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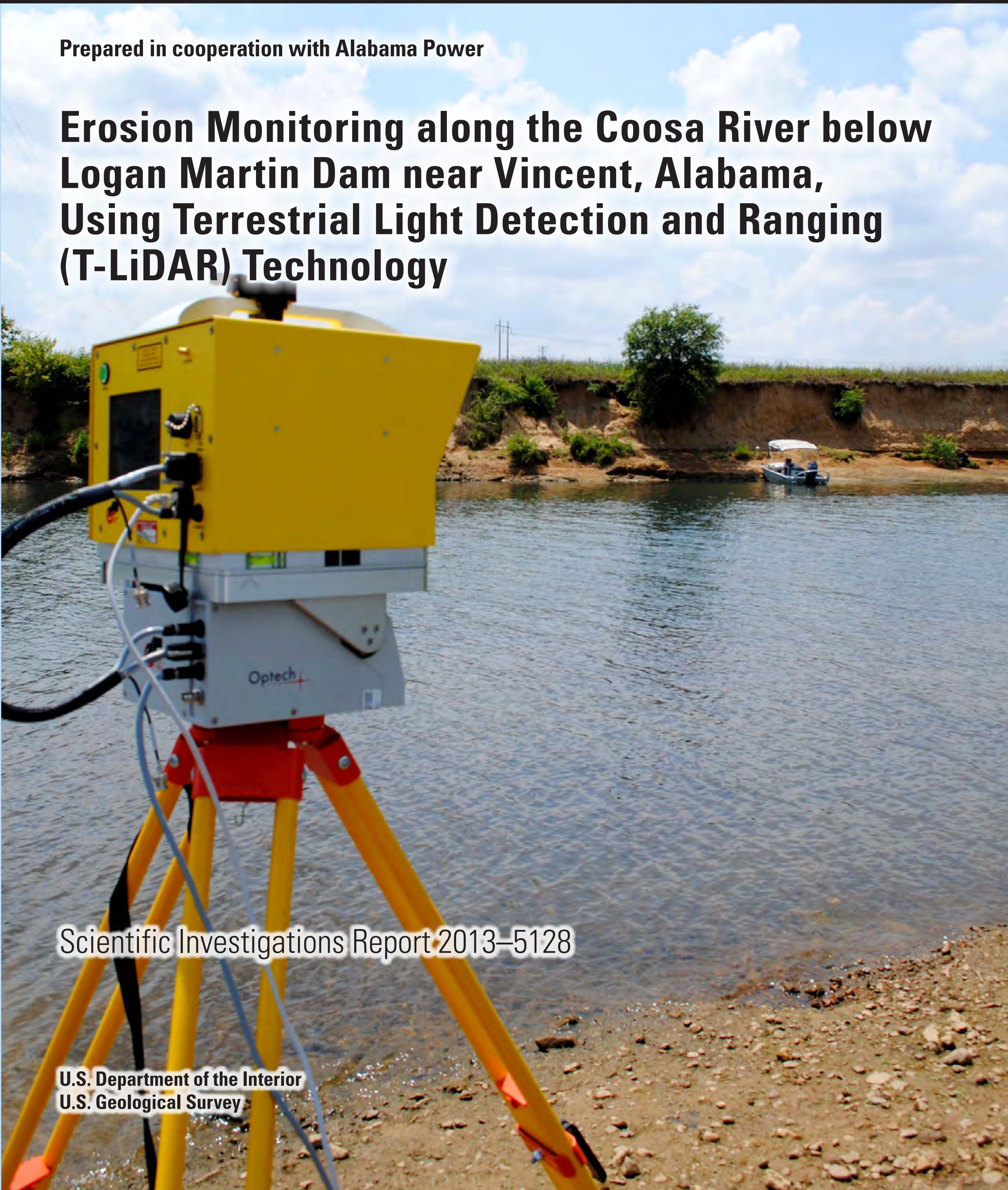
Erosion Monitoring along the Coosa River below Logan Martin Dam near Vincent, Alabama, Using Terrestrial Light Detection and Ranging (T-LiDAR) Technology



Scientific Investigations Report 2013–5128

U.S. Department of the Interior
U.S. Geological Survey

Cover: T-LiDAR instrument collecting data downstream of Logan Martin Dam near Vincent, Alabama.

