images (3-d tiffs and Intensity GeoTiff)

DVD 2: 1 meter Pixel Resolution GRIDs
Bare Earth Mosaic & Hillshade
First Return Mosaic & Hillshade

DVD 3: Ascii Data – Bins 001 to 050

DVD 4: Ascii Data – Bins 051 to 100

DVD 5: Ascii Data – Bins 101 to 150

DVD 6: Ascii Data – Bins 151 to 200

DVD 7: Ascii Data – Bins 200 to 261

Citations

Applanix. 2003a. POSPAC Product Manual. PUBS-MAN-000031. Revision 1.

Applanix. 2003b. POSGPS Product Manual. PUBS-MAN-000016. Revision 3.

Latypov, D. and E. Zosse. 2002. LiDAR data quality control and system calibration using overlapping flight lines in commercial environment. Proceedings of ACSM-ASPRS 2002. Washington D.C.

Optech. 2003a. REALM Survey Suite: Data Processing Manual. Document Number 195-090-06.

Optech. 2003b. ALTM-NAV Flight Management Software: Instruction Manual. Document Number 195-090-34.

Soininen, A. 2004. TerraScan User's Manual. Terrasolid.

Discussion of Images

Figure 8. Bare Ground Model, Wood River Study Area. The model is derived from last return LiDAR laser points, in other words, those points returned from bare ground and near ground surfaces. Vegetation and features such as rooftops, bridges, and other structures are removed to produce the closest approximation to 'bare' ground.

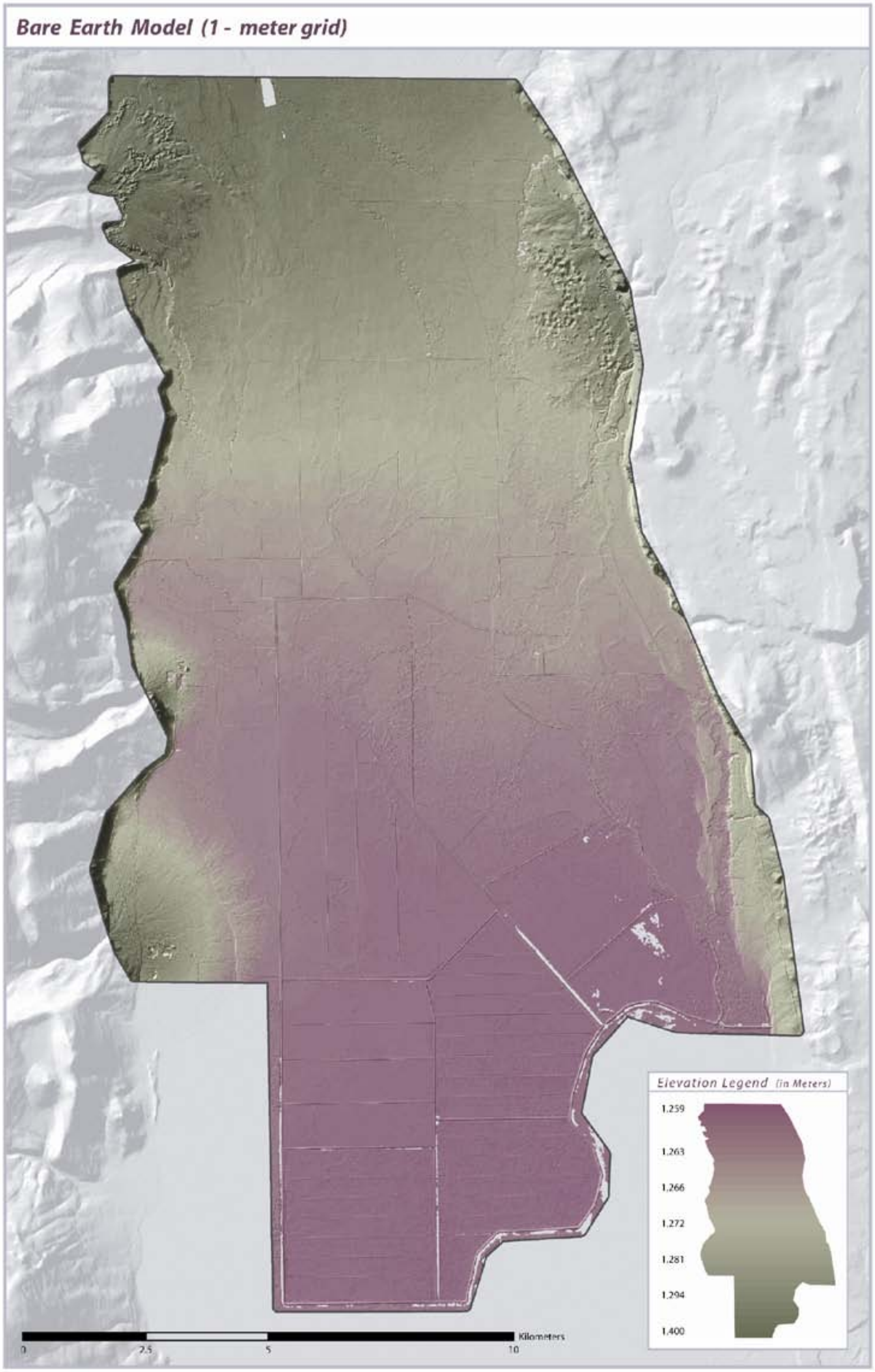


Figure 9. First Return Model, Wood River Study Area. This model is created from laser points returned from the highest surface encountered by each laser pulse. Where they occur, vegetation and features such as rooftops, bridges, and other structures appear prominently in the image.

