Western Coastal and Marine Geology

Applicability of Terrestrial LIDAR Scanning for Scientific Studies in Grand Canyon National Park, Arizona

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U.S. Geological Survey, Menlo Park, California

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Datum Information

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 to Arizona Central Zone 0202 State Plane coordinates.

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

Metadata for the products described in this report are available at:

http://walrus.wr.usgs.gov/infobank/r/r104gc/html/r-1-04-gc.geo.html

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By Brian D. Collins and Robert Kayen

Introduction

In November 2004, an experimental high flow release of water from Glen Canyon Dam into the Colorado River through Grand Canyon National Park in Arizona was conducted. The goal of the experiment was to evaluate the use of high flow events as a management tool for the preservation and restoration of natural resources in the Colorado River below Glen Canyon Dam. The U.S. Geological Survey (USGS), Grand Canyon Monitoring and Research Center (GCMRC) located in Flagstaff, Arizona performed oversight of all aspects of scientific data collection including suspended sediment transport studies, biological population variations, effects on archaeological resources, and morphological studies of river sand bars.

As part of the experimental high flow studies, the USGS Coastal and Marine Geology (CMG) team was invited to participate to test the effectiveness of utilizing terrestrial LIDAR technology for gathering morphological data on sand bars, biological habitats, and archaeological sites. The CMG is equipped with a terrestrial LIDAR unit and has used the technique in a variety of terrains to gather high-resolution morphological data (e.g. Collins and Sitar, 2002, 2004, 2005; Kayen and others, 2004, 2006, Collins and Kayen, 2005). A three-member team from CMG participated in the experiment, joining a GCMRC team on a river trip from November 18 to November 21, 2004 (United States Geological Survey, 2004).

This report begins with a brief description of the LIDAR technique and then outlines the data collected, processing required, and results for three study areas located within the Grand Canyon. Specifically, studies were performed at the Mile 30 Sand Bar, at Vaseys Paradise (Mile 32), and at the Mile 66 Palisades Archaeological Site (Figure 1). Conclusions and recommendations for utilizing terrestrial LIDAR for future studies at each of these sites are also included.

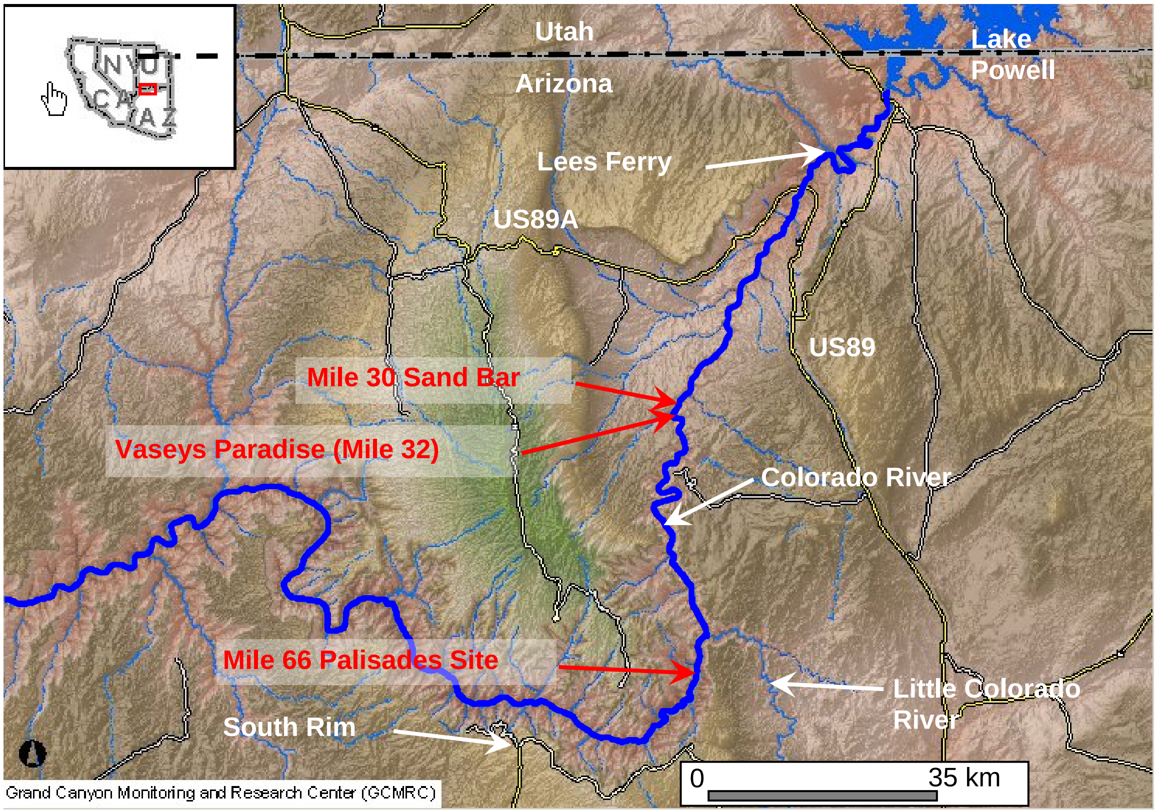


Figure 1. Location map of terrestrial LIDAR studies within Grand Canyon National Park during the November 2004 High Flow Experiment

Methodology

The terrestrial LIDAR technique, or 3D laser scanning as it is commonly known, consists of sending and receiving laser pulses to build a point file of three-dimensional coordinates of virtually any surface. The time of travel for a single pulse reflection is measured along a known trajectory such that the distance from the laser, and consequently the exact location of a point of interest can be computed. In addition, some lasers use a color sensor to obtain additional visual data on points located both within and outside of laser range. Given the rapid rate of data collection from the newest state of the art topographic laser scanning systems, the location of up to 12,000 surface points can be collected in one second. Thus, an entire surface, be it a building, a cliff face, or a sand bar can be surveyed quickly and accurately. The point file from a given scan is typically transformed into a three-dimensional surface so that cross-sections and volumetric calculations can be performed between consecutively scanned surfaces.

The technique has been utilized by the authors successfully in a wide range of environments, most recently for studies involving coastal bluff change along the California coast (Collins and Sitar, 2002, 2004, 2005), in earthquake reconnaissance studies (Kayen and others, 2004, 2006) and in the failure analysis of the New Orleans levee system during Hurricane Katrina (Collins and Kayen, 2005). Complete details of the laser scanning process can be found in these references.

In this study, the CMG’s Riegl Z210 laser scanner was utilized as a tripod mounted survey instrument (Figure 2) and transported to each Grand Canyon site by raft. The laser was set up over various locations and survey control was obtained from existing benchmarks using traditional total station survey techniques. Each laser scan collected data at a rate of 8000 points per second, scanning a range of 336 degrees in the horizontal direction and plus and minus 40 degrees from the horizontal in the vertical direction. Multiple scans were collected to fill in "shadow zones" of locations not directly in the line of sight of the laser and to expand the range and density of the point data.

Processing of the data was performed using the I-SiTE software program (I-SiTE, 2005) specifically designed to handle laser scanning data. Specific details of the processing procedures used in each location are provided with each locations summary. Metadata for the data collection effort and data products is available at *http://walrus.wr.usgs.gov/infobank/r/r104gc/html/r-1-04-gc.meta.html* (United States Geological Survey, 2004).

Figure 2. The USGS Coastal and Marine Geology program's terrestrial LIDAR unit.

Mile 30 Sand Bar

Background

The Mile 30 Sand Bar site was selected for detailed study by the GCMRC as a test location for obtaining high resolution topographic data of sand bars (Figure 3). Topographical surveys of sand bars are typically performed using standard survey methods involving personnel occupying and collecting data points on the sand bar itself. This type of technique generally leads to topographic changes to the surface by footprints as well as disturbances to steep, easily erodible slopes. The purpose of data collection using the laser scanning technique was therefore to test a less invasive method of surveying in this type of setting. Additionally, testing was performed to obtain information on the optimal location and number of scans required for full creation of sand bar digital terrain models along other portions of the Colorado River.

Data

A total of seven laser scans were collected of the Mile 30 Sand Bar area. For five of these scans, the laser was located on the sand bar itself; two other scans were collected from rock outcrops located across the river from the sand bar (Figure 4). These sand bar and cross-river scan sets each provided a data set for processing and comparison.

Standard field survey methods were also implemented by the GCMRC to obtain survey control at the Mile 30 site. A total station and prism reflectors collected precise survey data for the five laser set-up locations on the sand bar, in addition to several survey control points and back-sight points for data rectification (Table 1). No control points were collected on the cross-river laser set-up locations. Horizontal survey coordinates are referenced to the NAD83 metric datum, with an Arizona Central Zone 0202 State Plane projection. Vertical survey data is referenced to the NAVD88 datum.