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U.S. Geological Survey
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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	1.308	cubic yard (yd^3)

Elevation, as used in this report, refers to the distance above the vertical datum.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83), and projected in Universal Transverse Mercator (UTM).

Erosion Monitoring along the Coosa River below Logan Martin Dam near Vincent, Alabama, Using Terrestrial Light Detection and Ranging (T-LiDAR) Technology

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Abstract

Alabama Power operates a series of dams on the Coosa River in east central Alabama. These dams form six reservoirs that provide power generation, flood control, recreation, economic opportunity, and fish and wildlife habitats to the region. The Logan Martin Reservoir is located approximately 45 kilometers east of Birmingham and borders Saint Clair and Talladega Counties. Discharges below the reservoir are controlled by power generation at Logan Martin Dam, and there has been an ongoing concern about the stability of the streambanks downstream of the dam. The U.S. Geological Survey, in cooperation with Alabama Power conducted a scientific investigation of the geomorphic conditions of a 115-meter length of streambank along the Coosa River by using tripod-mounted terrestrial light detection and ranging technology. Two surveys were conducted before and after the winter flood season of 2010 to determine the extent and magnitude of geomorphic change. A comparison of the terrestrial light detection and ranging datasets indicated that approximately 40 cubic meters of material had been eroded from the upstream section of the study area. The terrestrial light detection and ranging data included in this report consist of electronic point cloud files containing several million georeferenced data points, as well as a surface model measuring changes between scans.

Introduction

The U.S. Geological Survey (USGS), in cooperation with Alabama Power, conducted a scientific investigation of the geomorphic conditions of a reach along the Coosa River downstream of Logan Martin Dam near Vincent, Alabama, by using tripod-mounted terrestrial light detection and ranging (T-LiDAR) technology (fig. 1). The Logan Martin Reservoir is located approximately 45 kilometers (km) east of Birmingham, Alabama, and borders Saint Clair and Talladega Counties. Discharges below the reservoir are controlled by power generation at Logan Martin Dam, and the stability of the banks downstream of the dam has been an ongoing concern. T-LiDAR technology has proven to be well suited for erosion and mass failure studies where conventional surveying techniques may be dangerous, as well as inadequate in supplying the necessary topographic detail for erosion-based analysis (Collins and others, 2007; Stock and others, 2011). The primary objective of this investigation was to use T-LiDAR technology to document any changes in streambank morphology and to quantify the observed changes. Two surveys were conducted before and after the winter flood season of 2010 to determine the extent and magnitude of geomorphic change on the right streambank located 0.75 km downstream of the dam. Specific details on the methods, data, and results of the geomorphic assessment are included in this report.

Data Collection Methods

T-LiDAR technology involves the use of laser pulses that are sent from the instrument and reflected off objects within its Field of View (FOV). The instrument calculates the distance of each returned laser pulse based on its velocity, and it also records the vertical and horizontal angle of each laser pulse. For both surveys completed in this investigation, an Optech ILRIS High Density (HD) Enhanced Range (ER) (Optech, 2009) laser scanner was mounted on a surveyor's tripod and set up on an island approximately 75 meters (m) from the study area (fig. 2). The Optech ILRIS HD ER has a laser repetition rate of 10 kilohertz with a laser wavelength of 1,535 nanometers, which is within the near-infrared (NIR) portion of the electromagnetic spectrum. The NIR portion of the electromagnetic spectrum has been traditionally used in the LiDAR community for standard topographic mapping and change analysis studies (J.J. Danielson, U.S. Geological Survey, written commun., 2012). The laser scanner was equipped with a pan/tilt base allowing the scanner's standard 40 x 40 degree (°) FOV to be rotated 360° and also tilted vertically, if necessary. The initial point cloud dataset acquired during the baseline survey in November 2010 consisted of 8 million data points with a point spacing typically less than 10 centimeters (cm). The subsequent point cloud dataset acquired after the winter flood season in July 2011 consisted of 9 million data points, also with a point spacing of less than 10 cm.