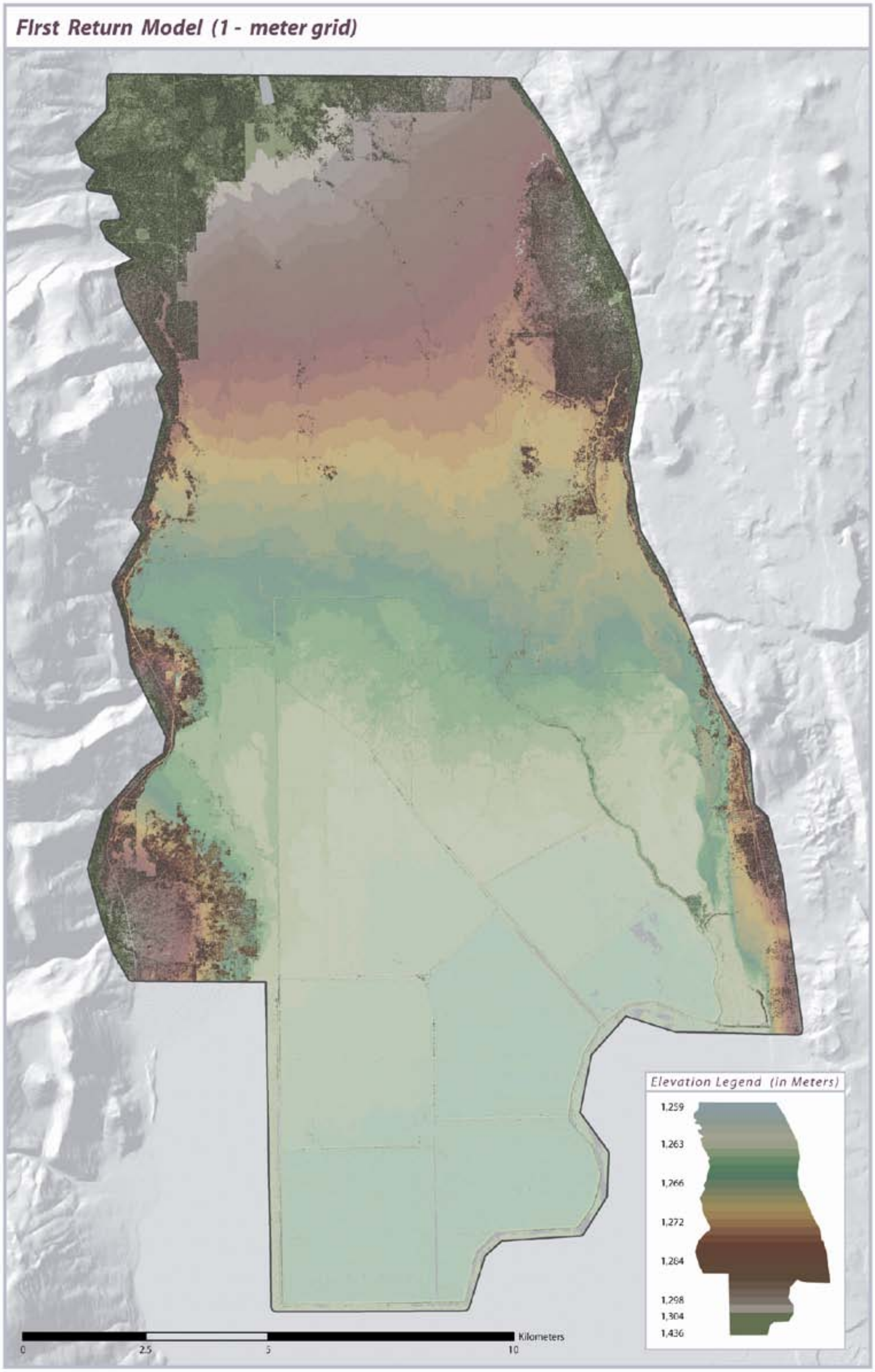


Figure 10. Southern Portion of Study Area showing Lake Inundation Levels

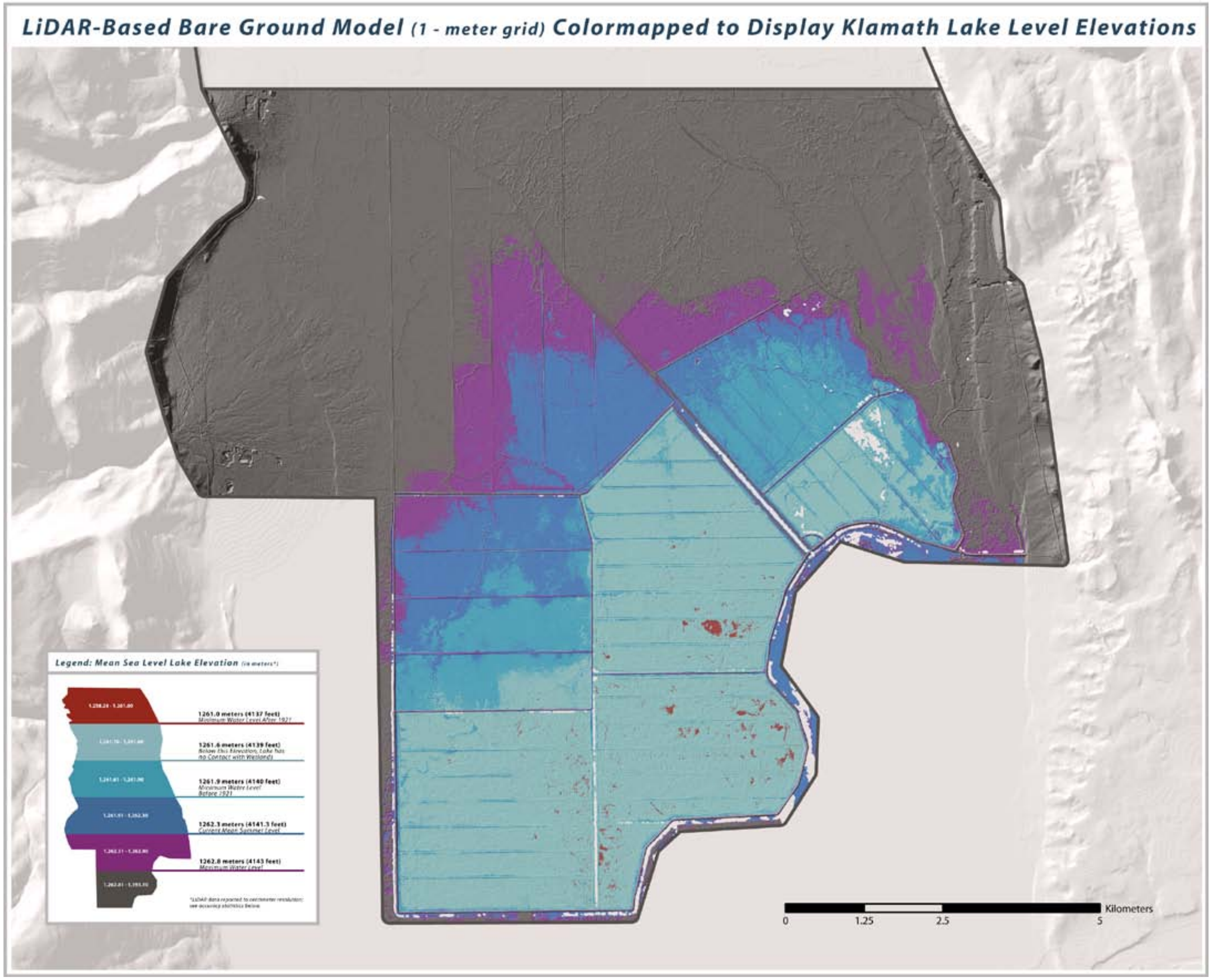


Figure 11. Map Showing Locations of Modeled Detail Views inside Study Area. The following models depict bare earth surfaces and first return laser points colored by elevation and intensity of the laser return. Each pair of images of shows oblique views (some oriented in non-north directions) of the bare earth model labeled with pertinent features (top images), and the first return laser points over the bare earth model (bottom images). At this resolution and accuracy, riparian vegetation, morphology, land use, road crossings, culverts, dikes, et cetera, are clearly articulated in the data.

