CHAPTER IX. SURFACE ROUGHNESS MEASUREMENTS

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A. INTRODUCTION

The primary objective of the Washita `92 experiment conducted in early June of 1992 was to study hydrologic process using remotely sensed data, specifically microwave radar backscattering data and millimeter-wave radiobrightness data gathered using NASA airborne sensors. Extensive soil moisture ground truth was collected both spatially across the Little Washita Watershed and temporally throughout the two week test period. However, soil moisture is but one of many surface parameters which can effect radiobrightness and radar backscattering values. Among these are surface vegetation parameters such as moisture content, plant structure, and constituent size. In addition, the roughness of the underlying soil can be more significant than soil moisture in effecting the values of the observed microwave data.

Because of this, the surface roughness statistics, both root-mean-square (rms) height and correlation length, were determined at nine representative sites located throughout the Little Washita Watershed. These sites included three bare soil surfaces, three rangeland sites, and three agricultural sites planted with single specie vegetation (alfalfa, wheat, and corn). The roughness data was estimated using two separate measurement techniques, a laser profilometer system which provides digital profile data directly, and a painted paper profiler which is later converted to digitized data in the lab. A limited amount of vegetation data was also collected, including biomass, plant density, and plant height, in addition to "aerodynamic roughness" data collected with the laser profilometer.

This report will describe the various methods for measuring surface roughness data, present the mathematical definition of each roughness parameter, and quantify this data at each of the relevant sites. In addition, photographs of the various test sites as well as maps displaying their specific locations shall be presented.

B. LASER PROFILOMETER

The laser profilometer measurement system, as shown in Figure IX-1, utilizes a laser distance measurement unit mounted on a one-by-one meter automated x,y positioning table. The table is placed approximately 1.5 meters over the test surface and the laser measures the vertical distance, at a given (x,y) point,from the table to the test surface. The position of the laser in the x,y plane can be precisely controlled, and by moving the laser in small but precise increments, a linear or a complete surface profile may be determined. The entire process, both x,y table control and laser data acquisition, is controlled via a laptop computer, and powered by 12V lead acid batteries. The specifications and performance of this system, including measurement resolution and accuracy, is given in Table IX-1.

For the Washita`92 test, eight linear profiles were determined. Four of these profiles were aligned along the same arbitrary direction, while the remaining four were aligned perpendicular to the first. In each of the two sets, the four linear profiles were spaced at approximately 1 foot intervals. The horizontal spacing between each vertical measurement for a given profile was 0.5 cm, which is less than 30 electrical degrees at the shortest radar wavelength.

C. PAINT AND PAPER PROFILER

Another valid, albeit less direct, method of obtaining surface profile estimates is by using paper and paint techniques. As shown in Figure IX-2, graph paper is wrapped length-wise around a long thin metal sheet, and the sheet is then inserted into the soil such that the horizontal plane of the paper remains level. The soil-paper boundary is then painted using black spray paint, thus imposing the surface profile onto the graph paper. By using a very long sheet, a continuous surface profile can be recorded which is much longer than that possible by the laser profilometer, whose length (0.95 meters) is limited by the maximum dimension of the (x,y) table.

However, to make this painted profile useful, it must be transformed into numerical data. This is achieved by recording the vertical distance to the paint line at uniformly spaced horizontal points. Although this is possible by manually counting increments directly from the graph paper, the use of an electronic device to both determine and log its relative position on the graph paper is far more efficient.

D. PROFILE DATA

To be useful, the information contained in a numerical representation of a surface profile must be reduced to a simpler, but equally descriptive form. Since the surface profile of a natural surface is random, statistical parameters are appropriate for describing its characteristics. The two parameters most often used in this characterization are rms height (denoted as σ) and correlation length (denoted as l_c).

The rms height is an estimate of the variance of the vertical dimension of the test surface. Denoting the vertical measurement of the surface at a given horizontal

$$\sigma = \sqrt{[1/(N-1)] \Sigma [h(p_n)-h(p)]^2} \qquad (1)$$

where $h(p_n)$ is the vertical measurement taken at the nth of N horizontal positions, and h(p) is the mean value of the measurements, given as:

$$h(p) = (1/N)\ \Sigma\ h(p_n) \qquad (2)$$

In addition to rms height, the profile of a random surface is characterized by its correlation function, which relates the statistical correlation between any two points on a given surface. If the surface statistics are assumed to remain constant across the horizontal plane (wide-sense stationary), then the correlation function is dependent only on the distance between any two points, $|p_n-p_m|$. Thus, the correlation function can be estimated from a measurement of a sufficiently long linear (p=xx) profile extending in any arbitrary direction. The data collected in a profile of 2N+1 points, denoted as $h(x_n)$, can be used to estimate the correlation function using the equation:

$$C(|x_0-x_m|) = [1/C(0)]\ \Sigma\ [h(x_n)-h(x)][h(x_{n-m})-h(x)] \quad m=0,1,2,3... \qquad (3)$$

