Laser altimeter measurements at Walnut Gulch Watershed, Arizona

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ABSTRACT: Measurements of landscape surface roughness properties are necessary for understanding many watershed processes. This paper reviews the use of an airborne laser altimeter to measure topography and surface roughness properties of the landscape at Walnut Gulch Watershed in Arizona. Airborne laser data were used to measure macro and micro topography as well as canopy topography, height, cover, and distribution. Macro topography of landscape profiles for segments up to 5 km (3 mi) were measured and were in agreement with available topographic maps but provided more detail. Gullies and stream channel cross-sections and their associated floodplains were measured. Laser measurements of vegetation properties (height and cover) were highly correlated with ground measurements. Landscape segments for any length can be used to measure these landscape roughness properties. Airborne laser altimeter measurements of landscape profiles can provide detailed information on watershed surface properties for improving the management of watersheds.

The functions of natural and agricultural landscapes are influenced by patterns of topography and surface roughness. Measurements of surface features and patterns can provide information to understand the landscape and its interactions with hydrological and biological systems. Topography and other landscape features can be measured using ground techniques, aerial photography, and satellite imagery. Using conventional techniques, however, to measure these features and their spatial patterns is difficult and time consuming and provides only limited temporal and spatial information.

This paper reviews the application of an airborne laser altimeter for measuring vertical features and patterns of the landscape surface at Walnut Gulch Watershed. It also discusses their applications to understanding hydrological systems and vegetation patterns on Walnut Gulch Watershed. The laser flights were part of the larger MONSOON'90 study (Kustas and Goodrich 1994).

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Methods and materials

A laser profiling altimeter mounted on a twin engine airplane was used to measure the distance between the laser receiver and the landscape surface at the Walnut Gulch Watershed on July 31, 1991, along six flight lines (Figure 1). Each flight line was flown two times. Flights were also made along seven other flight lines in the watershed.

Objects (i.e., soil, rock, vegetation, and man-made structures) on the landscape surface reflect the laser pulses (Ritchie and Jackson 1989) and are measured to define the vertical landscape surface profile. The laser altimeter is a pulsed gallium-arsenide diode laser, transmitting and receiving up to 4,000 pulses per second at a wavelength of 0.904μm. Nominal ground speed of the airplane during the flights was between 50 and 100m per second (164 and 328ft/sec) at an altitude between 150 and 300m (490 and 980ft). Under these operating conditions, a laser measurement occurred at horizonal intervals between 0.0125 and 0.025m (0.5 and 1in) along the flight line. The field-of-view of the laser is 0.6 milliradians, which gives a "footprint" on the ground that is approximately 0.06% of the altitude. The timing electronics of the laser receiver allow a vertical recording resolution of 0.05m (2in) for a single measurement.

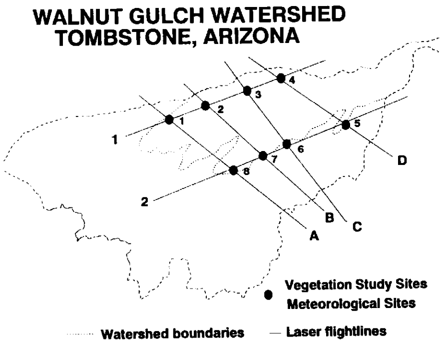

Figure 1. Map of Walnut Gulch Watershed and a subwatershed showing the location of the laser flight lines and the meteorological and vegetation study sites

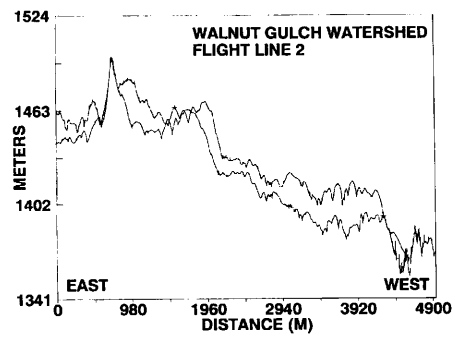

Figure 2. Topographic profiles along flight line 2 measured during two different flights