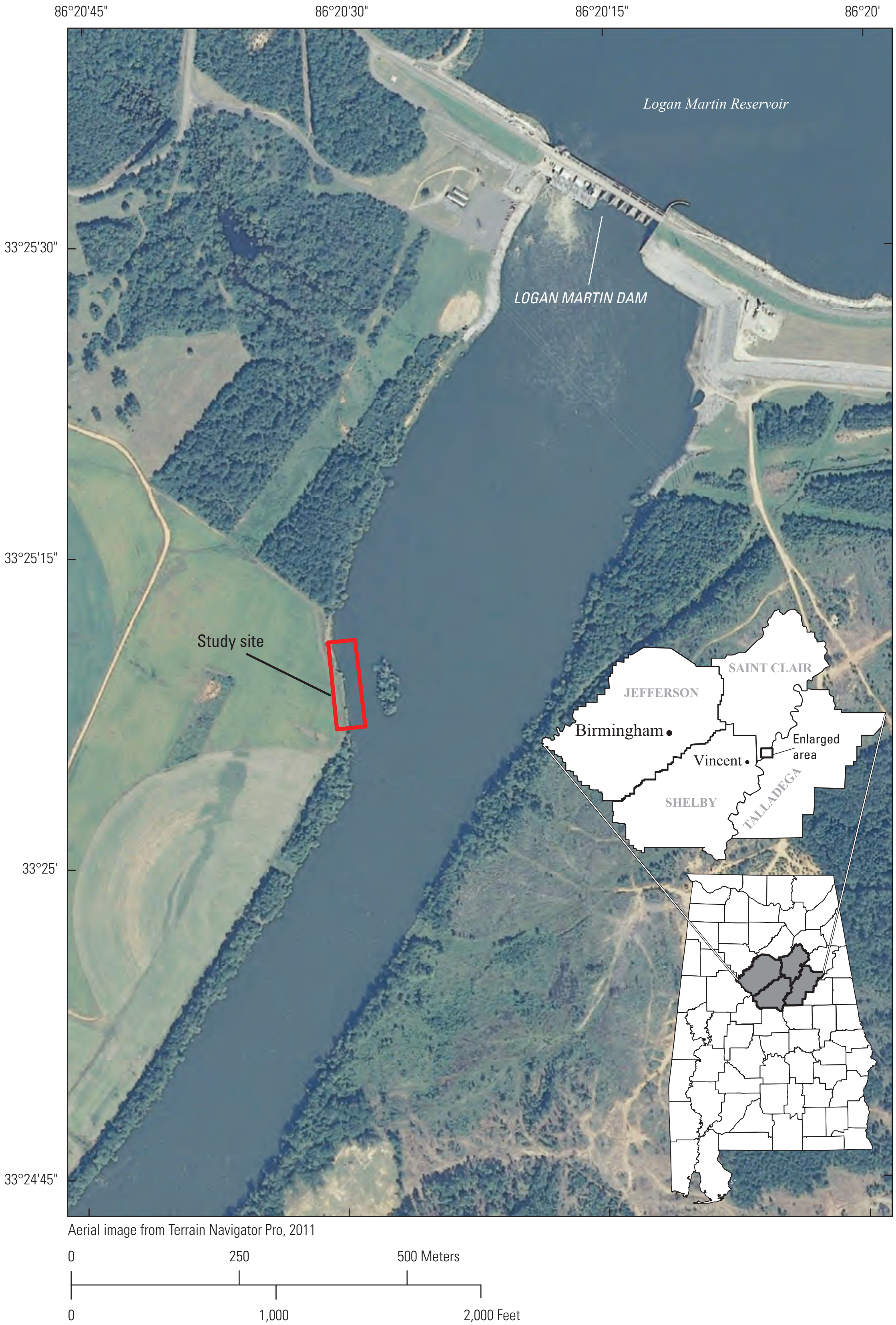

Figure 1. Location of the study area below Logan Martin Dam near Vincent, Alabama.