As m becomes large, $C(|x_0-x_m|)$ will decrease toward zero, indicating that the height of two surface points decorrelate as their horizontal distance increases (assuming nonperiodic surfaces). The distance required for this decorrelation can be specified by the correlation length l_c, which is defined as $C(l_c)=1/e=0.3678$. For a valid estimate of $C(|x_0-x_m|)$, the length of the linear profile must be much greater than l_c.

Because the laser profilometer leaves the soil surface undisturbed and provides a direct electronic measurement, the profilometer provides the superior data for rms height estimation. In addition, for surfaces with small correlation lengths l_c, a linear profile measured by the laser can also be used to estimate l_c. However, for surfaces with greater correlation lengths, the maximum linear dimension (95 cm) of the profiler is not sufficient to provide an accurate correlation length estimate. Thus, the paint and paper profile method is required in these cases to provide sufficient length to estimate l_c.

E. TEST SITES

Various data was collected at nine test sites across the Little Washita watershed; three each of rangeland, cropland, and bare soil surfaces. Figure IX-3 shows a map of the Little Washita watershed basin with each of the nine sites marked.

1. Bare Soil Surfaces

a. Site PR001

Site PR001, located in the flood plain of the Little Washita River, was a flat, bare, plowed field located directly across from site RG136. With physical dimensions of approximately 400 by 400 meters, this site is outlined on the topographical map (USGS) of Figure IX-4. Figure IX-5 shows a photo of this surface, displaying the very rough characteristics of the soil. The rms height for this surface was determined to be 2.29 cm, and its correlation length to be 8.75 cm. The estimated correlation function for this surface is given in Figure IX-6.

b. Site AG005

Site AG005 was located just to the north of the ARS offices in Chickasha, OK (Figure IX-7). This site consisted of a large flat cotton field of approximately 600 by 720 meters. Although the field had been planted in cotton, the plants at the time of the test were just a few centimeters in height and therefore this site was considered a bare surface. As shown in Figure IX-8, this surface was considerably smoother than that of site PR001, with a rms height of 1.29 cm and a correlation length of 16.25 cm. The estimated correlation function is given in Figure IX-9.

c. Site AG002

The third bare soil surface characterized in this experiment was located at the test site examined by the NASA Goddard L-band truck-mounted scatterometer team, just southeast of Chickasha as shown in Figure IX-10. With a correlation length of 17.75 cm and a rms height of 1.82 cm, this surface is considered to be of moderate roughness. The physical size of this site was estimated to be 700 by 1400 meters.

2. Agricultural Sites

a. Site AG001 - Corn Field

Site AG001 was likewise located at the Goddard scatterometer test location, and consisted of a corn field of approximately 2.5 km^2, as shown in Figure IX-10. A small section of the corn canopy was removed and the laser profilometer was then used to estimate the surface roughness as shown in Figure IX-12. The estimated surface roughness parameters are 11.25 cm for correlation length and 1.23 cm for rms height. The estimated correlation function is shown in Figure IX-13.

b. Site AG006 - Wheat Field

The surface roughness measurements of the soil under a wheat field were collected at a site in the northeast corner of the Little Washita watershed area (Figure IX-14). The field, approximately 500 meters by 750 meters, is located in flat bottomland along the Washita river, and at the time of the test was covered in fully mature wheat (the wet weather had delayed harvesting), as shown in Figure IX-15. The estimated surface roughness parameters included a correlation length of 17.25 cm, a rms height of 0.68 cm, and a correlation function given in Figure IX-16. Estimates of the vegetation parameters were taken as well, including estimates of plant height, density biomass and gravimetric moisture content, and these estimates are given in Table IX-2.

c. Site AG007 - Alfalfa Field

Located immediately east of the wheat field (Figure IX-14) was a large 400 by 750 meter field covered with alfalfa plants. A small section of the plants were removed (Figure IX-17) and the soil roughness parameters were estimated, with an rms height of 0.50 cm, a correlation length of 13.25 cm, and an correlation function estimate as given in Figure IX-18. Unlike the fully mature wheat field, these alfalfa plants were green and moist, as shown in Table IX-2 along with other vegetation parameter estimates.