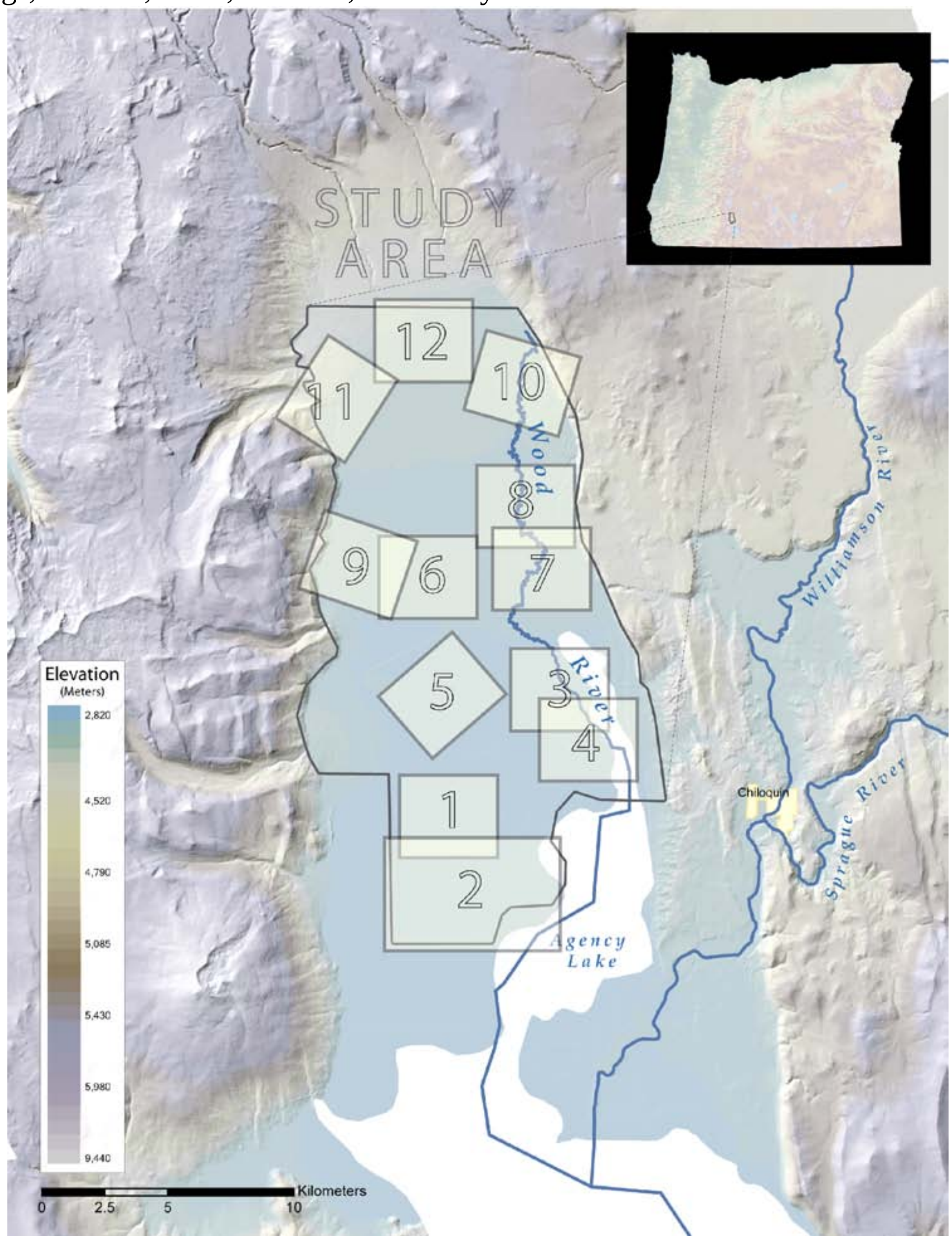


Figure 12. Detail View 1: Looking South into Diked Portions of Study Area

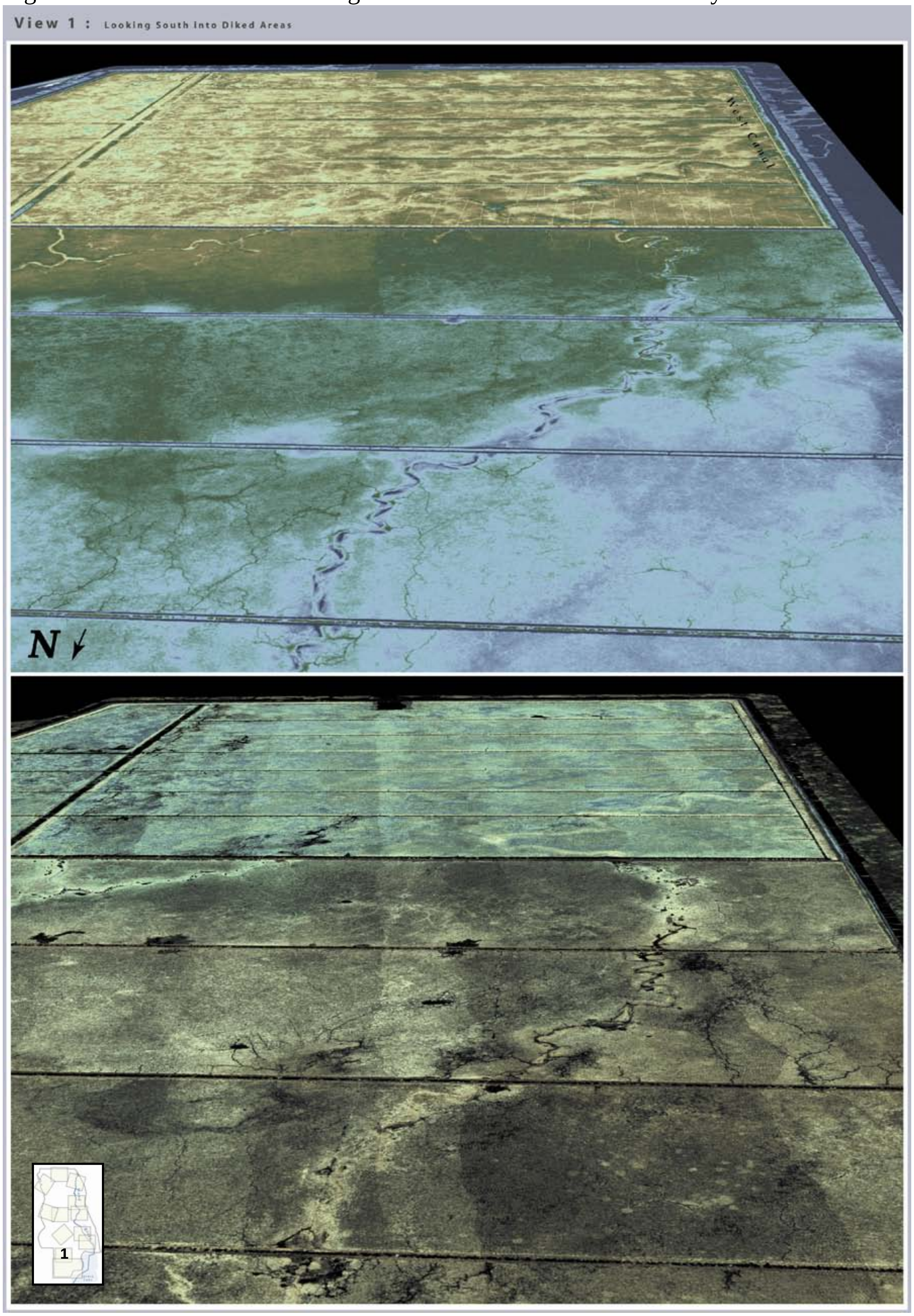


Figure 13. Detail View 2: Looking East into Diked Portions of Study Area

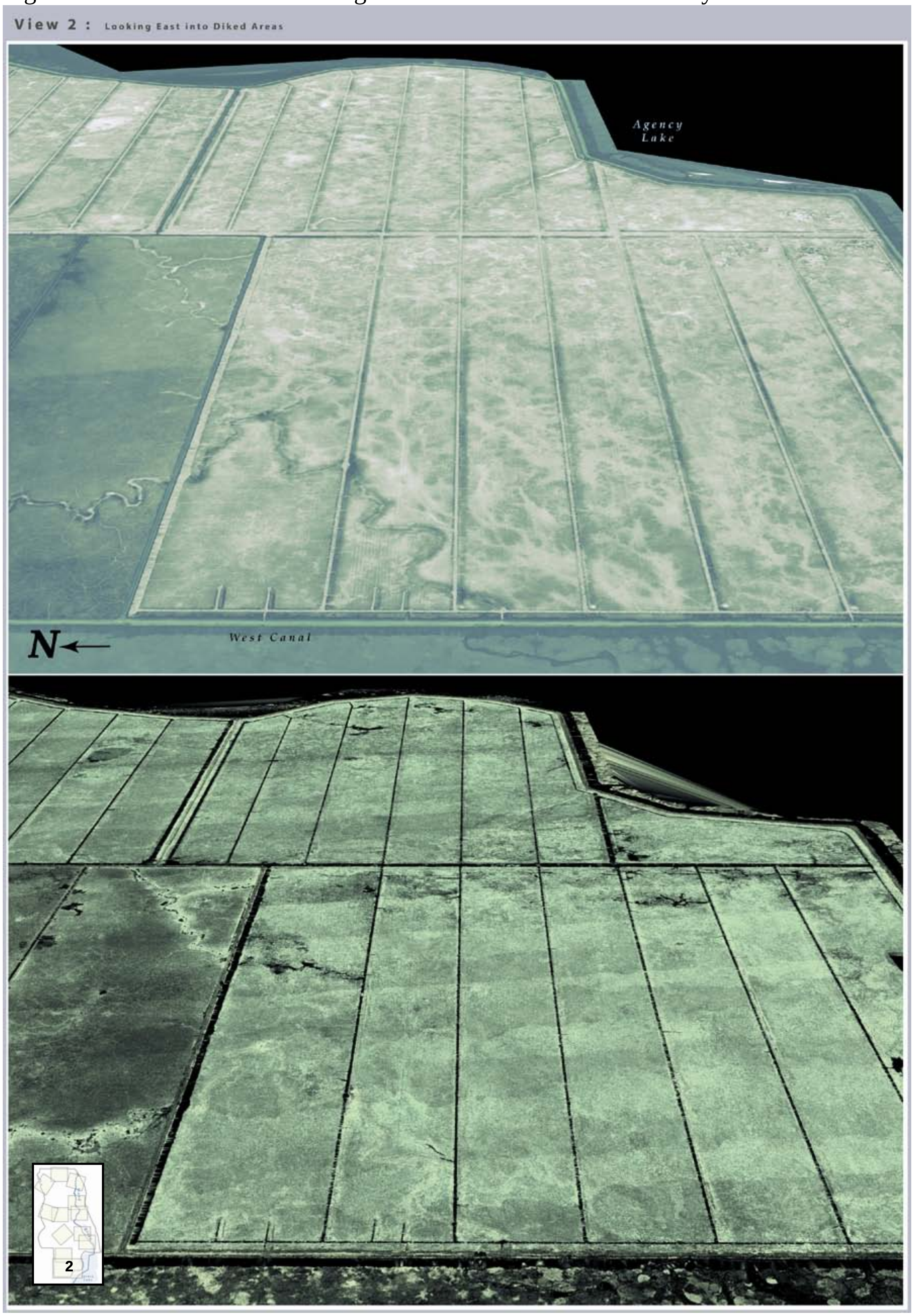