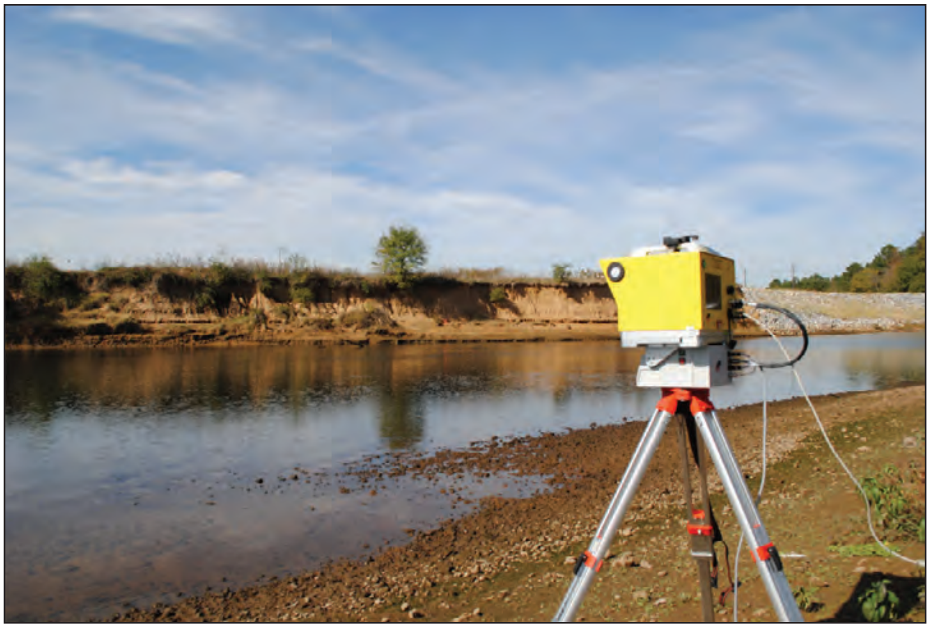

Figure 2. The study area and T-LiDAR instrument downstream of Logan Martin Dam near Vincent, Alabama.

Data Processing and Accuracy

Laser scanning data require several post-processing steps in order for useable datasets to be generated. Data were collected from only one setup location during each survey; however, the laser scanner automatically divides the raw data into overlapping tasks when the pan/tilt base is used. The degree of overlap is specified by the user of the laser scanner. After each field survey, the raw data files from each task were imported into the Optech Parser software, where scan settings were adjusted and the .pif files (Innovmetric, 2012) were created from the raw scanner data. The .pif files were then imported into Polyworks IMAlign software module (Innovmetric, 2012) in order to precisely merge each scan file together. The IMAlign software module creates a surface model of each .pif file and uses best-fit algorithms to precisely match the overlapping surfaces based on common topographic features between the scan files. The alignment error in this process ranged from 0.001 m to 0.01 m for both time series datasets. This error was determined by inspecting the color-shaded comparison maps and histogram outputs by the IMAlign software module. Once proper alignment was achieved, the overlapping .pif files for each separate survey were merged into a single file.

The IMAlign software module can also be used to precisely align datasets that were acquired at different time periods, provided there are stable objects of sufficient size within both datasets that can be used as common reference objects (for example, a stable rock outcrop). However, in this investigation there were no such objects of sufficient size, so the alignment of the two different surveys was completed in the Polyworks IMSurvey software module (Innovmetric, 2012) by using geodetic reference targets rather than control surfaces. Three geodetic reference targets consisting of concrete-filled PVC pipes, each with a metal rod slightly extending above the top of each pipe and set in concrete 0.5 m below the ground, were constructed in the study area prior to the survey. Virtual reference points were created using the IMSurvey module in both datasets at the top of these metal rods and also at points on a boulder that was stable during the time series. However, Target 1 was not used as alignment control due to sparse data in the November 2010 scan. The alignment errors between the November 2010 and July 2011 datasets were determined based on the variation in position between the virtual reference points (table 1).