Table 1. Survey Control for Mile 30 Sand Bar

Control Point	Northing (m)	Easting (m)	Ground Elev. (m)	Instrument Height (m)	Instrument Elev. (m)
m30lsu1	611760.814	219555.120	856.418	1.820	858.238
m30lsu2	611785.650	219539.469	856.888	1.820	858.708
m30lsu3	611767.555	219523.297	860.963	1.820	862.783
m30lsu4	611747.468	219537.323	857.333	1.820	859.153
m30lsu5	611721.384	219519.959	856.463	1.820	858.283
m30lsu6	N/A[1]	N/A[1]	N/A[1]	N/A[1]	N/A[1]
m30lsu7	N/A[1]	N/A[1]	N/A[1]	N/A[1]	N/A[1]
beachtemp	611766.208	219563.059	855.907	1.939	857.846
new1	611753.346	219509.750	862.994	1.461	864.455
new2	611830.986	219556.016	858.307	N/A[2]	N/A[2]

Horizontal datum is NAD83 metric. Horizontal projection is Arizona Central Zone 0202 State Plane.

Vertical datum is NAVD88.

[1] Points were not surveyed during data acquisition.

[2] Point could not be located in the scan data and instrument height was not measured in the field.

Given the close proximity of the laser scans to one another, extremely high resolution topographic data was collected at this site. As an example, the scanner collected and resolved footprints made on the surface of the sand bar (Figure 5). A complete view of the majority of the raw data at the site is shown in Figure 6. As discussed, an additional capability of the laser system is its ability to obtain background visual information on features out of range of the scanner. The photographic color sensor collects the color value and intensity of these background points (termed “sky points”) providing useful data for surface orientation. In Figure 7, two views of the raw laser scan data along with the background color information are shown and highlight this type of data.

Figure 3. The Mile 30 Sand Bar Site.

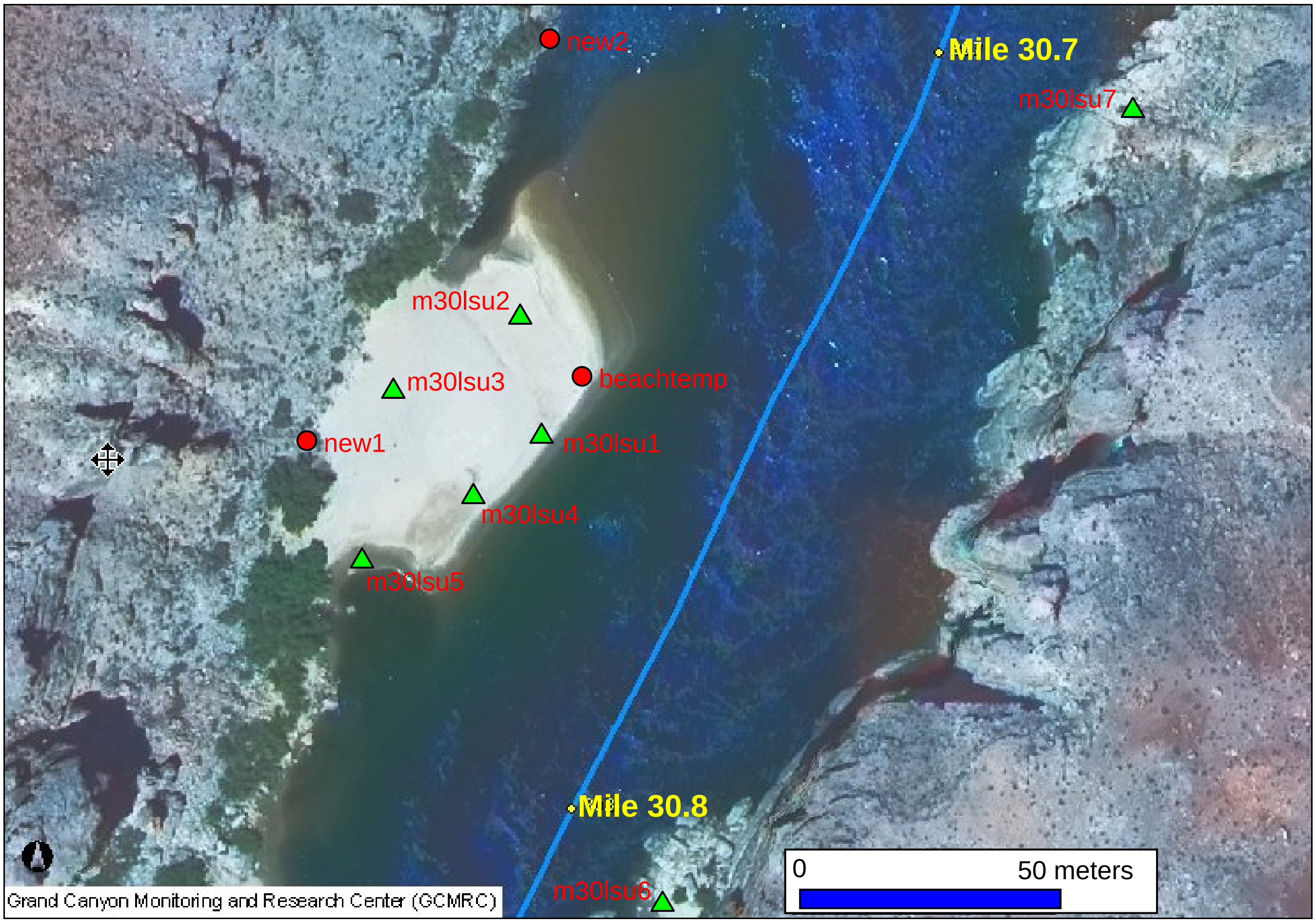


Figure 4. Mile 30 Sand Bar Site showing locations of laser set-up points (triangles) and survey control points (circles).

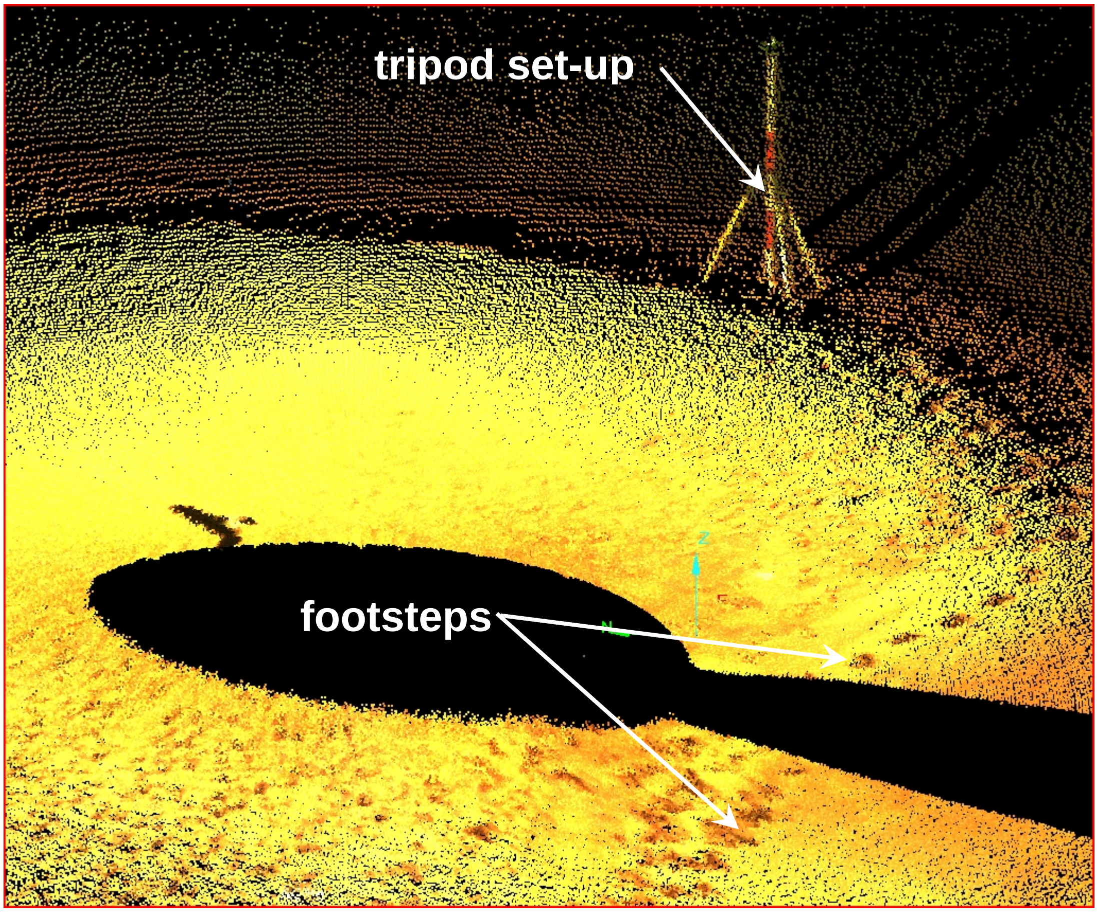


Figure 5. Laser scan data of Mile 30 Sand Bar showing footsteps and tripod control point setup. Black area indicates area where no data was collected beneath the tripod and outside of the 336° data collection area of the laser.