Figure 14. Detail View 3: Looking South, Downstream Wood River

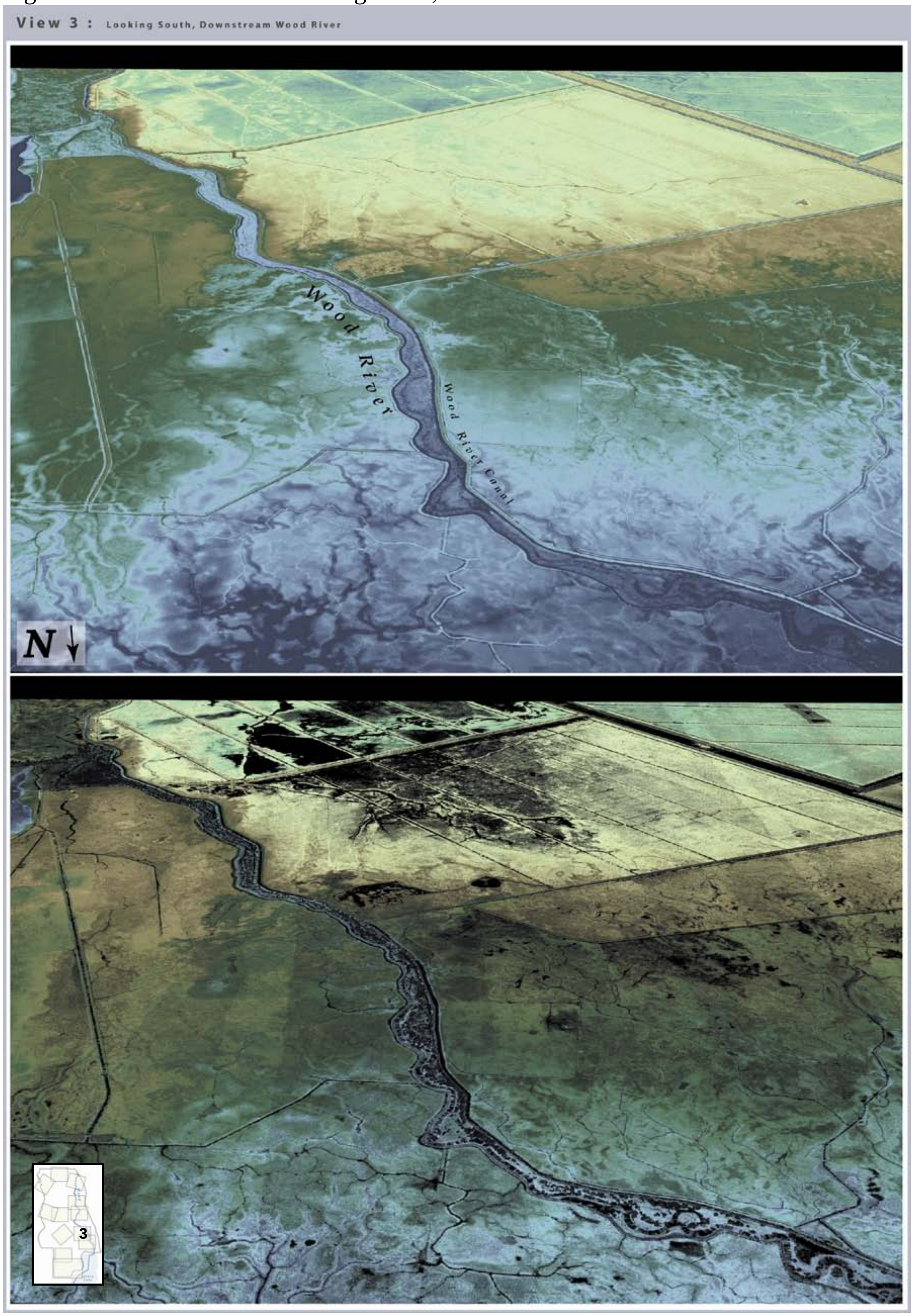


Figure 15. Detail View 4: Looking North, Upstream Wood River and Crooked Creek

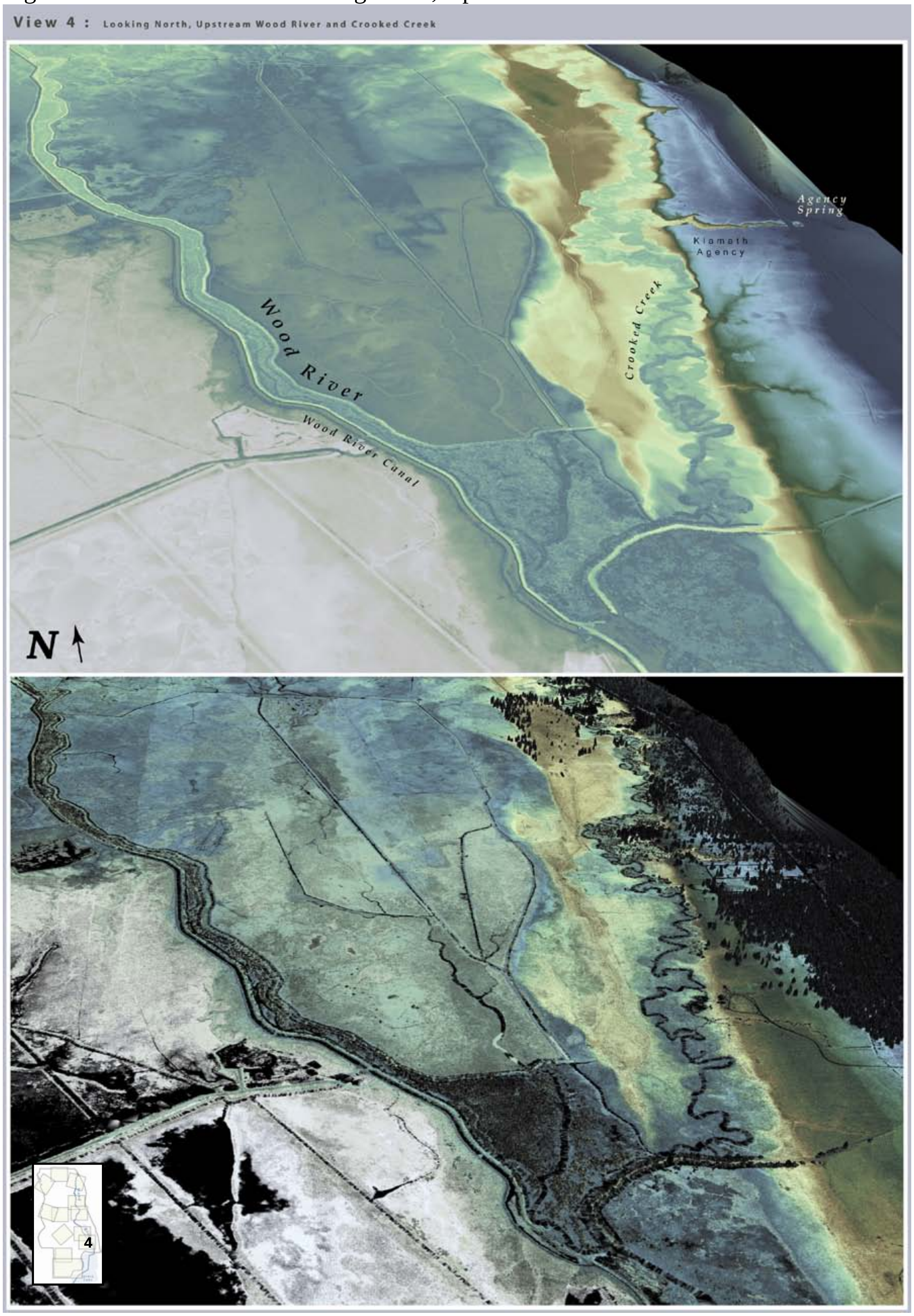


Figure 16. Detail View 5: Looking Southeast, Downstream Sevenmile Creek and Fourmile Creek