Table 1. Alignment errors between virtual reference points used for the November 2010 and July 2011 datasets for part of the streambank downstream of Logan Martin Dam near Vincent, Alabama.

[RMSE, root mean square error]

Virtual reference point	Error between time series datasets, in meters			
	Easting	Northing	Elevation	RMSE
Target 2	0.001	0.022	0.001	0.013
Target 3	0.016	0.031	0.003	0.02
Boulder	0.014	0.053	0.002	0.032

Georeferencing

The laser scanner collects three-dimensional point data with reference to a relative datum, where the Cartesian coordinate origin is a reference point located on the base of the instrument. The point clouds collected in this study were subsequently transformed to a commonly used horizontal and vertical datum to utilize these data along with other geographically referenced datasets. A real-time kinematic (RTK) global positioning system (GPS) rover unit was leveled over the top of the threaded rod extending above each PVC pipe target, and three RTK GPS positions were measured at each of the three targets. The GPS coordinates were averaged for each target and then imported into IMSurvey as GPS control points. The three GPS control points were then matched to the three virtually created reference points in the July 2011 point cloud dataset. By using this process, both the November 2010 and the July 2011 datasets were transformed from the scanner's relative horizontal datum to the North American Datum of 1983 and projected to Universal Transverse Mercator Zone 16 North. This process also converted the original elevation values in both datasets to the North American Vertical Datum of 1988. The georeferencing error was determined based on the difference in the easting, northing, and elevation values between the known coordinates of the GPS control points and the position of the virtual reference points in each point cloud (table 2).

The overall accuracy of both point cloud datasets included in this report is limited by three factors: laser error, alignment error, and georeferencing error (Collins and others, 2009). Laser error is inherent to all data acquired by the laser scanner, and is 0.008 m as stated by the manufacturer (Optech, 2009). The combined point cloud root mean square error (RMSE) from all three factors was 0.263 m for the November 2010 dataset and 0.138 m for the July 2011 dataset.

Geomorphic Assessment

The objective of this investigation was to use T-LiDAR technology to document and quantify changes in streambank morphology during the winter flood season of 2010. The initial baseline survey was completed in November 2010 during low-flow conditions, and the second survey was done in July 2011 when the likelihood of sustained high flows had diminished. Geomorphic changes were quantified at 10 cross sections by measuring the linear difference of points on the streambank between survey scans at the top of slope, mid-slope, and bottom of slope. The points along the slope that were compared were chosen based on their point on the slope (top, middle, bottom) and the exact Universal Transverse Mercator (UTM) Northing coordinate between survey scans. The linear differences between cross sections were then computed along the UTM Easting axis using the survey measurement tool in the IMSurvey module. The UTM Easting axis was used as the comparison axis in order to remove bias in point selection between cross sections, and it also approximates the direction of bank retreat.

The volume of material eroded from the streambank during the time series was also computed. In order to determine this volume, a continuous surface model of the point data from each scan was created in IMSurvey by interpolating between nearby data points, producing a triangulated irregular network (TIN). This process used all data points for interpolation, and the maximum triangle edge length for the TIN was limited to 1.0 m. Volumes were then calculated by creating a vertical plane positioned parallel to the surface models and using the surface-to-plane volume tool to determine the volume of space between each individual surface model and the plane (fig. 3). The difference between the two values was considered the net change in volume, or net erosion.

A limitation of comparing time series T-LiDAR datasets is the occurrence of data shadows in areas out of the line of sight of the laser scanner, particularly when the shadow areas are incongruent between datasets. Vegetative cover was more prominent in July 2011 than in November 2010, causing large data shadows. Accurate interpolation across these large data shadows was not possible. In order to minimize measurement error, comparisons were limited to the most upstream portion of the streambank that exhibited the least amount of vegetation in both datasets.

