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Monitoring streambank and gully erosion by airborne laser

JERRY C. RITCHIE
United States Department of Agriculture, Agriculture Research Service, Hydrology Laboratory, Beltsville, Maryland 20705, USA
JOSEPH B. MURPHEY, EARL H. GRISSINGER
United States Department of Agriculture, Agriculture Research Service, National Sedimentation Laboratory, Oxford, Mississippi 38655, USA
JURGEN D. GARBRECHT
United States Department of Agriculture, Agriculture Research Service, National Agricultural Water Quality Laboratory, Durant, Oklahoma 74702, USA

Abstract Erosional features of the landscape such as topography, stream channels, gullies, and canopy cover are measured by an airborne laser altimeter. The airborne laser makes 4000 measurements per second with a specified vertical accuracy of 5 cm per measurement. Aircraft altitudes ranges from 100 to 300 m, and aircraft speed from 60 to 80 m per second. Digital data from the laser are recorded on and analyzed with a portable computer. The measurements provide quick and accurate data on the morphology and cross sectional area of channels and gullies. While ground based techniques could be used to make these measurements, the airborne laser profiler technique allows data to be collected faster, with greater density, and in areas with limited access for ground surveys. The airborne laser altimeter data are valuable for monitoring natural resources, assessing conservation needs, providing input into natural resource models, and studying spatial patterns across the landscape.

INTRODUCTION

Gully and stream patterns and morphology are controlled by a combination of hydrology, geology, geomorphology, biology, and man-made factors (Wolman & Miller, 1960; Heede, 1976; Little *et al.*, 1982; Yang & Molinas, 1988). Erosion and deposition can occur in different parts of the channel and channel cross section simultaneously. Patterns and rates of change in gullies and channels can be rapid (Murphey & Grissinger, 1985; Wolman, 1959) and are a major concern for erosion control and monitoring, operation of agricultural machinery through field gullies, and safety of channel crossing.

Accurate and timely measurements of the changes in gully and stream channel morphology are necessary for many environmental and engineering studies related to planning, conservation, and construction. Currently these measurements are made by field surveys or photogrammetric techniques. While these techniques can provide accurate measurements of the morphology, they are time consuming and often difficult to obtain in a timely manner.

The purpose of this paper is to describe a technique using a laser altimeter mounted in an airplane to make rapid and accurate measurements of gully and channel cross sections.

METHODS AND MATERIALS

A laser altimeter mounted in a small twin engine airplane was used to measure the distance from the airplane to the landscape surface as defined by any object (i.e. soil, rock, vegetation, man-made structure) reflecting the laser pulse (Ritchie & Jackson, 1989). Altitude of the airplane ranged from 100 to 300 m with speeds from 60 to 80 m per second. The laser is a pulsed gallium-arsenide diode laser, transmitting and receiving 4000 pulses per second at a wavelength of 904 nm. Under these operating conditions, a laser measurement from the aircraft to landscape surface occurred at 0.015 to 0.020 m horizonal intervals along the flight line. According to system specifications, the vertical recording accuracy of the laser is 0.05 m on a single measurement. However, measurements under controlled laboratory conditions show a standard deviation between 0.10 and 0.11 m. The laser cannot penetrate water or a dense canopy cover. Therefore, caution is advised when using the instrument to measure water carrying channels or landscape features under dense canopy cover.

A portable personal computer is used to record the digital data collected by the laser. A video camera, borehole-sighted with the laser, records a visual image of the flight line. Video frames are recorded 60 times per second and annotated with consecutive frame numbers and clock time. The video frame number and data from a gyroscope and an accelerometer are recorded simultaneously with the digital laser data. Ground speed is obtained from aircraft instruments. With this information the laser data are corrected for aircraft pitch, roll, and vertical deviation from a straight line to allow precise location of the laser data.

Landscape surface elevation was calculated for each laser measurement based on known elevations along the flight lines. The minimum elevations along a laser flight line segment are assumed to be ground surface elevation with measurements above this minimum being due to vegetation or man-made structures. In areas of vegetation, the minimum values (ground surface) were estimated by calculating a moving minimum elevation for 21 laser measurements. Some manual editing of these minimum elevations was required in areas of dense vegetation cover.

Data were analyzed based on the length of the segment measured. For segments less than 100 m, all data points were used. An 11 point moving average filter was used to reduce random and system errors and to enhance systematic variation in the laser data (McCuen & Snyder, 1986). For segments greater than 100 m, a block average of the laser measurements was used to reduce the total amount of data and overcome limitation in computer software. The number of measurements averaged depended on the length of the segment under investigation.

The data used to show the application of airborne laser data to measure gully and stream channel cross sections were collected from the Little Washita Watershed near Chickasha, Oklahoma and the Goodwin Creek Watershed near Oxford, Mississippi. The data were collected during a two day aircraft experiment in October 1989.