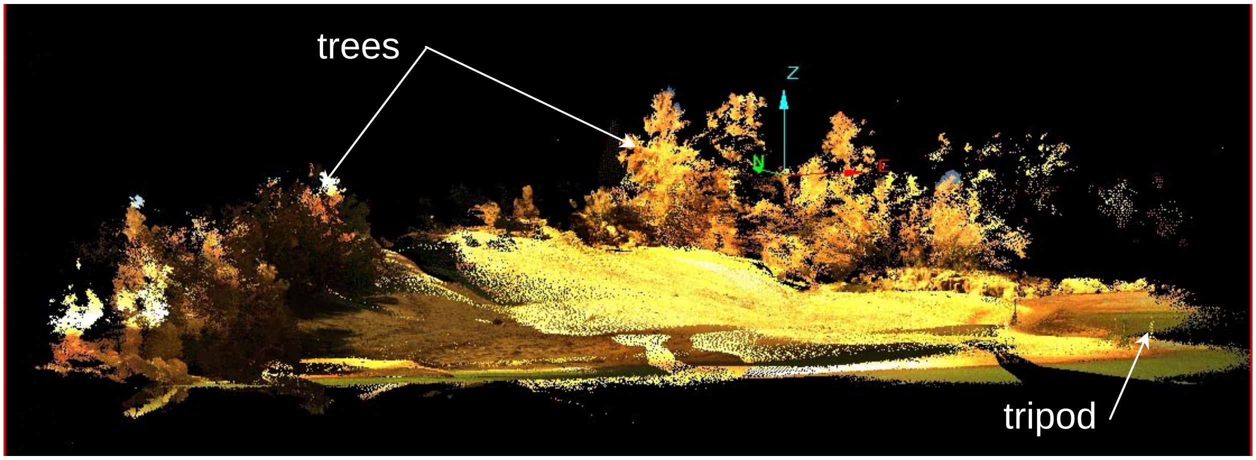
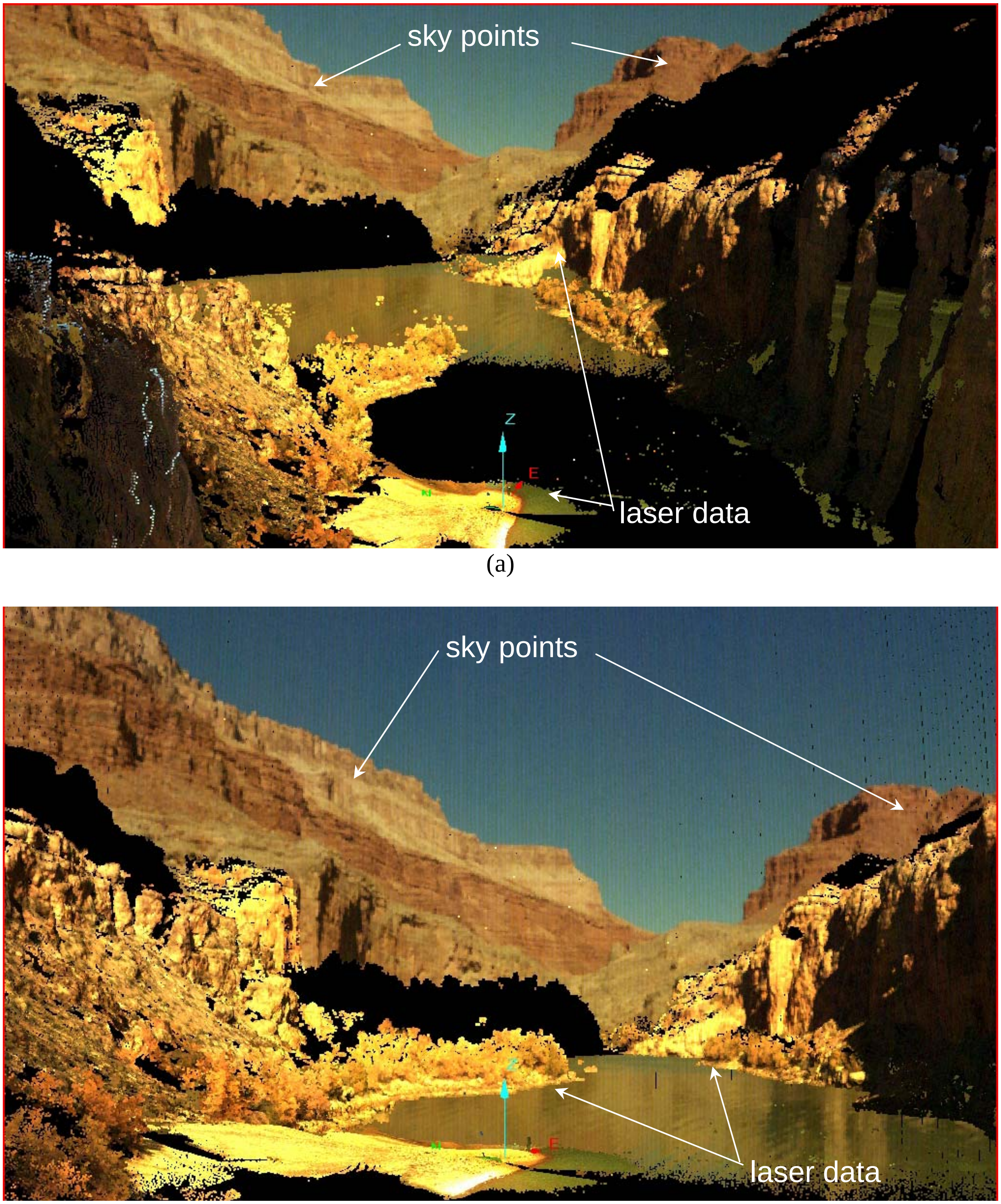


Figure 6. Point cloud data of Mile 30 Sand Bar showing trees and survey features.



(a)

(b)

Figure 7. Mile 30 Sand Bar showing both laser data and “sky points” of background (non-laser) data.

Processing

Processing of each data set was performed using identical methods. A step by step outline of this methodology for the five sand bar collected scans is outlined here for reference. Each scan was initially surface registered to one another using the entire point cloud from each scan. Typical root-mean squared (RMS) error calculated between data point sets was on the order of 10 centimeters. Each scan was then filtered to a minimum point separation of 25 centimeters and a topographical triangulation was created from each scan. Scan Number 1 provided the best overall coverage of the site, thus each scan was registered to the triangulation for this scan resulting in a typical RMS error of 4 centimeters. Each of the remaining triangulations were then recreated from the newly matched scan data sets and surface registered to the Scan Number 1 triangulation. This improved the RMS error estimate to approximately 1 centimeter which was deemed a sufficiently tight fit for the collected scan data.

Each topographic triangulation was then merged with a neighboring triangulation resulting in a final fused topographic triangulation for the entire data set. The final surface consists of approximately 238,000 triangular facets with 121,000 points describing a surface area of 4,200 square meters. Two views of the completed final surface are shown in Figure 8.

Data georeferencing was performed by registering the collected survey data to control point reflectors and laser scan set-up points identified in the scan data. In total, 7 points could be identified out of a possible 8 control points (5 laser set-up locations, 2 fixed control points, and 1 temporary control point) Fixed control point “new2” could not be identified in the scan data. All scans and surfaces created from processing were moved to match the real-world coordinates of the surveyed control points. An initial fit of 44 centimeters was obtained using all 7 points, however a final fit of 8.5 centimeters was obtained using only 5 of the control points. The improvement of the fit was likely due to the removal of points with inherent survey errors, such as inaccurate measurement of tripod height or misrepresentation of the survey target.

An identical methodology was applied to the cross-river scans. Here, only two scans were collected from rock outcrops on the east side of the river. Topographical surface registration error for the two scans was calculated to be 5 centimeters with the final fusion surface consisting of 205,000 facets with 105,000 points describing a surface area of 3,300 square meters. The slightly smaller surface area calculated with the cross-river scans represents only the exclusion of some of the higher cliff data; the entire sand bar area of interest was obtained using the cross-river scans. Georeferencing of the scan and surface data to real world coordinates could not be performed using the control point method since only one control point was visible in the scan data and precise survey data was not collected for the cross-river scanner origins. Instead, georeferencing relied on performing a surface registration from the cross-river fusion surface to the sand bar fusion surface. A final RMS error of 4.4 centimeters was obtained using this process. This type of registration could also have been performed on any area of scan data that overlaps with the cross-river scan. For example, for future surveys, an area of cliff located above the sand bar could just as easily be utilized for the registration process given an initial georeferenced data set.

Results

The end result of the processing for the sand-bar collected scans was an individual scan fit of 1 centimeter between data sets and a georeferenced fit of 8.5 centimeters error to the surveyed coordinates. The final topographic surface consists of 238,000 triangular facets and provides a high resolution DTM of the Mile 30 sand bar area.