3. Rangeland Sites

a. Site MS001

The terrain of site MS001 consisted of a large field which had once been used as cropland but had recently been plowed under and returned to pasture land. Therefore, the surface was sparsely covered in multiple species of small vegetation, as shown in Figure IX-20. Since the land was currently being used for cattle grazing, the underlying surface was fairly rough. The location of the site was in the northwestern region of the Little Washita watershed, as shown in Figure IX-19. The roughness estimates for this surface are 1.23 cm for rms height, and 7.75 cm for correlation length, with the correlation function given in Figure IX-21.

In addition to the surface roughness measurements, the laser profilometer was used to measure the raw data required to determine the ``aerodynamic roughness'' of the vegetation surface. Prior to removing the vegetation for surface roughness estimation, the profilometer was assembled over the vegetation and used to measure the vertical distance to the vegetation at horizontal increments of 0.5 cm. Since the vegetation consisted mainly of grasses and other small vegetation, the measurements between adjacent horizontal locations were highly uncorrelated, except for those measurements where the laser penetrated through the vegetation to the soil surface. In addition, the wind caused the vegetation to move during measurement and made it difficult to obtain reliable estimates, particularly for vegetation which extended large distances above the soil. The measured data is has not been processed but instead given in its raw form, as shown in Figure IX-22. This data was normalized to the lowest measured data point, with all other data given as the vertical height above this minimum point.

b. Site MS004

Site MS004, located in the north central portion of the watershed (Figure IX-23), was likewise used for cattle grazing and was covered by long thin blade grass of approximately 20 cm in height (Figure IX-24). However, unlike site MS001, the surface vegetation so dense that after removing the vegetation the majority of surface area was covered in grass stubble, with little exposed bare surface. Because of this, no soil roughness estimates could be determined, as the ``surface'' could not specifically be defined among the thick grass stubble. Therefore, only aerodynamic roughness data was collected at this site, a sample of which is displayed in Figure IX-25.

c. Site MS002

The ninth and final test site was located at Met Site 2 (Figure IX-26), in a dense field consisting of multiple species of grasses and other short vegetation (Figure IX-27). As with site MS004, the surface roughness estimates could not be adequately defined, and therefore only aerodynamic roughness data was collected. Figure IX-28 displays a sample of this raw data.

F. SUMMARY

As the physical properties of a natural surface can be as important as soil moisture in influencing its electromagnetic properties (radiobrightness, scattering coefficients), this report attempts to provide some physical description of a representative set of the Washita `92 test surfaces. Table IX-3 presents a summary of the roughness data at the seven sites where roughness measurements were taken, and Table IX-2 gives some of the relevant biophysical descriptions for the agricultural fields. All data has been reduced to relevant description parameters (rms height, correlation length) with the exception of aerodynamic roughness data, wherein only a sample of the raw data was given. For the complete set of raw aerodynamic roughness data, or the raw surface roughness data, requests may be sent to the publisher of this document.

Table IX-1. Performance specifications of laser profilometer system, as used during Washita '92 testing.

Parameter	value	units
Horizontal Step Size	0.5	cm
Horizontal Step Accuracy	< 0.1	cm
Vertical Measurement Resolution	0.001	cm
Vertical Measurement Accuracy	0.3	cm
Average Measurement Speed	4	sec/point

Table IX-2. Compilation of vegetation parameters taken at sites AG006 (wheat) and AG007 (alfalfa).

Parameter	Wheat	Alfalfa	Units
plant height	60	50	cm
biomass	410	1450	g/m2
plant density	590	410	plants/m2
gravimetric moisture content	18.5	79.5	%

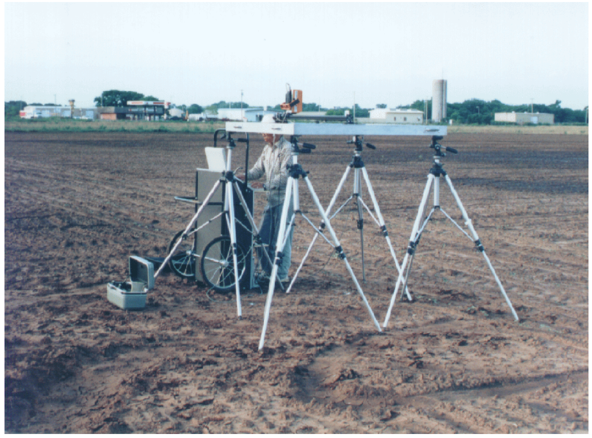

Figure IX-1. Photo of laser profilometer system including laser, position table, computer, controllers and power supply.