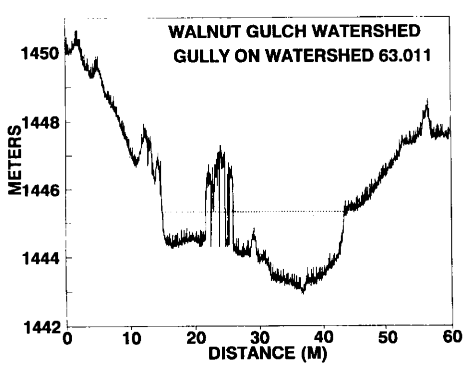

Figure 3. Cross section measurement of a gully on watershed 63.011 on Walnut Gulch Watershed made with an airborne laser

Digital data from the laser receiver are recorded with a portable personal computer. Data from a gyroscope and an accelerometer mounted on the base of the laser platform are recorded simultaneously (60 times per second) and used to correct for airplane motion. A video camera, borehole-sighted with the laser, records an image of the flight line. Sixty video frames are recorded per second and each frame is annotated with consecutive numbers and clock time. Each video frame number is recorded with the digital laser data by the computer to allow precise location of the laser data on the landscape.

Known elevations along a flight line were used to calculate the landscape surface elevation. The minimum elevations (maximum laser measurements between airplane and the landscape) along a laser flight line are assumed to be ground surface elevation. Measurements above these minimums are due to vegetation or man-made structures. Ground topography in areas of vegetation can be estimated graphically by connecting minimum values.

Results and discussion

Airborne laser altimeter data can be used to measure topography over long segments quickly and efficiently. At an airplane ground speed of 50m per second (164ft/sec) (slowest speed used in these studies), a 3km (1.8mi) profile can be measured each minute (240,000 laser measurements). Two topographic profiles collected over flight line 2 (Figure 1) are used to illustrate the use of the laser altimeter for measuring long topographic profiles (Figure 2).

These two topographic profiles (Figure 2) were measured during two flights along approximately the same flight line. At the east end the flight lines were less than 100m (328ft) apart but at the western end they were approximately a kilometer (0.62mi) apart. Even with the best navigation, it is not possible to repeat the measurement of the same flight line exactly so while the peaks and valleys match fairly well in horizontal space there are differences in vertical relief measured in the profiles. The laser data for these profiles were reduced by block averaging 30 laser measurements giving a "footprint" of approximately 50cm (20in). There were only small shrub vegetation (<1m tall) along these flight lines (Ritchie and Weltz 1992; Weltz et al. 1994) so roughness due to vegetation is not evident at the scale used to plot these 5km (3mi) profiles.

Such profiles can be collected easily and efficiently with an airborne laser altimeter and used to provide topographic profiles of the landscape. Ease and speed of data collection would allow measurement of several profiles with a minimum of extra survey cost. These measurements allow detail measurements of topographic patterns in the watershed along the flight lines for understanding water and wind movement.

While long topographic profiles across the landscape can be easily made, airborne laser data can also be used for detailed measurements of short cross sections of gullies and stream channels. A cross section of a gully on watershed 63.011 on Walnut Gulch Watershed is shown in Figure 3. This figure shows the data as measured with the associated random and systematic noise related to the laser system. The development and growth of the head cut of this gully has been documented (Osborn and Simanton 1986). The total cross section in Figure 3 is defined by 2998 laser measurements (0.75 seconds of laser data) made at horizonal intervals of 0.02m (0.8in). The gully is approximately 29m (95ft) wide at the cross section measured and has an island of tall vegetation growing in it. The sides of the gully are almost vertical. If it is assumed that the soil surface of the pre-erosion landscape can be defined with a straight line (dashed line on Figure 3) then the cross sectional area of the gully is measured to be 40m^2 (430ft^2). If a curvilinear line is used to define the pre-erosion landscape (solid line on Figure 3) then the cross sectional area of the gully is approximately 45m^2 (484ft^2). Other types of line or vertical placement of the line is possible. The problem of determining the placement of

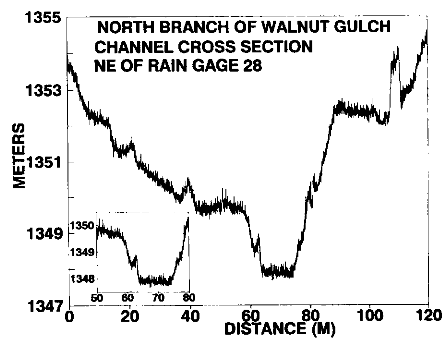

Figure 4. Cross section of the channel of the north branch of Walnut Gulch northeast of rain gage 28