RESULTS AND DISCUSSION

In an earlier study, Ritchie & Jackson (1989) had used airborne laser data to measure furrows (man-made gullies) made in a level tilled field. They measured depths of 0.20 to 0.30 m under these "controlled" conditions. Such small channels are important in understanding the soil loss from fields (Foster, 1986). A small gully in a natural grassed area in Oklahoma is shown in Fig. 1. It shows the original laser data, data smoothed with an 11 point moving average filter, and the extracted cross section of the gully. The original data show the basic shape of the gully with variations in height measured by the laser. The variations are due to system noise (random and system errors) and to change in the microtopography along the line. An 11 point moving

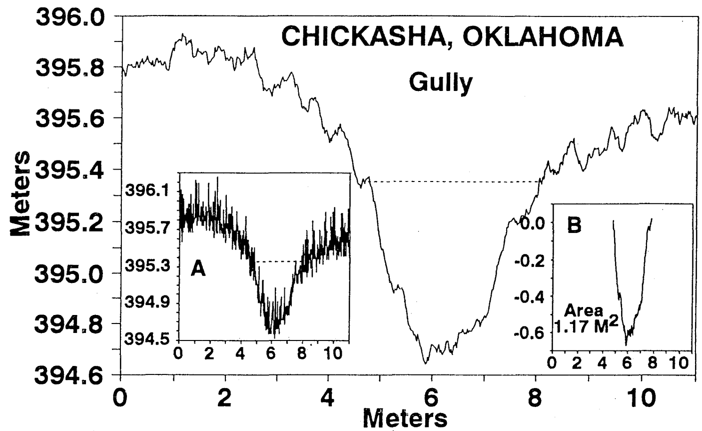

Fig. 1 Laser altimeter cross section measurement of a small gully using an 11 measurement moving average filter. Left insert (A) shows the original laser data and the right insert (B) shows the final computed cross section.

average filter reduces the random and system error and enhances the changes in the microtopography caused by soil surface roughness and vegetation patterns. Assuming the original noneroded landscape can be estimated by a flat surface (straight line), the cross section of the gully is computed to be 1.17 m^2 with a depth between 0.6 and 0.7 m and a width at the top of 3 m. Arguments can be made for using a curvilinear concave line instead of the straight line to define the original surface at this site. Decisions about the shape of the original surface need to be made on an individual basis for each gully since each landscape pattern is unique.

As the gully gets larger, the efficiency of the laser to measure the area in comparison to ground survey techniques increases. Figure 2 shows a large gully system with patterns of gully channels within the larger systems. The figure shows a plot of 2 seconds of laser data using an 11 point moving average. The original noneroded landscape surface is estimated assuming a flat surface.

The above two examples were in grassed areas with the gully area having little or no vegetation cover. However the laser also can be used to measure gully areas with vegetation cover (Fig. 3) since the laser beam often penetrates openings in the canopy allowing the determination of the current ground surface. The data shown in Fig. 3 represent 4 seconds of laser data using a block average of 4 to reduce the amount of

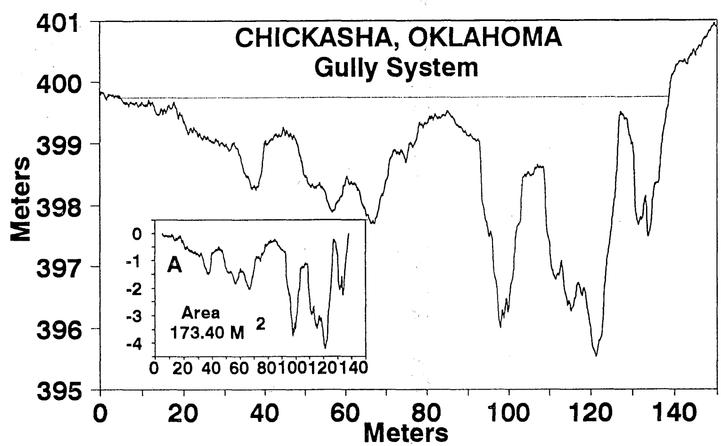

Fig. 2 Laser altimeter cross section measurement of a gully system using an 11 point moving average filter. Left insert (A) shows the final computed cross section.

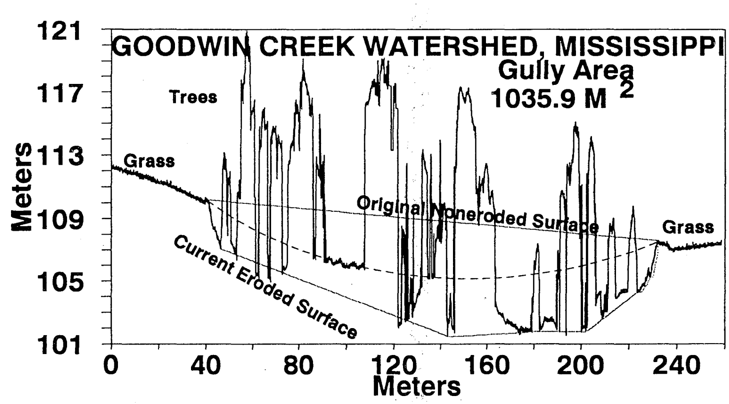

Fig. 3 Laser altimeter cross section measurement of a gully area that is partially revegetated using a block average of four measurements. Dotted line shows the current eroded surface and the estimated original noneroded surface used to estimate the cross section area (1035.9 m^2). Dashed line is another possible original noneroded surface.