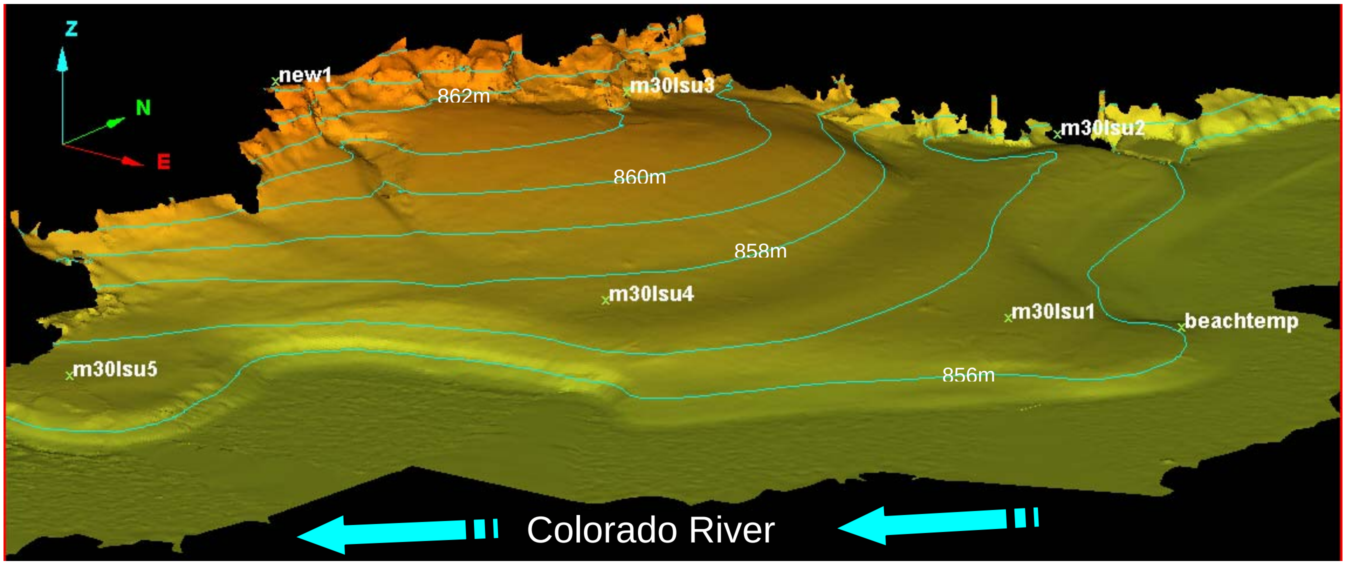
The cross-river collected scans resulted in an individual scan fit of 5 centimeters between data sets and a georeferenced fit of 4.4 centimeters error relative to the sand bar georeferenced fit. The final topographic surface using these two scans consists of 205,000 triangular facets and also provides a high resolution DTM of the Mile 30 Sand Bar.

The final surfaces for each scan set are nearly identical and can best be compared using cross-sections taken along the axis of the river. A total of 12 sections were cut along the length of the sand bar at 10 meter intervals (Figure 9), four of which are shown in Figure 10. The sections show an almost identical match to one another, and prove the utility of the lower impact cross-river scan methodology for characterizing the overall sand bar morphology. Only in areas higher up the sand bar, at the intersection of the bar with the cliff debris slope, are discrepancies found between the two data sets. In these areas, the discrepancies are related to a combination of dense vegetation and low-angle, oblique laser reflections from the cross-river scans. If the upper, fringe sections of sand bars are shown to be important for geomorphologic studies, additional, closer scans may be necessary, or additional vantage points from higher cross-river platforms may be utilized to scan these areas in higher detail.

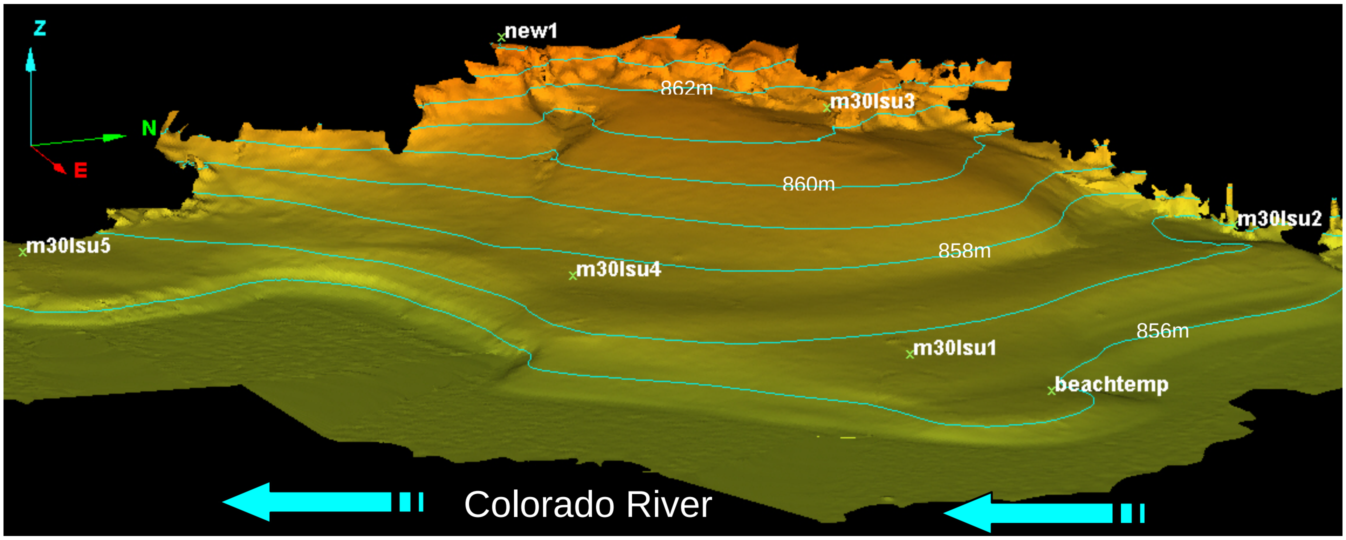
Conclusions and Recommendations

The Mile 30 Sand Bar data shows the utility of the terrestrial LIDAR scanning method for performing surface generation of complex and evolving topography. Here, two methods were utilized comprising near-range and far-range data acquisition. Given that the two data sets are within an order of magnitude of each other for scan and georeference fit error, we feel that the extra effort of collecting scans from the sand bar itself is not worth the additional effort. The cross-river data set provides the necessary data for generating accurate, high-resolution cross sections and can be used in volumetric calculations when future data sets are collected. Georeferencing of future data sets can be performed using either the surface registration techniques outlined in this report, or by conventional survey control of each scanner location along with at least one additional survey point located on the opposite side of the river.

Future scans of sand bar topography in other areas of the Grand Canyon can therefore be performed from outcrops of rock located across river from the target sand bar. This will lessen the impact of foot traffic to the sand bars and will result in more efficient data acquisition trips in the Grand Canyon.



(a)



(b)

Figure 8. Views of final DTM surface of Mile 30 Sand Bar from the sand bar scan set (labels indicate location of control points). One-meter contour elevations are shown relative to NAVD88.