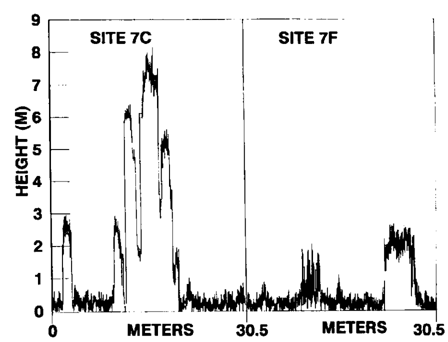

Figure 5. Laser profiles from two vegetation study sites on Walnut Gulch Watershed showing a tree and short shrubs

a line representing the pre-existing landscape surface is the same as it is with conventional field surveys. While it is not possible to make a direct comparison with other studies of this gully (Osborn and Simanton 1986), the pattern, shape, and island of vegetation in the gully are similar to those described in the other study (Osborn and Simanton 1986). Knowledge about cross sectional area of gullies leads to a better understanding of volume of soil loss from a gully and water movement.

The same method was used to measure a cross section of the stream channel of the North Branch of Walnut Gulch northeast of rain gage 28 (Figure 4) on flight line A (Figure 1). The cross section showing the stream channel and the valley associated with the stream channel was calculated using 6,000 laser measurement (1.5 seconds of data). The insert in Figure 4 shows the cross section of the stream with a dashed line indicating the top of the channel for a stage of 2m (7ft) above the base of the channel. The cross sectional area of the stream for this stage is calculated to be $24.3m^2$ ($260ft^2$). These calculations could be made for any stage necessary. Such measurements allow us to calculate the volume of water that can be carried for different stream stages for this location. Channel roughness can also be noted from the shape of the channel bottom and what appears to be a small shrub growing in the channel. Channel roughness measurements allow better estimates of flow rates.

The distribution of vegetation patterns can be used for estimating infiltration, soil and wind erosion, and evapotranspiration. Airborne laser measurements of vegetation properties were made for 30.5m (100ft) transects at eight vegetation study sites (Figure 1) on the Walnut Gulch Watershed. The height of vegetation for two 30.5m transects at vegetation study site 7 (Figure 1) are shown in Figure 5. A walnut tree was measured at site 7C while shorter shrub vegetation was measured at site 7F. Weltz et al. (Ritchie and Weltz 1992) found no significant difference between classical line-intercept measurements and laser measurements for canopy height and cover at these eight sites. They concluded that an airborne laser can be used to measure spatial variation in vegetation properties quickly for large areas of rangelands. The laser could be used in areas from which it might be impossible to collect data otherwise because of inaccessibility or cost.

Menenti and Ritchie (1992; 1994) using laser derived data on topographic and vegetation patterns at Walnut Gulch Watershed concluded that effective aerodynamic roughness parameters could be estimated. Comparison of laser estimates with field measurements of effective aerodynamic roughness made at eight meteorological study sites were good. They concluded that the use of airborne laser data to estimate effective aerodynamic roughness parameters would provide a new method for determining spatial patterns of aerodynamic roughness for local, regional, and global models. Humes et al. (1994) are studying methods to combine the spatially distributed data from the laser with other remotely sensed data in order to understanding spatial patterns of water fluxes on Walnut Gulch and other watersheds.

Conclusions

Topographic differences and vegetation canopy patterns are integral parts of the landscape. To understand hydrology and biological effects on natural and agricultural resources on a large scale, these properties have to be measured and evaluated. Airborne laser altimeter data have been used to quantify landscape topography, gully and stream cross sections, and vegetation canopy properties on Walnut Gulch Watershed. Measurements of micro and macro topography can help quantify water retention, infiltration, evaporation, and movement from landscape surfaces, across flood plains, and in channels. Channel and gully development and degradation can be measured and used to estimate soil loss and explain water quality and flow patterns. Measurements of canopy properties and their distribution across the landscape and their effect on water movement and aerodynamic roughness allow better understanding of evaporative loss, infiltration, and surface water movement. Airborne laser altimeters offer the potential to measure these landscape roughness properties over large areas quickly and easily. Such measurements will improve our understanding of the effects of these factors on the hydrological and biological systems of natural and agricultural landscapes.

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