data. It shows the gully to be between two grassed areas. Within the gully, 15 to 20 m tall trees were present. By connecting minimum laser altimeter measurement (using best judgement) between tree crowns, the "current eroded surface" of the gully scar could be estimated. If we assume a straight line between grassed areas represents the noneroded surface, then by determining the area between the current and original ground surface, a cross section of 1035.9 m^2 is estimated. Using a curvilinear line for the noneroded surface, the cross sectional area is reduced by about 50%. The example demonstrates the utility of laser altimeter data to measure gully cross sections which are partly covered by vegetation and to study gully restoration.

Cross sectional areas for channels can be measured using the same techniques as illustrated in the previous examples for gullies. Figure 4 shows the cross section of a stream channel about 5 m below gauging station #4 on Goodwin Creek Watershed in Mississippi. The original nonfiltered data are shown. The sloped sides of the channel

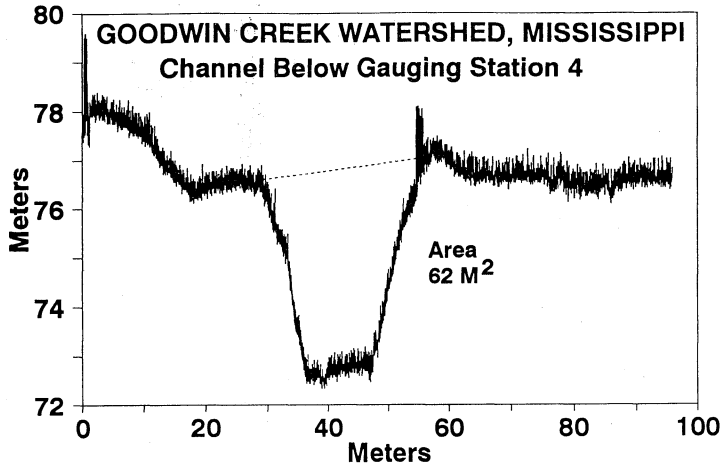

Fig. 4 Laser altimeter cross section measurement of a channel using original data.

and the flat wide bottom show that the section was shaped during the construction of the concrete measuring weir at this channel cross section. An examination of the bottom of the channel shows the development of a smaller channel within the wide channel which is most likely the low flow channel. A review of the video shows that the sudden rise on the top of the right bank is a small (1 to 2 m tall) clump of vegetation growing on the side of the channel. The area of the channel is 62 m^2.

Analyses of laser data from more complex topographic cross sections can provide information on channels, their flood plains, and the corresponding upland areas. Figure 5 is a topographic cross section for a 7 to 8 second segment of laser data. The data has been averaged in blocks of 8 to show a 500 m section. The section crosses a meandering section of Goodwin Creek so that the channel is measured at two locations. The trees associated with the areas near the channels can be distinguished from the pasture (grass) area in the upland areas. A review of the video is necessary to

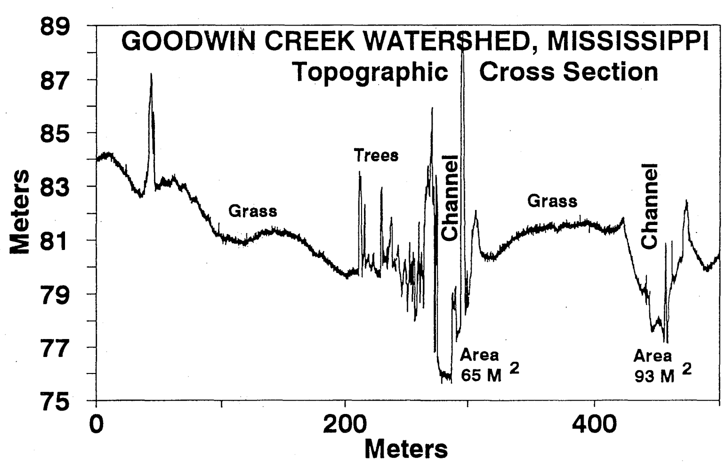

Fig. 5 Laser altimeter measured topographic cross section showing the relationship of the channel to the surrounding area.

distinguish bank vegetation from natural levees. Channel shapes and roughness due to vegetation could be examined by analyzing the original laser data for each channel using corresponding short segments of laser data. However, the intent of a long topographic section is the analyses of the relationship between channels and the larger landscape elements surrounding it.

Laser altimeter measurements of the physical properties of the surface of the landscape provide unique and rapid measurements of gully and channel morphology. Such measurements of macroscale and microscale topography can be used to measure channel and gully degradation and aggradation and to study their relationship to the landscape. Airborne laser altimeter further offers the potential to measure landscape properties over large areas quickly and easily. Such large area measurements can provide valuable information for understanding and managing of the erosion cycle.

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