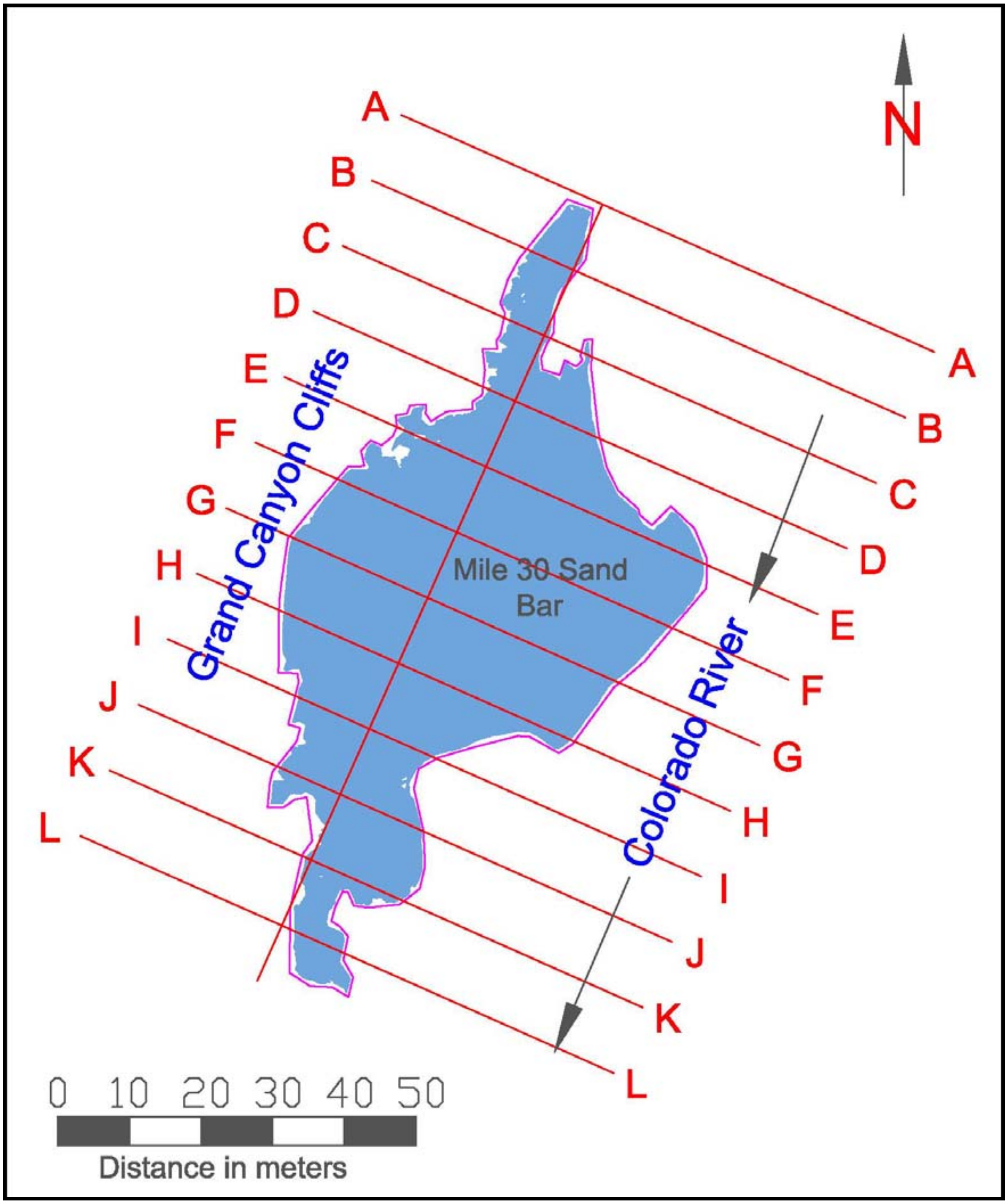
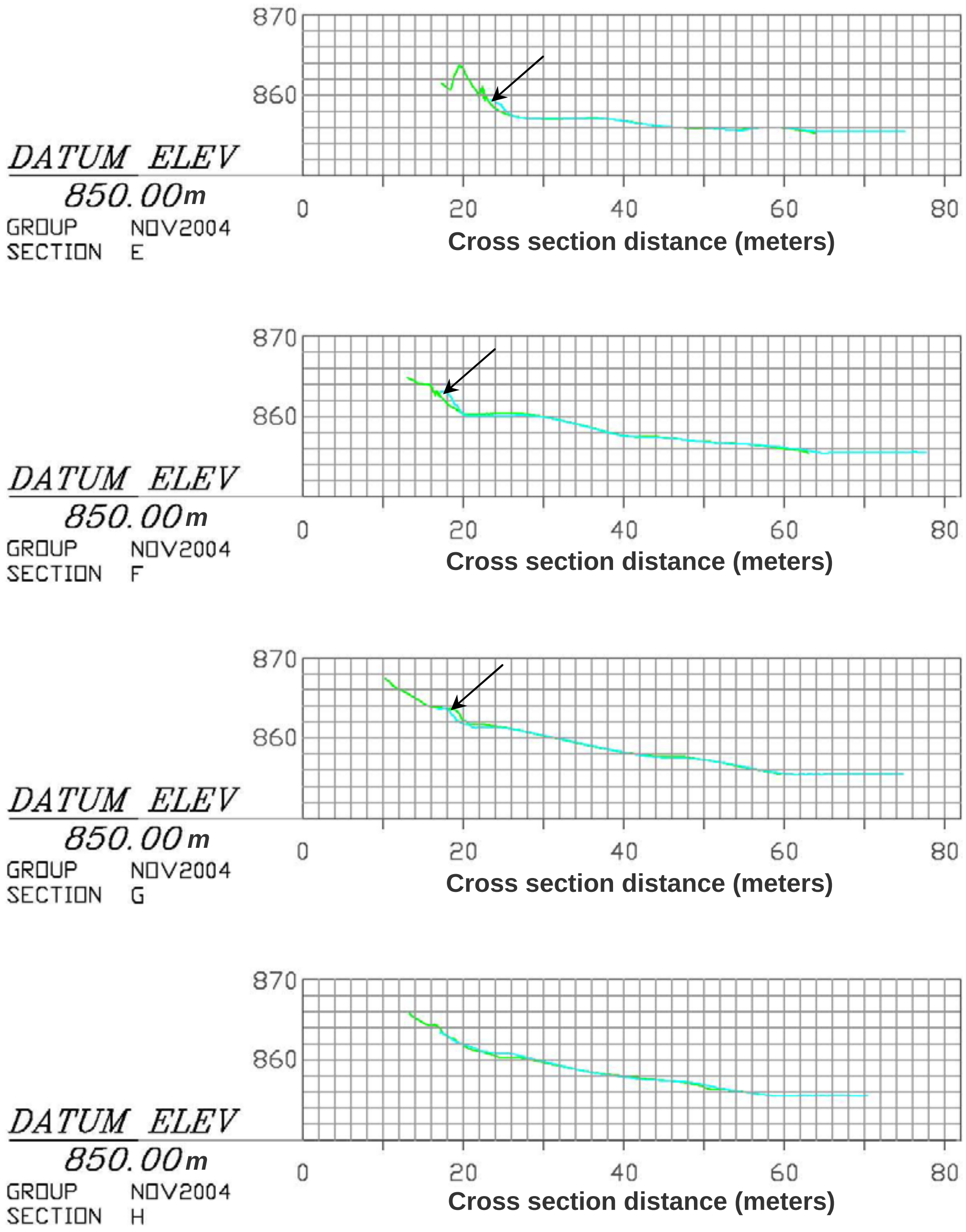


Figure 9. Location of cross sections at the Mile 30 Sand Bar site.



Note: Vertical datum is referenced to NAVD88.

Figure 10. Selected cross sections of the Mile 30 Sand Bar. Both sand bar (blue) and cross-river (green) data sets are shown, but appear as one line due to the nearly identical surface matching that was obtained. Arrows delineate upper slope discrepancies in and near vegetation.

Vaseys Paradise (Mile 32)

Background

Vaseys Paradise is located approximately 1.5 miles below the Mile 30 Sand Bar (Figure 1) and is an oasis along the Colorado River, with dense vegetation and waterfalls emanating from the upper cliff faces (Figure 11). The area hosts a federally listed endangered species of snail (Kanab ambersnail) and is therefore a highly sensitive habitat when considering the impacts of an artificial high flow experiment. Since the predicted high-water line from the experimental high flow was predicted to reach the level of the snail habitat, biological researchers with the GCMRC were tasked with temporarily transplanting snails and their habitat to above the high water line. We collected several scans of the area to test the ability of the LIDAR unit to collect baseline habitat data for the biological researchers.

Data

Two scans were collected of the Vaseys Paradise area (Figure 12) consisting of 2.9 million data points (Figure 13). Scans were performed with the full 336° horizontal range of the scanner providing detailed point coverage of both sides of the canyon. While reflections were obtained from topography at the full 350 meter range of the scanner, the vertical range of collected data was limited by the height and narrowness of the canyon. However, this still allowed laser data returns from cliff faces located some 100 meters above the river (Figure 13).

Processing

The two data scans were registered to one another by a surface registration algorithm. This provided a full data coverage of the river right side of the canyon, with few data gaps. Since survey data was not obtained on the scanner origins or other control points, georeferencing was not performed on this data set. Each point set was first filtered to a minimum point separation of 0.5 meters, then built into a spherical triangulation. The two triangulations were then merged using a fusion surface algorithm which resulted in the finished digital terrain surface of the area (Figure 14).

Results

The fusion surface provides a high resolution surface of the Vaseys Paradise area and can be utilized for topographic measurements or as a vertical base map of the area. Additionally, the surface can be compared with future laser scans to calculate any topographical changes to the area if needed. Perhaps the most interesting utility of the laser scan data for this location is in distinguishing areas of habitat removed during the high flow experiment. At the time of scanning, an area approximately 230 m^2 in size was identified as habitat that had been removed (Figure 15).

Conclusions and Recommendations

The laser scanning technique shows much promise for use in documenting changes in habitat area for biological resources inventories. Personnel from the biological group should be consulted to identify other possible uses of the technique and to verify if the data collected is worth the process of data acquisition.

Studies of cliff change can also be performed using this data, as necessary. Detecting cliff change is a standard use of the laser for the CMG team and processing of this type of data is well understood and has been implemented by the team members in many settings (Collins and Sitar, 2004).

Figure 11. Vaseys Paradise with laser scanning equipment in foreground.