A comparison of the T-LiDAR datasets was used to quantify erosion of the streambank during the winter flood season of 2010. Linear differences between datasets at 3 points on the slope of the streambank (top, middle, bottom) were measured along each of 10 cross sections (table 3). The volume of eroded material was quantified by comparing the volume of space between a user-defined plane and a surface model of the data points. This value was computed for both datasets, and it was determined from these measurements that approximately 40 cubic meters of material was removed from the upstream section of the streambank during the time series. This calculation was limited to the upstream section of the streambank in order to minimize errors in the surface model creation phase due to vegetation interference. Figure 4 is an error map depicting change detection analysis of the streambank. The color spectrum ranges from red to blue, with red indicating erosion up to 2 m and blue indicating sedimentation up to 2 m. The color green depicts zero change.

Table 2. Georeferencing error between global positioning system (GPS) control points and virtual reference points, November 2010 and July 2011, downstream of Logan Martin Dam near Vincent, Alabama.

[RMSE, root mean square error]

GPS control point	Error between GPS control points and virtual reference points, in meters							
	November 2010 virtual reference point				July 2011 virtual reference point			
	Easting	Northing	Elevation	RMSE	Easting	Northing	Elevation	RMSE
1	–0.17	0.252	–0.445	0.311	0.038	0.066	0.031	0.047
2	–0.045	0.105	0.021	0.067	0.044	0.127	0.02	0.078
3	–0.098	–0.092	–0.054	0.084	0.082	0.061	0.051	0.066