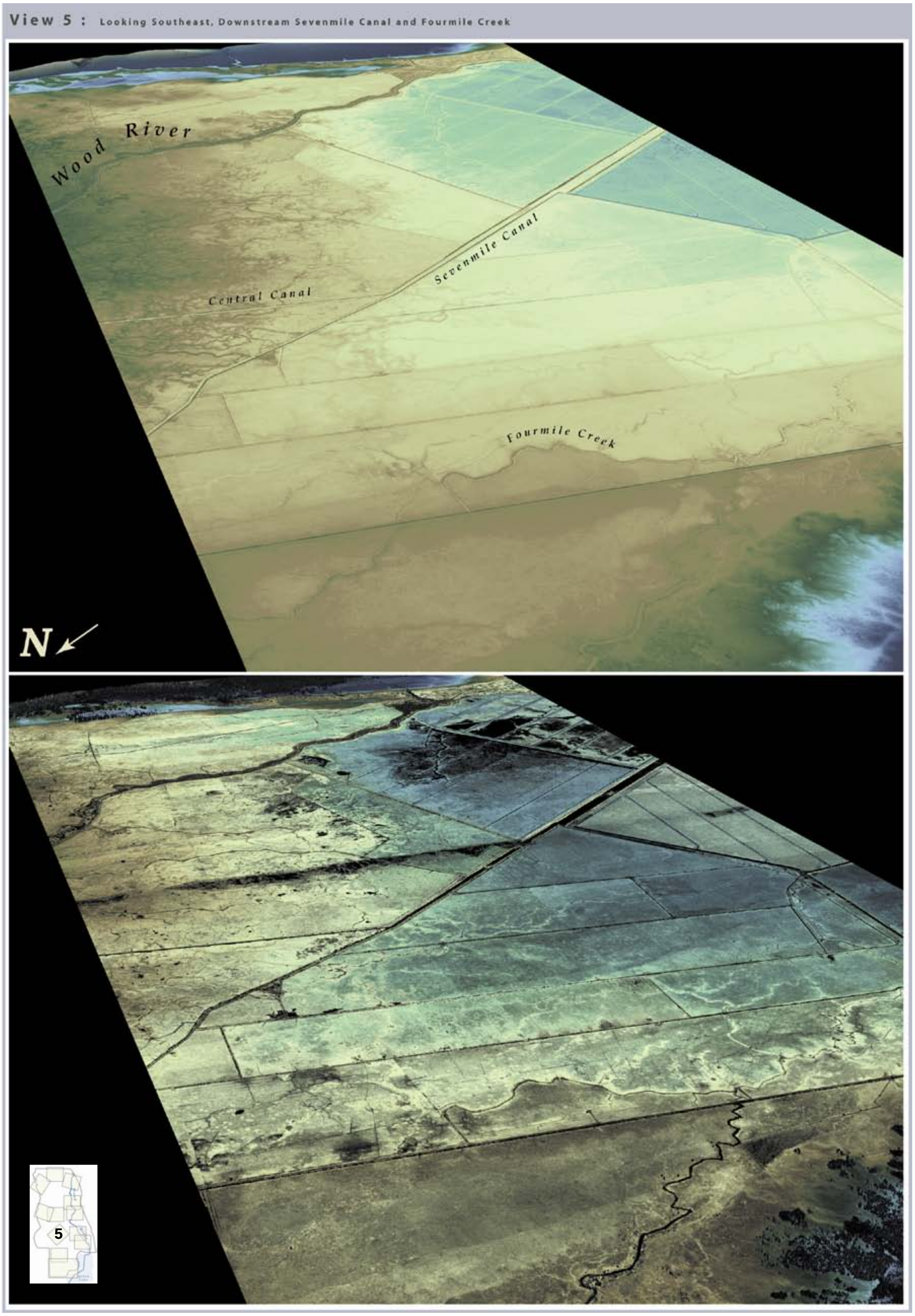


Figure 17. Detail View 6: Looking North Toward North Canal Ditch

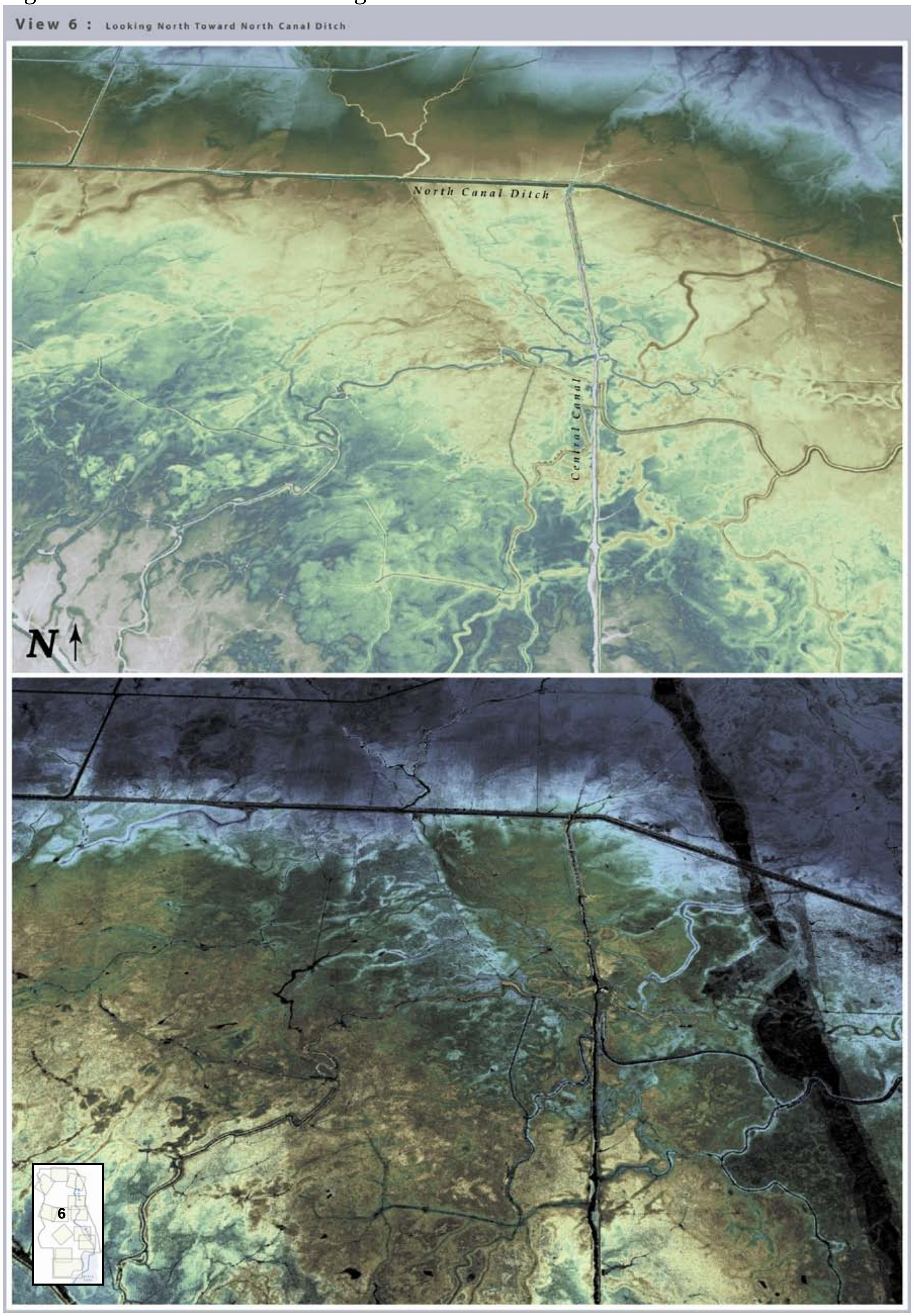


Figure 18. Detail View 7: Looking South, Downstream