Table IX-3. Compilation of surface roughness estimates taken at seven sites in the Little Washita Watershed.

Site	Type	u (cm)	(cm)
PR00l	bare	2.29	8.75
AG005	bare	1.29	16.25
AG002	bare	1.82	17.75
AG001	corn	1.23	11.25
AG006	wheat	0.68	17.25
AG007	alfalfa	0.50	13.25
MS001	rangeland	1.23	7.75

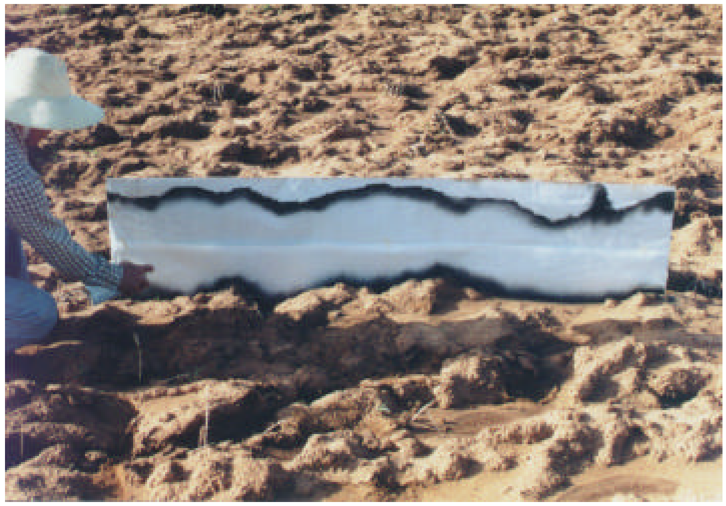

Figure IX-2. Paint and paper profiling technique.

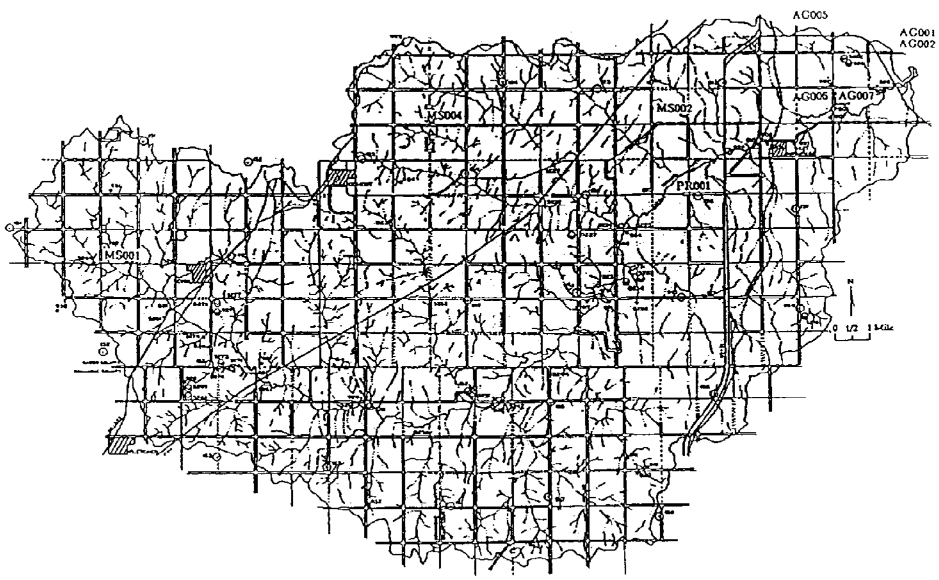

Figure IX-3 *Map of the Little Washita Watershed showing the location of the measurement sites.*

Figure IX-3. Map of the Little Washita Watershed showing the location of measuring sites.