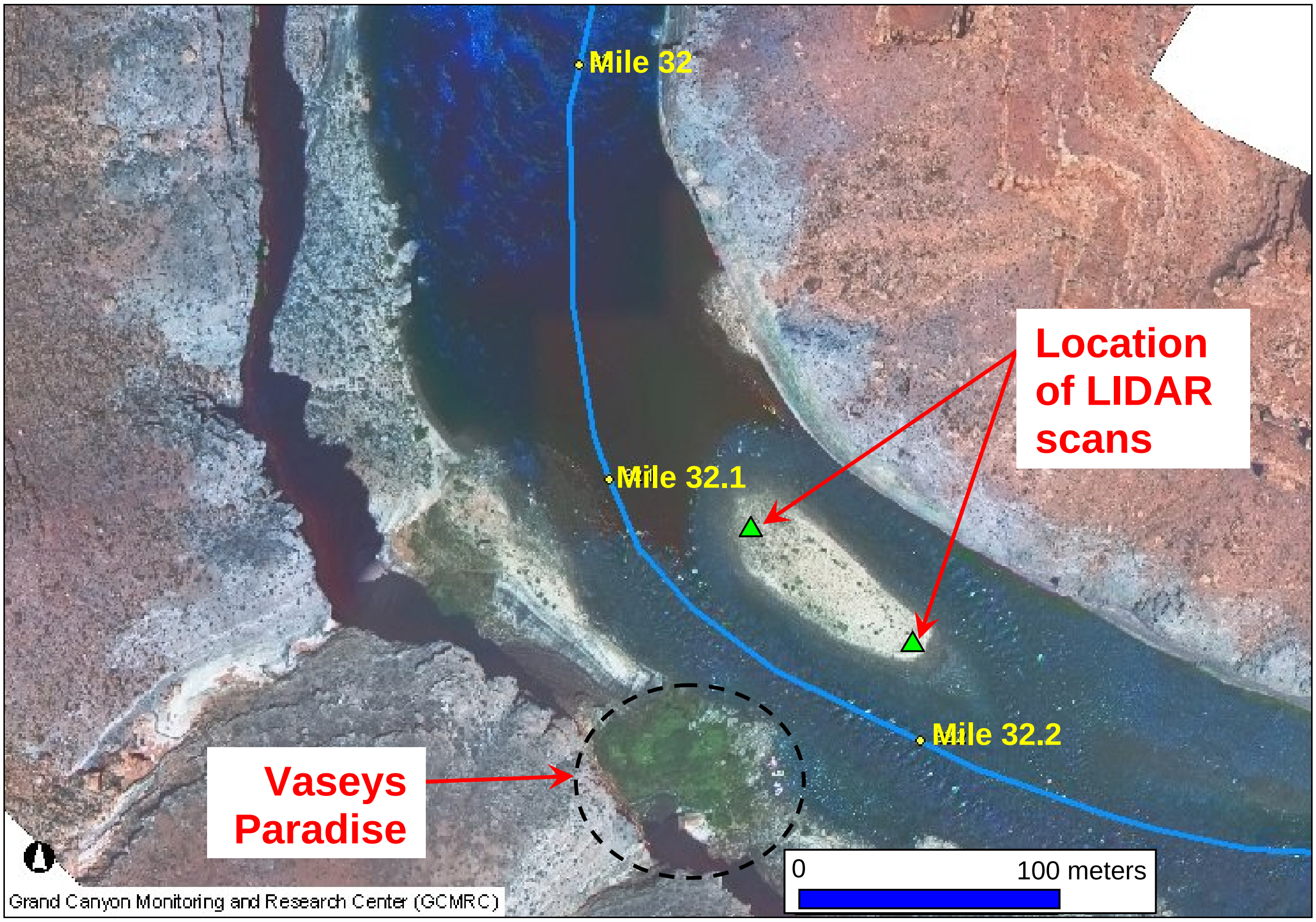


Figure 12. Vaseys Paradise (Mile 32) site map showing LIDAR scan locations.

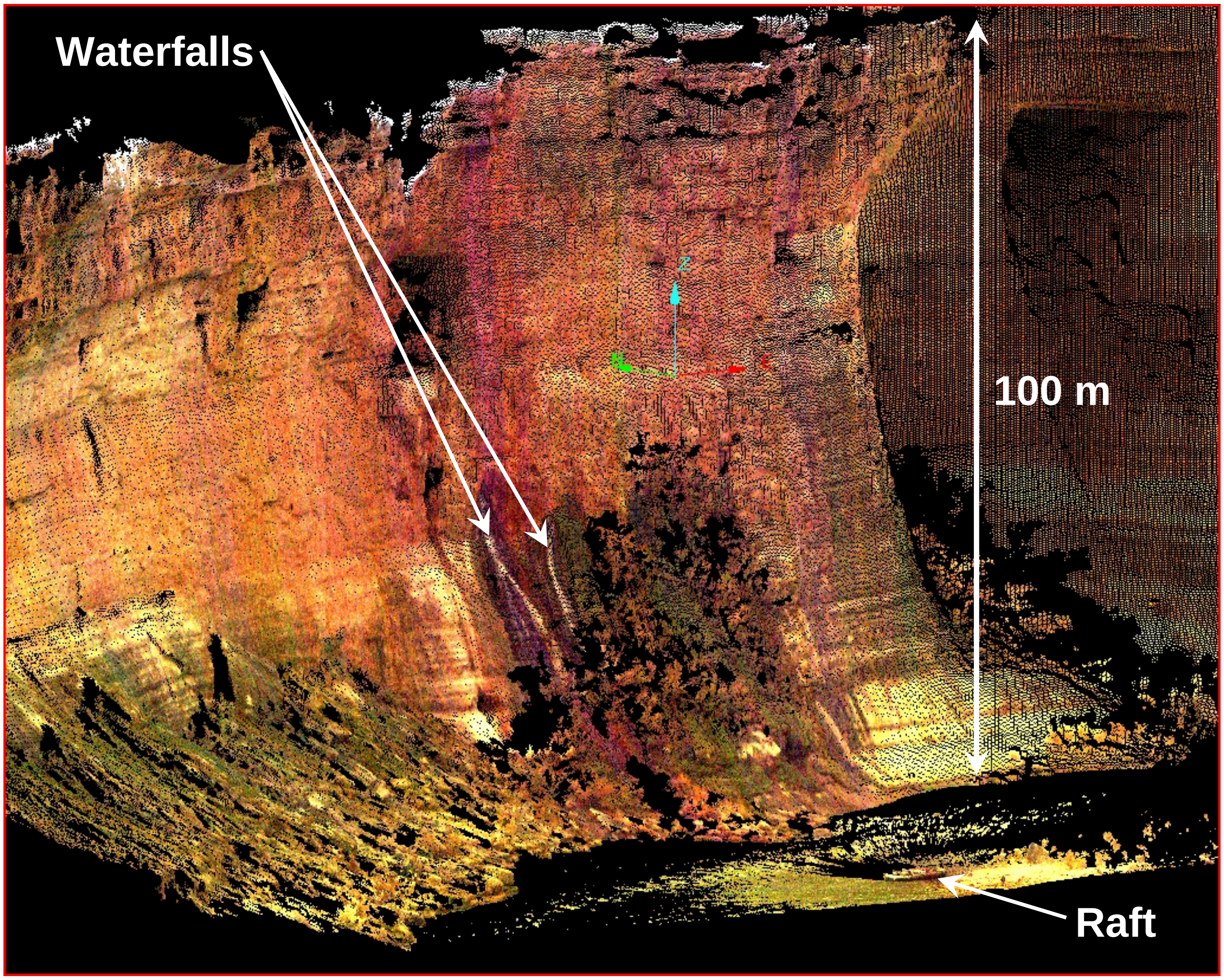


Figure 13. Composite scan data for Vaseys Paradise.

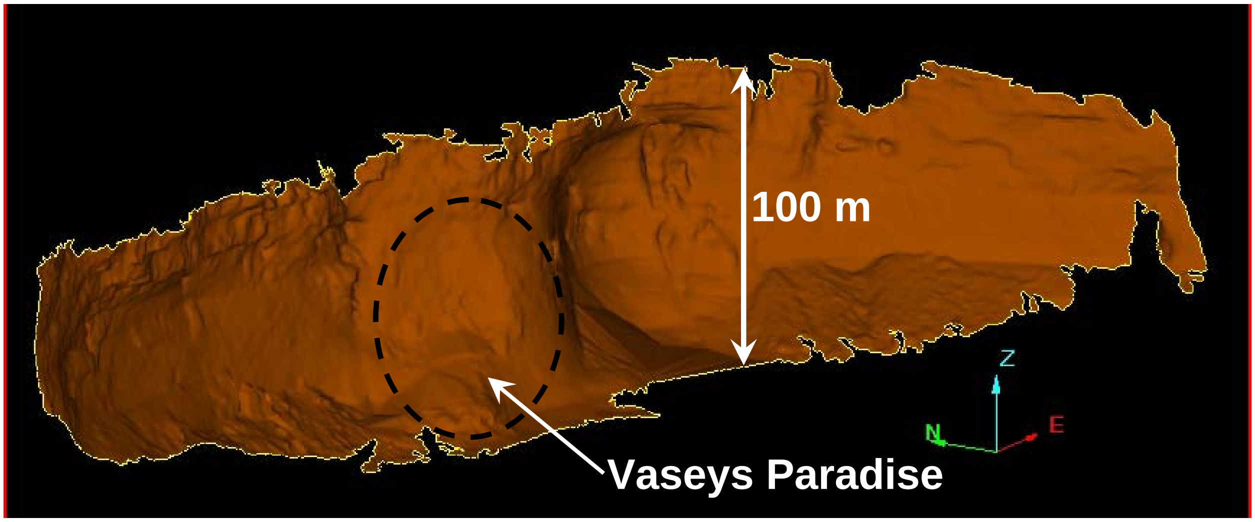


Figure 14. Completed fusion surface of Vaseys Paradise cliff topography.