Wood River and Fort Creek

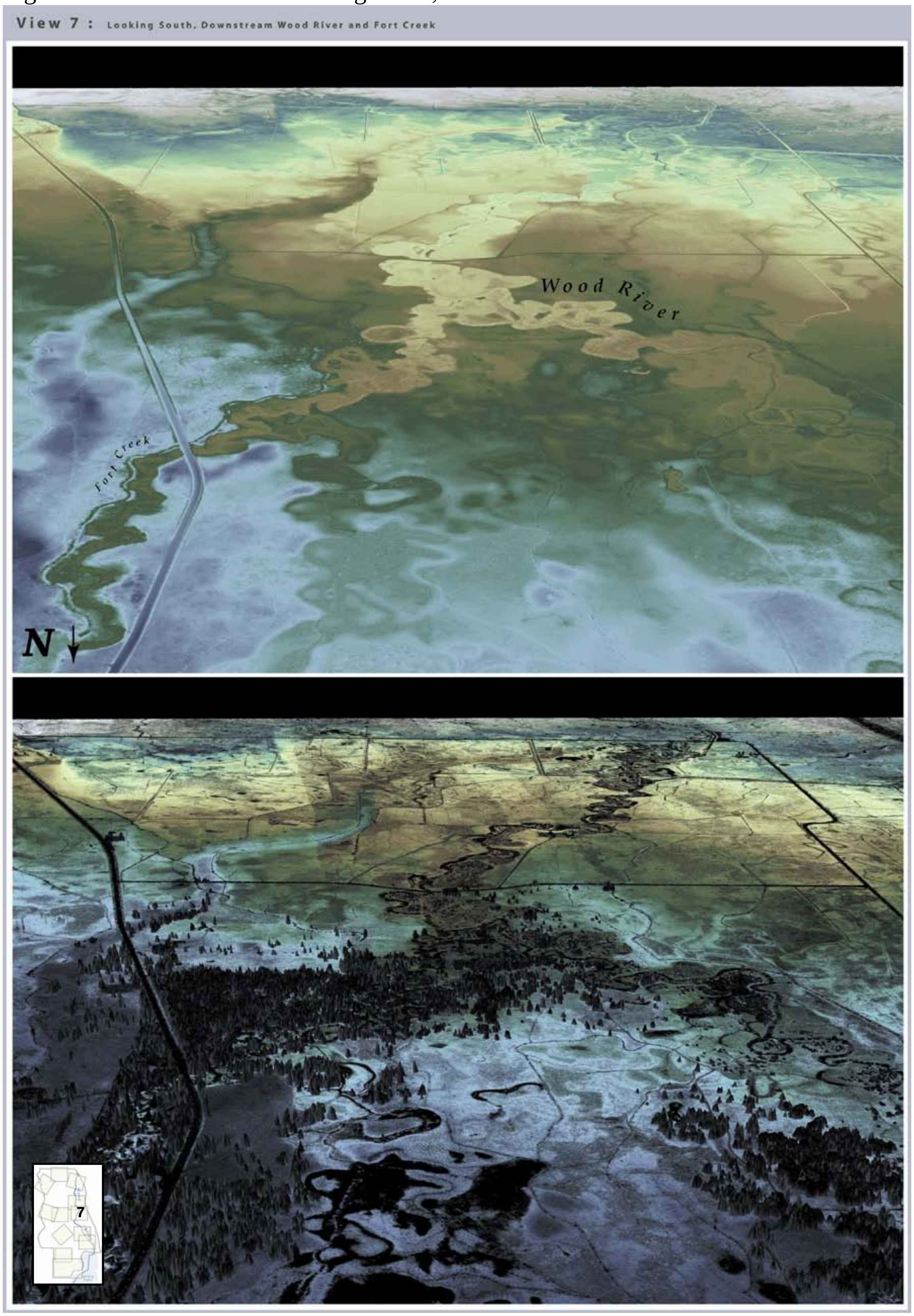


Figure 19. Detail View 8: Looking North, Upstream Wood River and Fort Creek

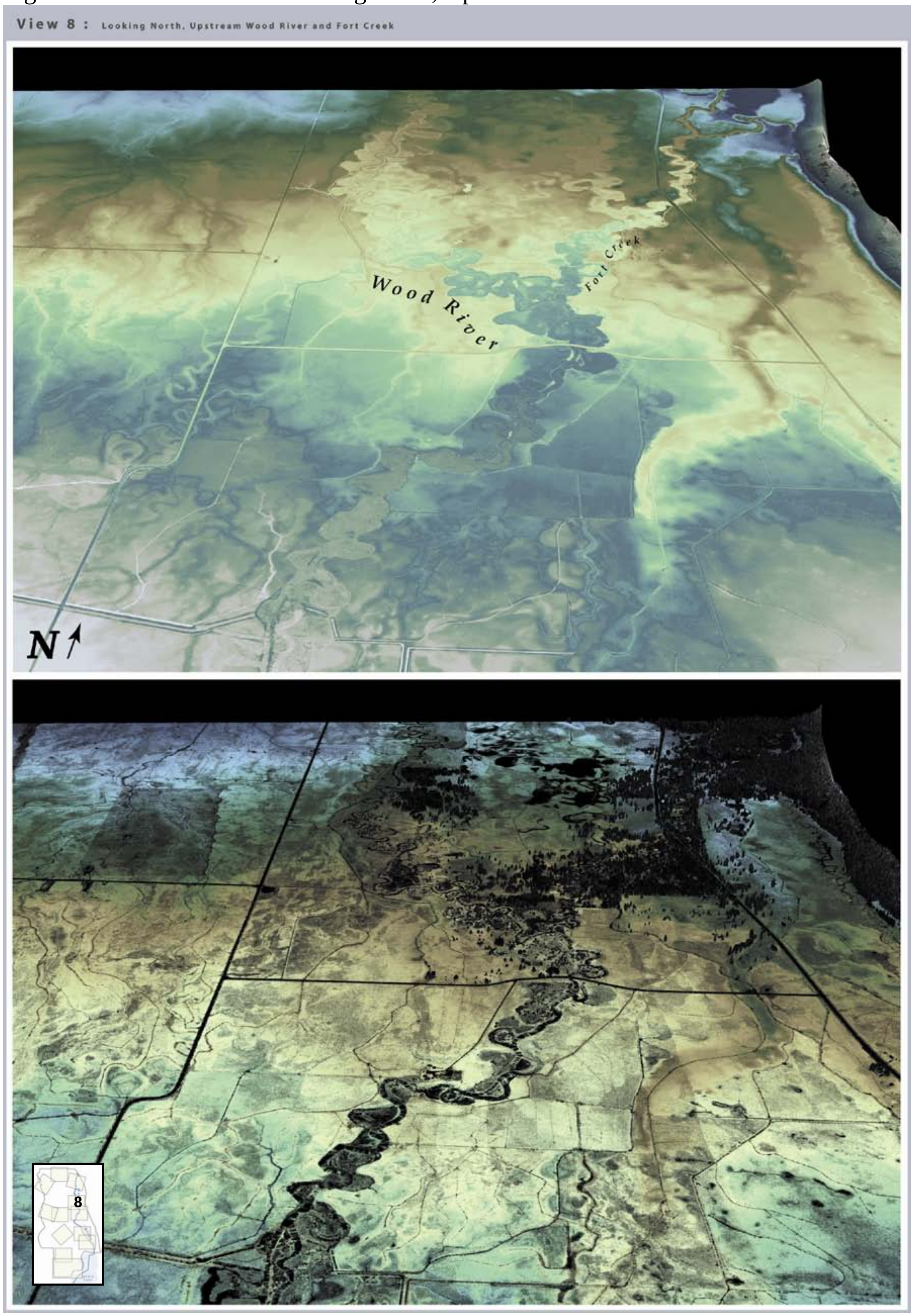