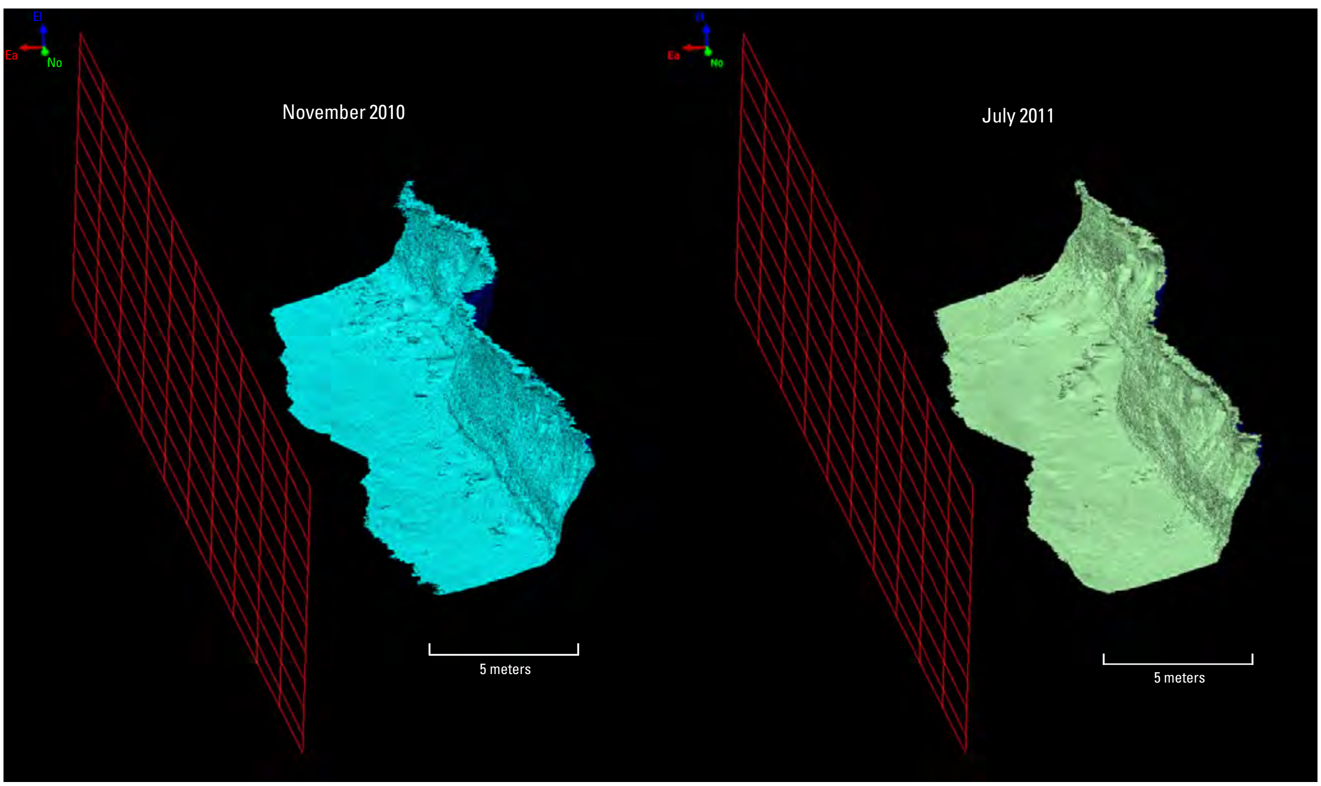

Figure 3. Three-dimensional map demonstrating how the change in volume between datasets was computed by comparing each surface model to a plane, downstream of Logan Martin Dam near Vincent, Alabama.

Table 3. Erosion at points along cross sections downstream of Logan Martin Dam near Vincent, Alabama, from November 2010 to July 2011.

Cross section (beginning upstream)	Erosion from November 2010 to July 2011, in meters		
	Top of slope	Mid-slope	Bottom of slope
1	0.29	0.17	0.14
2	0.45	0.18	0.43
3	0.22	0.11	0.39
4	0.83	0.10	0.20
5	0.05	0.13	0.22
6	0.61	0.10	0.25
7	1.34	0.20	0.29
8	0.58	0.07	0.19
9	0.55	0.21	0.29
10	0.44	0.27	0.13