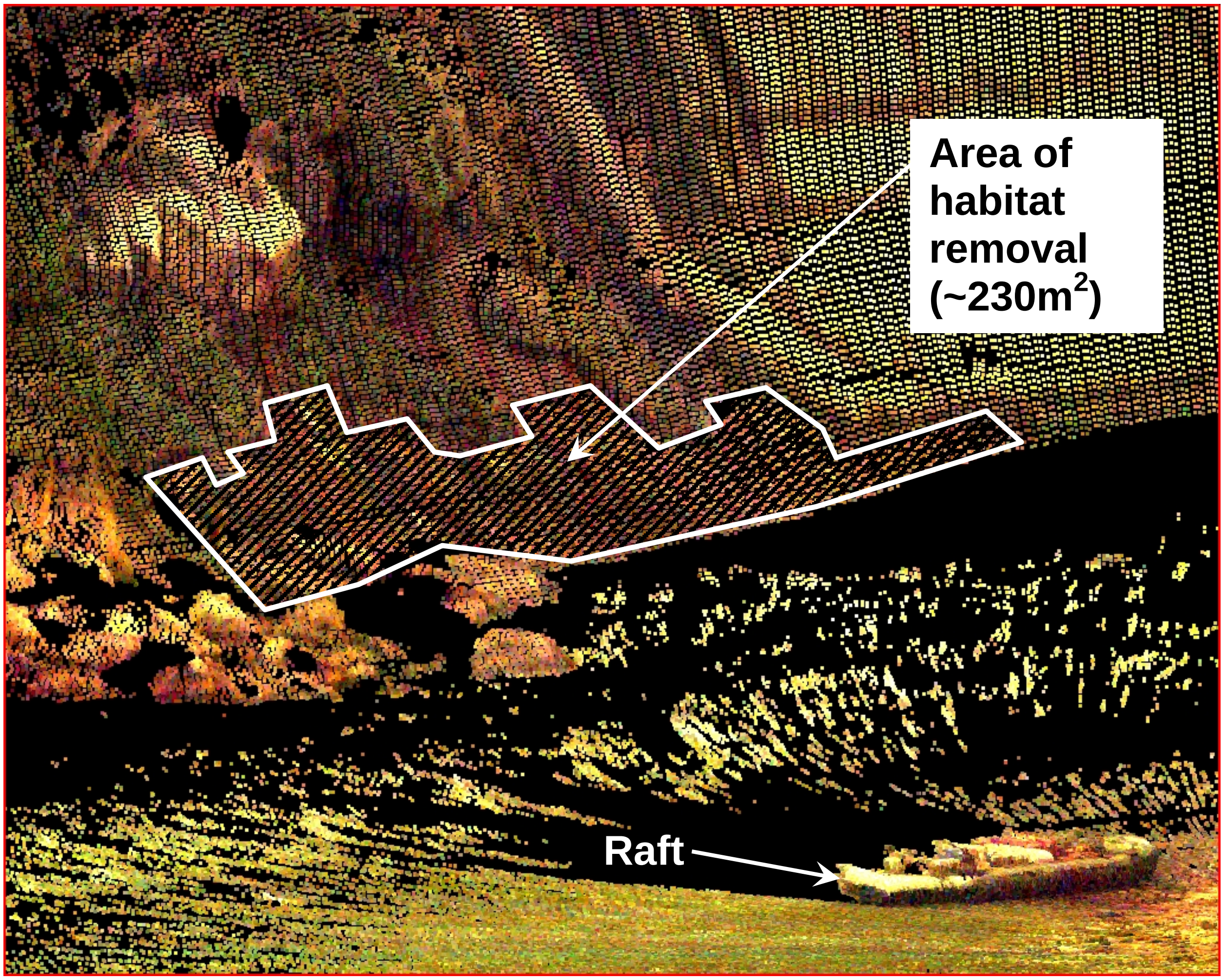


Figure 15. Vaseys Paradise data showing area of Kanab Ambersnail habitat removed prior to high flow experiment.

Palisades Arroyo Archaeological Site (Mile 66)

Background

The Palisades Arroyo Archaeological Site comprises a location within the Grand Canyon containing artifacts of historical native populations. At least two arroyos (intermittent drainages, dry throughout most of the year) cut across the Palisades site and often reveal artifacts as they excavate through existing surficial soils. A goal of the GCMRC is to monitor the down cutting of the existing arroyos to determine their rate of retreat upslope into existing archaeological sites. The CMG LIDAR team was tasked with collecting as much data as possible in this location to determine the applicability of the technique in this type of setting.

Data

Data collection in the Palisades area was extremely difficult due to two primary factors. First, the site is relatively flat and does not lend itself easily to a terrestrial based approach. We found few locations where the standard range of the scanner (~500 meters) could be utilized. These are typically locations that are either perched below or above the object of interest to be scanned. In some locations, a small area could be scanned, but this typically covered only a 10 meter by 20 meter area. The second factor limiting data collection was the presence of dense vegetation. The vegetation at the site was typically 2 to 3 meters in height which was just higher than the scanner when set on a tripod, limiting the range of the laser pulses. Additionally, the denseness of the vegetation limited data collection of the ground farther than a few meters from the scanner.

Environmental variables also limited data collection during this trip. A large storm brought heavy precipitation and light fog to the Palisades area on the two days that the team was in the area. These two weather forms are among the most limiting for ideal data collection using the terrestrial LIDAR technique; laser pulse returns are reflected off both water drops from precipitation and water vapor droplets from fog. Given these conditions, the data scans showed that only a small fraction of the possible data points were reflected from the ground topography.

Finally, heavy precipitation led to problems with the battery and connection cables during the data collection time period. As a result, only one scan was collected and saved for data processing. The scan was initiated from the edge of the low-water line, near the raft landing area for the Palisades campsite and included topographic data of the end of the southern-most arroyo at the site (Figure 16).

Processing

No processing of the scan was attempted due to the poor spatial coverage of the data.

Results

Images of the point cloud from the collected scan are included as Figures 17 and 18 and show the general quality of the data. Here, only the topography within 5 to 15 meters from the scanner origin was collected due to the heavy vegetation and limited flat ground sight distance.

Conclusions and Recommendations

Despite the poor data coverage collected at the Palisades site, the terrestrial LIDAR technique may still be applicable for certain areas at this location. Point data was collected of a cliff face located several hundred meters away on the far side of the river, and may provide a promising location to locate the scanner for future surveys.

The need to elevate the laser scanner to a sufficient height over the ground surface is of paramount importance. For future site visits, we would propose to use light-weight scaffolding to raise the scanner from 3 to 5 meters above the ground surface. This would result in a larger quantity of laser returns, while also reducing blocking effects from vegetation. As an example, in Figure 18 the maximum range of laser returns on nearly flat ground were approximately 13 meters using a tripod platform height of approximately 1.75 meters. If the laser scanner were to be positioned at a height of 3 meters, the maximum range increases by 70% to 22 meters.

Finally, since some problems with dense vegetation will always be encountered, we suggest that the LIDAR technique only be utilized for specific areas of archaeological interest that require high resolution positional documentation such as the footprints shown in Figure 5. Collecting data in this location for large scale, topographical model generation should only be attempted on a trial and experimental basis.