Figure 20. Detail View 9: Looking Northwest, Upstream Sevenmile Creek

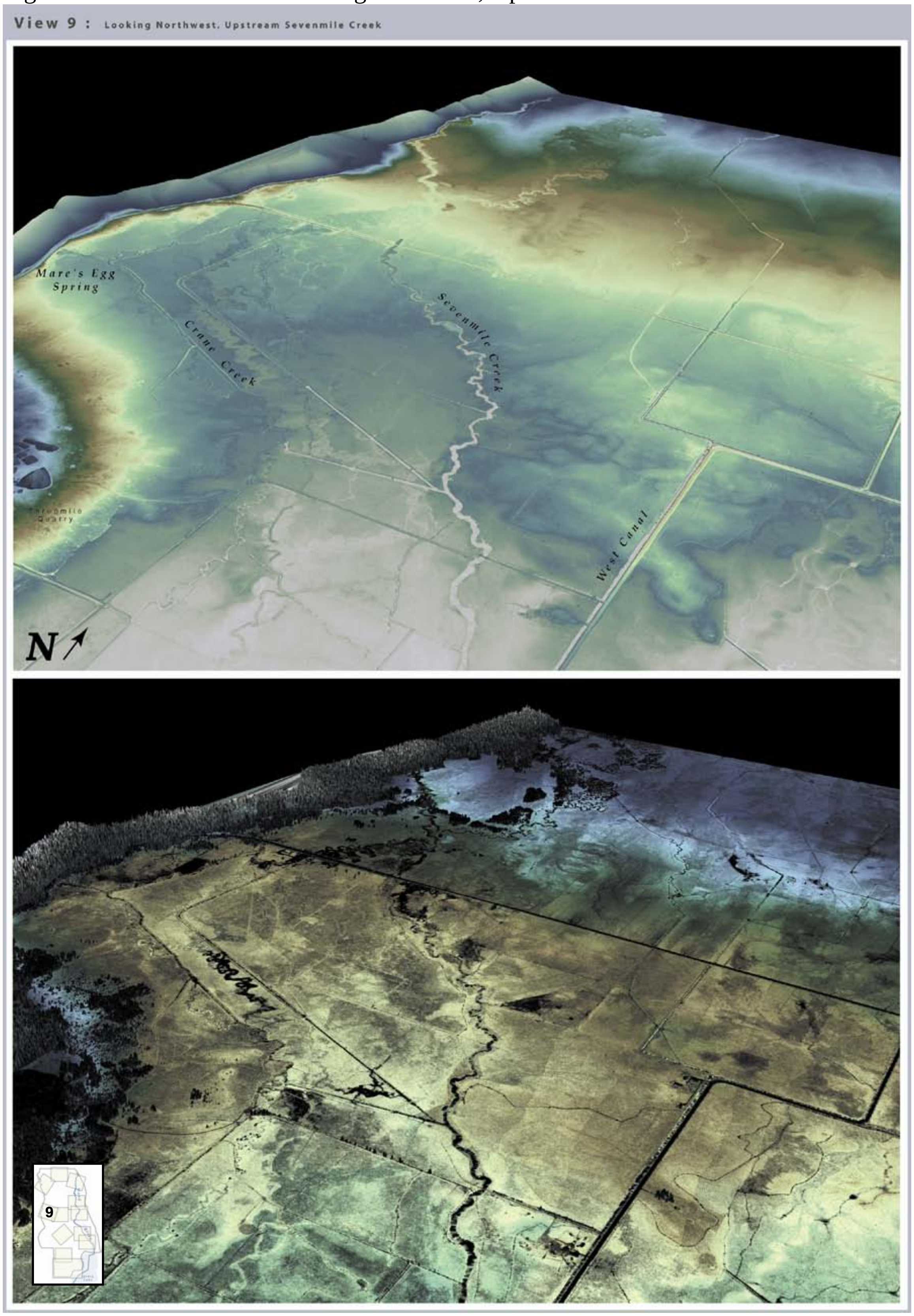


Figure 21. Detail View 10: Looking Northeast from Fort Klamath, Upstream Wood R.