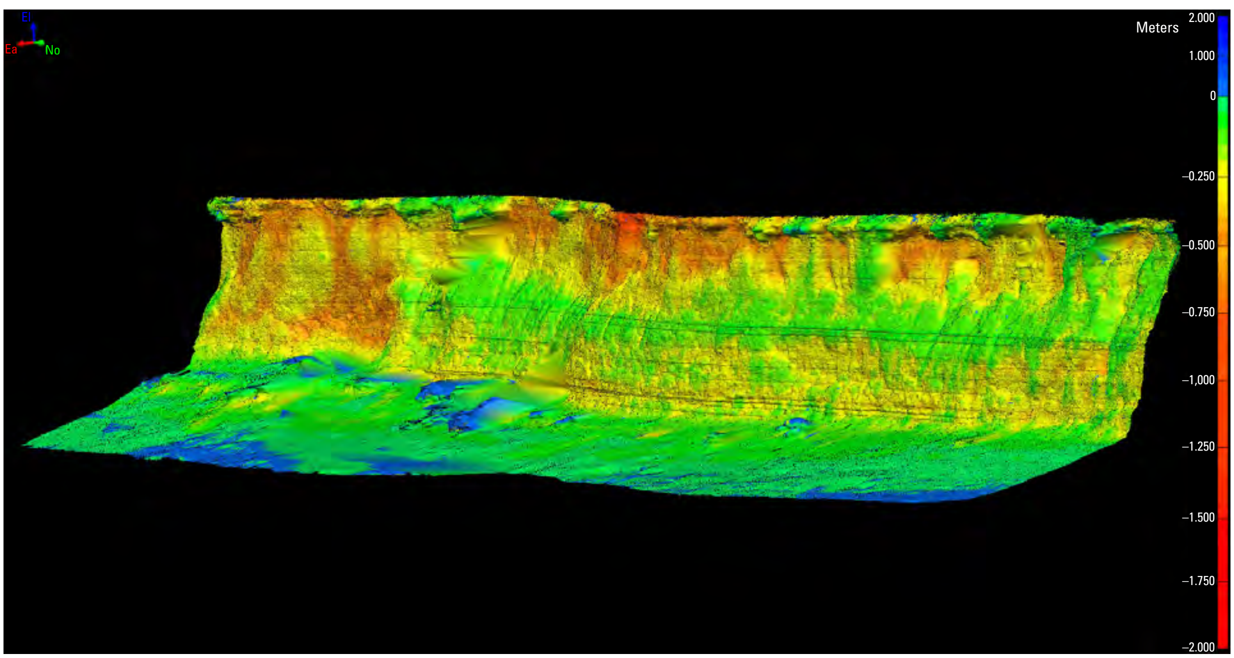

Figure 4. Error map depicting the geomorphic change along the streambank from November 2010 to July 2011, downstream of Logan Martin Dam near Vincent, Alabama.

Electronic Data Format

This report contains time series T-LiDAR point cloud datasets in ASCII text format with the extension .xyz. The horizontal XY coordinates have been cast in the North American Datum of 1983, Univeral Transverse Mercator, Zone 16 North coordinate system. The vertical Z values have been positioned in the North American Vertical Datum of 1988 vertical reference system. Although the data files are compressed (.zip), file sizes are relatively large and typically require specialized viewing software. Polyworks software was used for analysis and viewing of these data for this study, but many similar software packages are available. Three point cloud files are included in this report, and each is named according to the date on which the data were acquired and the manner in which each point is displayed (for example, 20101110_intensity.xyz). These data are formatted as text and contain x,y,z coordinates along with either intensity or red, green, blue (RGB) color values. Metadata are also included for each of the point cloud files in .xml format. Also included as a separate file is a surface model with colors depicting the quantity of change along the streambank (fig. 4). This file type (.pol) may only be viewed using Polyworks software. Included with the data is a link to the Polyworks IMView software (Innovmetric, 2012), which is available for free download.

Summary

A scientific investigation of geomorphic conditions of a 115-meter length of streambank along the Coosa River below Logan Martin Dam near Vincent, Alabama, using tripod-mounted T-LiDAR technology was conducted to assess the extent and magnitude of geomorphic change after the winter flood season of 2010. A survey was conducted before and after the flood season, and a comparison of the datasets was used to quantify erosion during the time series. Approximately 40 cubic meters of material was eroded from the upstream section of the streambank, and a comparison of cross sections showed upwards of 1 meter of bank retreat in some areas. This study demonstrated the utlility of T-LiDAR for change detection and geomorphic analysis.

References Cited

Collins, B.D., Kayen, R., Minasian, D., and Reiss, T., 2009, Terrestrial lidar datasets of New Orleans, Louisiana, levee failures from Hurricane Katrina, August 29, 2005: U.S. Geological Survey Data Series 470, 24 p.

Collins, B.D., Kayen, R., Reiss, T., and Sitar, N., 2007, Terrestrial LIDAR investigation of the December 2003 and January 2007 activations of the Northridge Bluff Landslide, Daly City, California: U.S. Geological Survey Open-File Report 2007–1079, 32 p., accessed December 17, 2012, at *http://pubs.usgs.gov/of/2007/1079/*.

Innovmetric, 2012, Parametric Image Format, Polyworks/IMView software, accessed February 12, 2012, at *http://www.innovmetric.com/polyworks/3D-scanners/viewer.aspx?lang=en*.

Optech, 2009, ILRIS summary specification sheet, accessed February 12, 2012, at *http://www.optech.ca/pdf/ILRIS_SpecSheet_110309_Web.pdf*.

Stock, G.M., Bawden, G., Green, J., Hanson, E., Downing, G., Collins, B., Bond, S., and Leslar, M., 2011, High resolution three-dimensional imaging and analysis of rock falls in Yosemite Valley, California: Geosphere, v. 7, no. 2, p. 573–581.

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