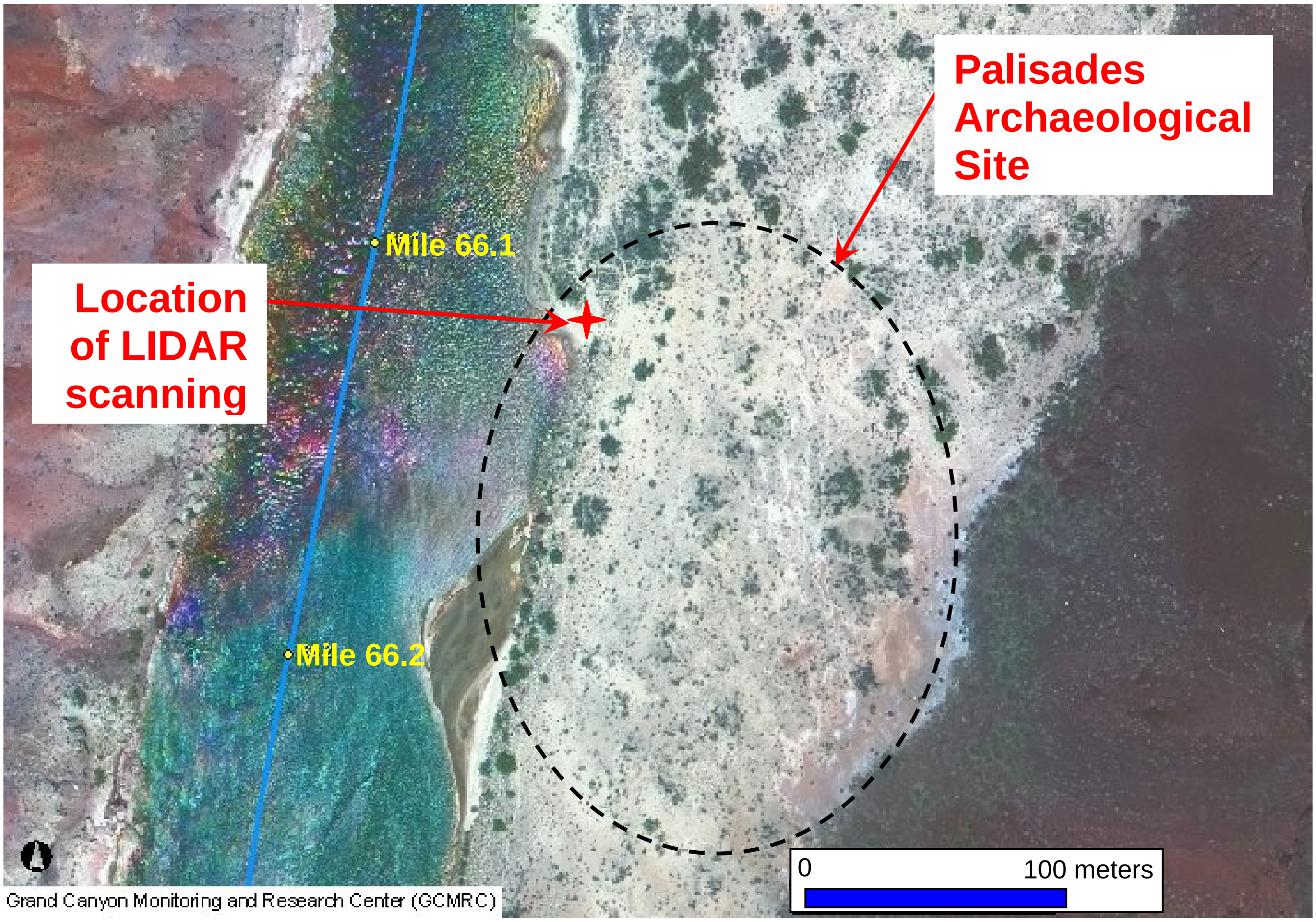


Figure 16. Location of LIDAR scanning at the Palisades Site.

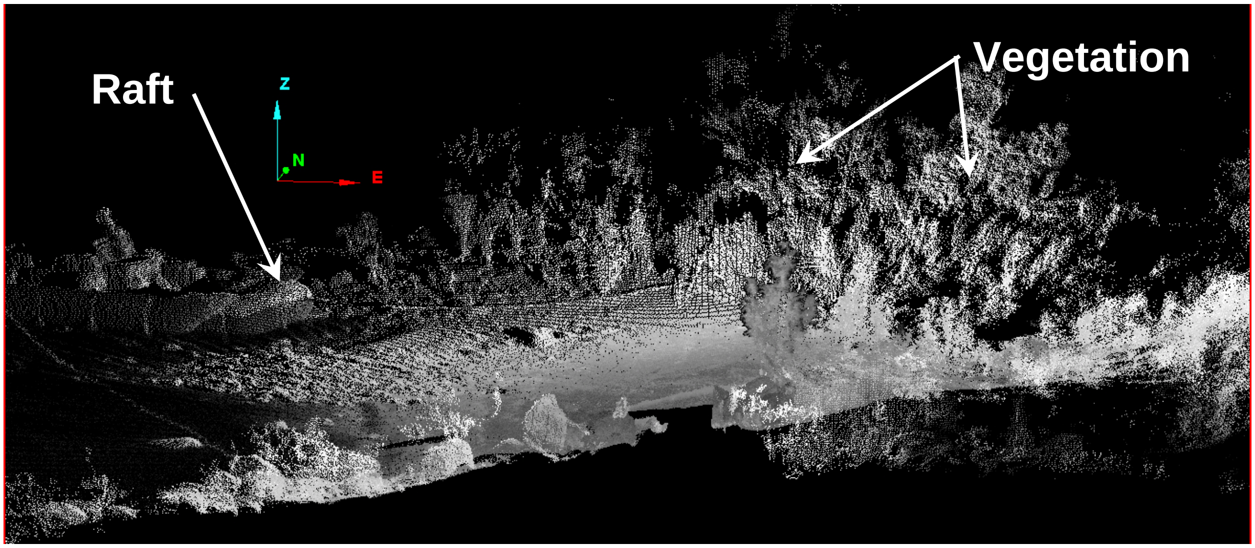


Figure 17. Palisades Site – Oblique view of unprocessed scan data showing heavy laser returns from vegetation.

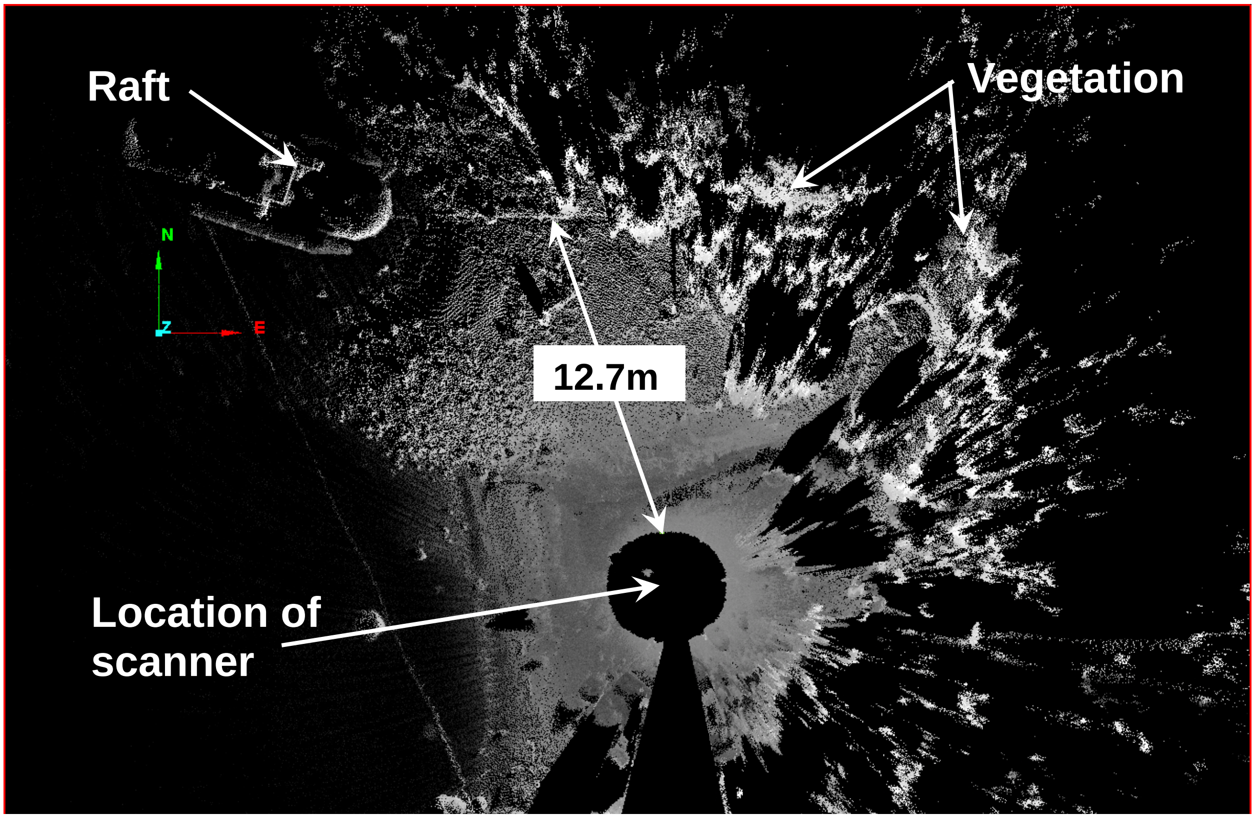


Figure 18. Palisades Site – Vertical view of unprocessed scan data showing heavy laser returns from vegetation and limited range distance.

General Conclusions

This report has outlined the applicability of utilizing terrestrial LIDAR scanning to perform scientific studies of sand bar morphology, biological habitat change and archaeological documentation. In all cases, we find the technology suitable, but with varying degree. For performing geomorphologic studies, the technique is perfectly suited and it is recommended that this approach be pursued in the future. The Mile 30 Sand Bar study has shown the efficiency of the method and the high-resolution results that can be obtained. For biological studies, we also find the technique applicable, but recognize that the primary contribution may be in two-dimensional mapping rather than three-dimensional process morphology. Finally, for archaeological studies, the technique shows promise, but should be re-evaluated upon data collection under more favorable conditions. Selecting non-vegetated sites for scanning will improve upon meaningful data returns and form a more robust basis for evaluation of this technology for archaeological documentation and monitoring of morphological effects on these resources.

Several items scheduled to be tested during this primary study were not performed and should be pursued upon further studies. These include studying the vegetative density along the river corridor by collection of continuous scans along the river banks and the applicability of night scanning for studying short-term sand bar morphology during future high flow (and lowering) events.

Acknowledgments

Thanks are due to Kristin Brown of the GCMRC, Flagstaff, Arizona and Ann Gibbs of the CMG Group, USGS, Menlo Park, California for ground survey and organizational work associated with this project. Technical reviews by Ann Gibbs and Diane Minasian from the USGS CMG are also gratefully acknowledged.

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