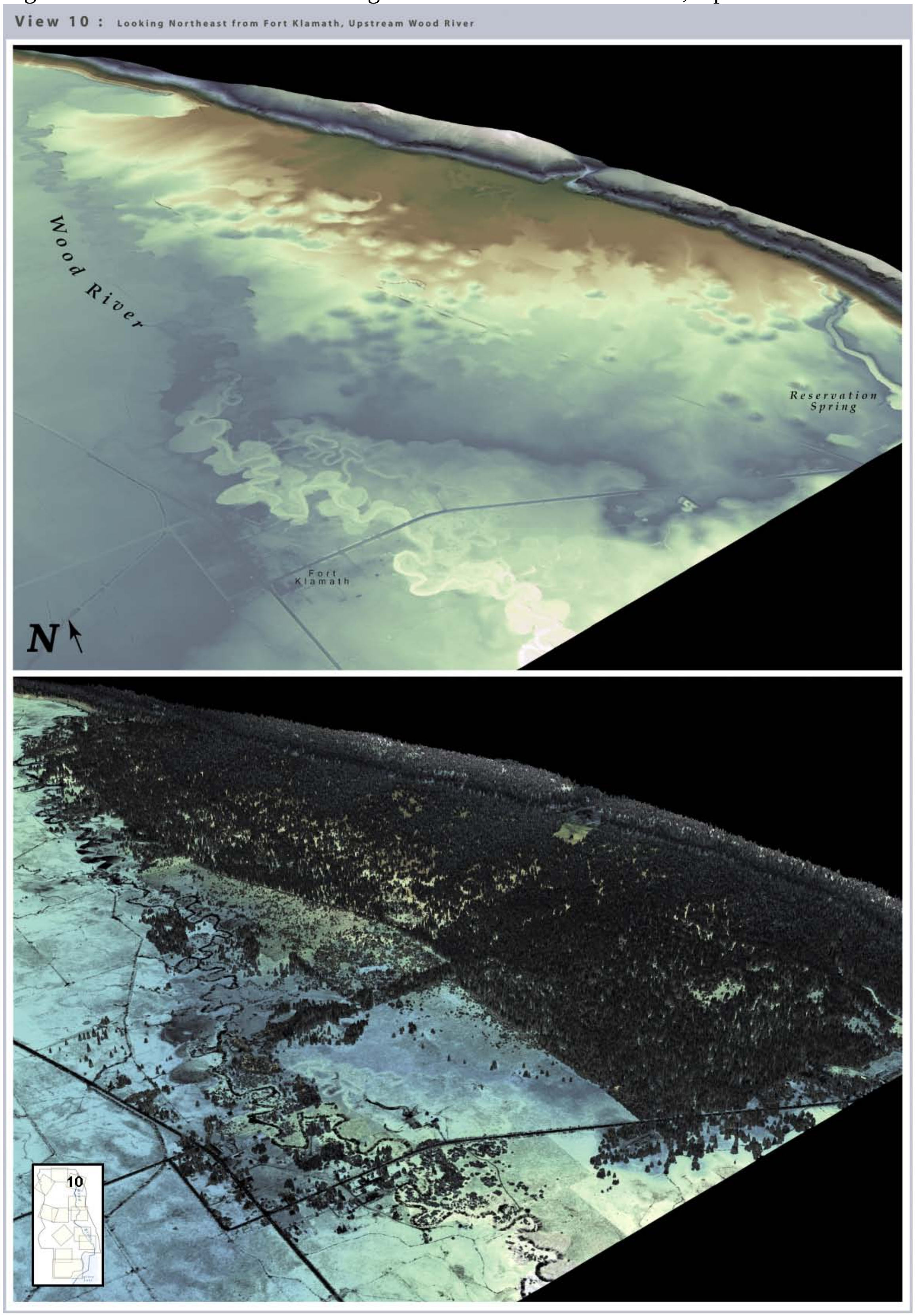


Figure 22. Detail View 11: Looking Northwest, Upstream Sevenmile Cr. to Dry Cr.

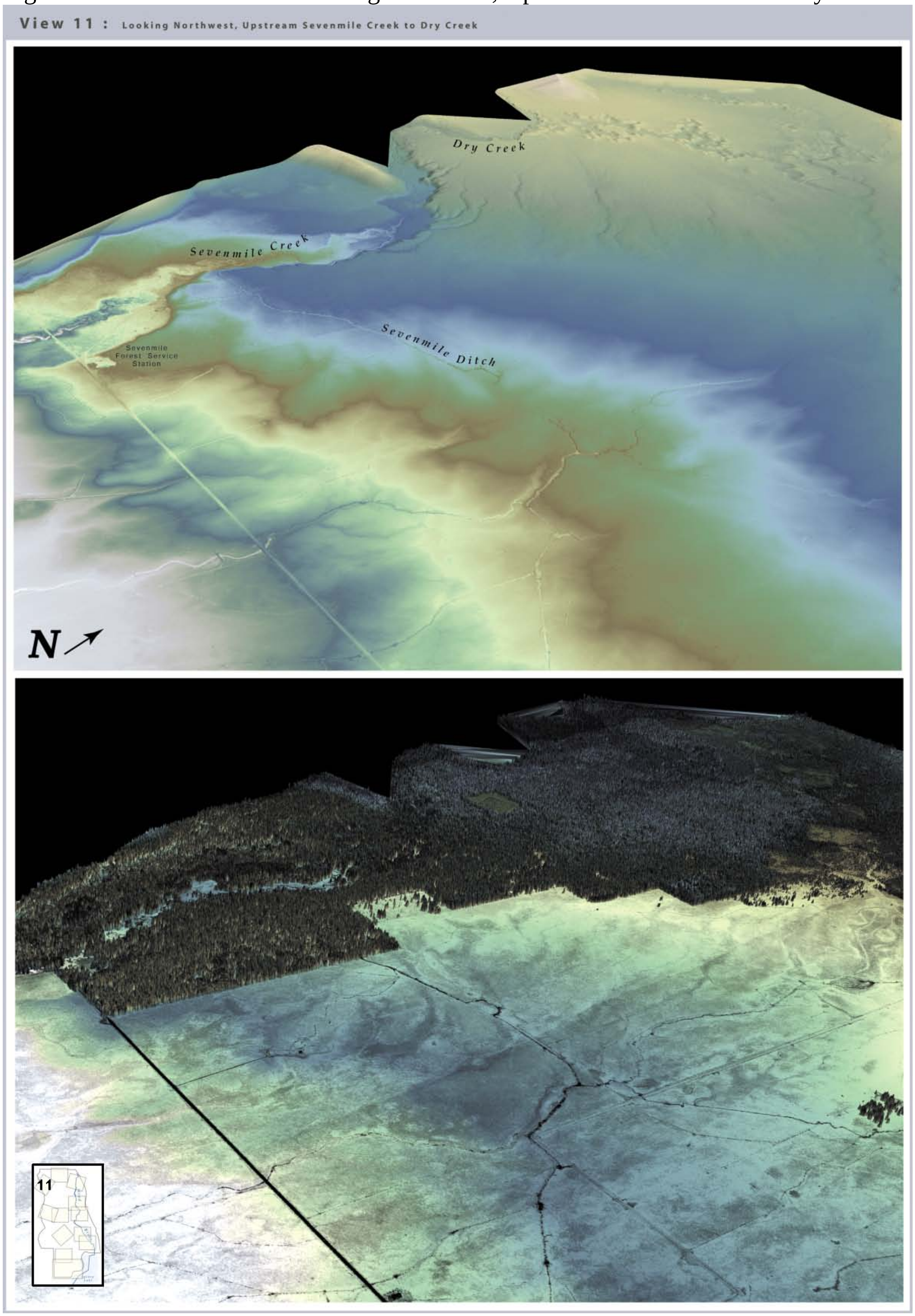


Figure 23. Detail View 12: Looking North, Upstream Annie Creek and Slough