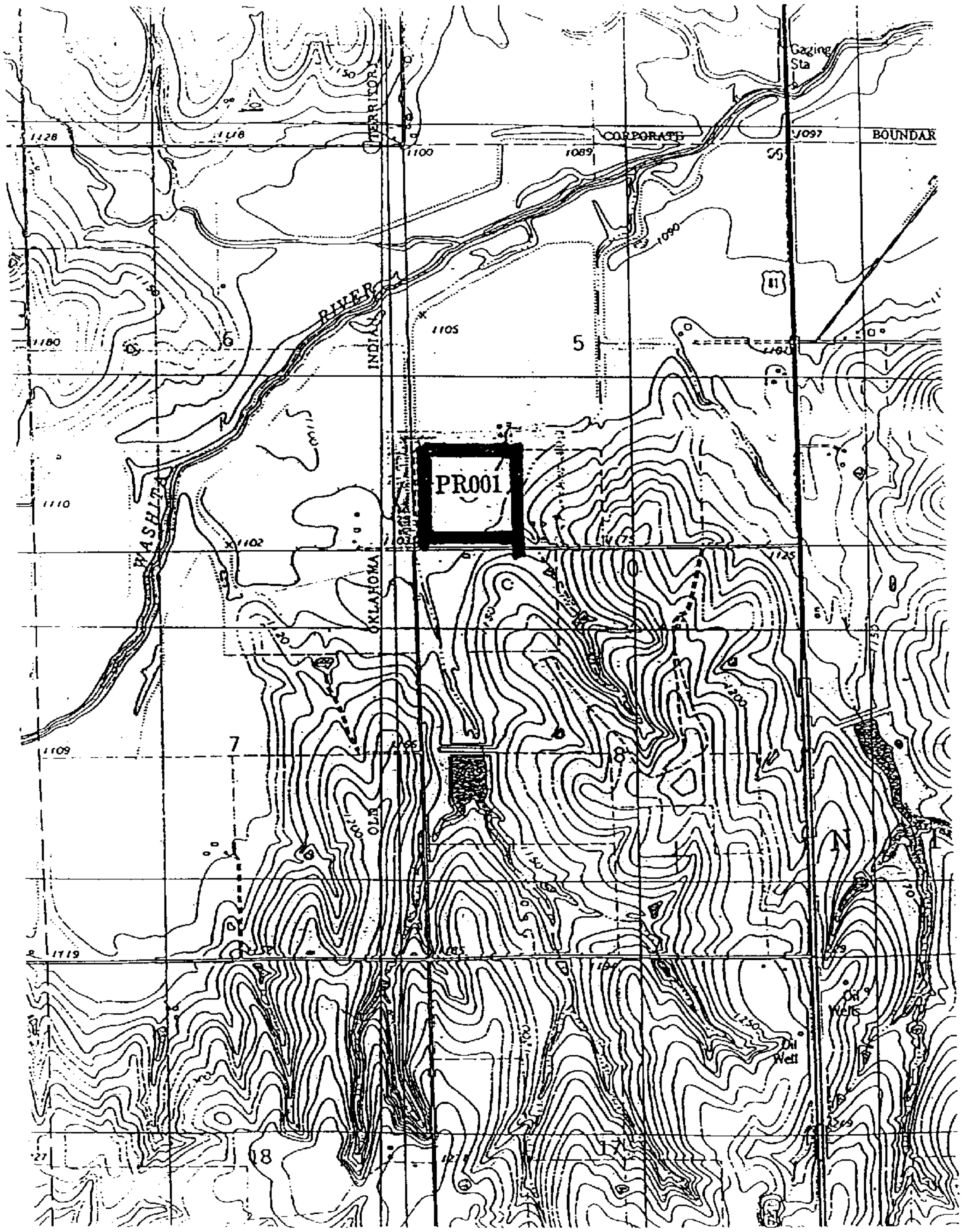

Figure IX-4 *Map showing site PR001 and surrounding area, located at approximately* 34° 56′ *latitude,* 97° 58′ *longitude.*

Figure IX-5. Bare surface of site PR001 showing rough surface characteristics. Note six inch ruler inn center of photo.

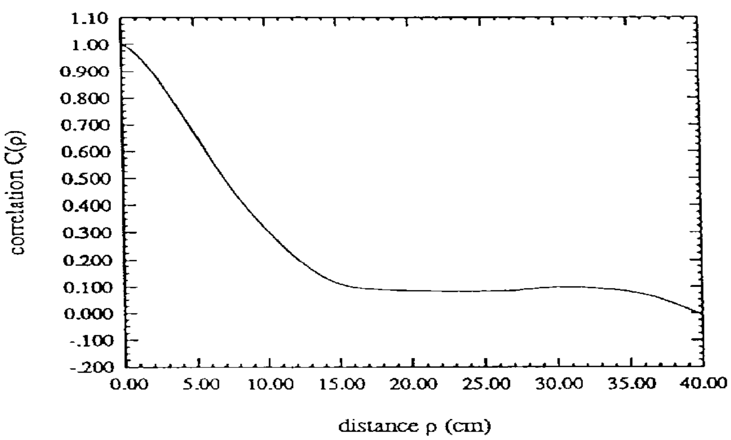

Figure IX-6 *Estimated correlation function of bare soil surface located at site PR001.*

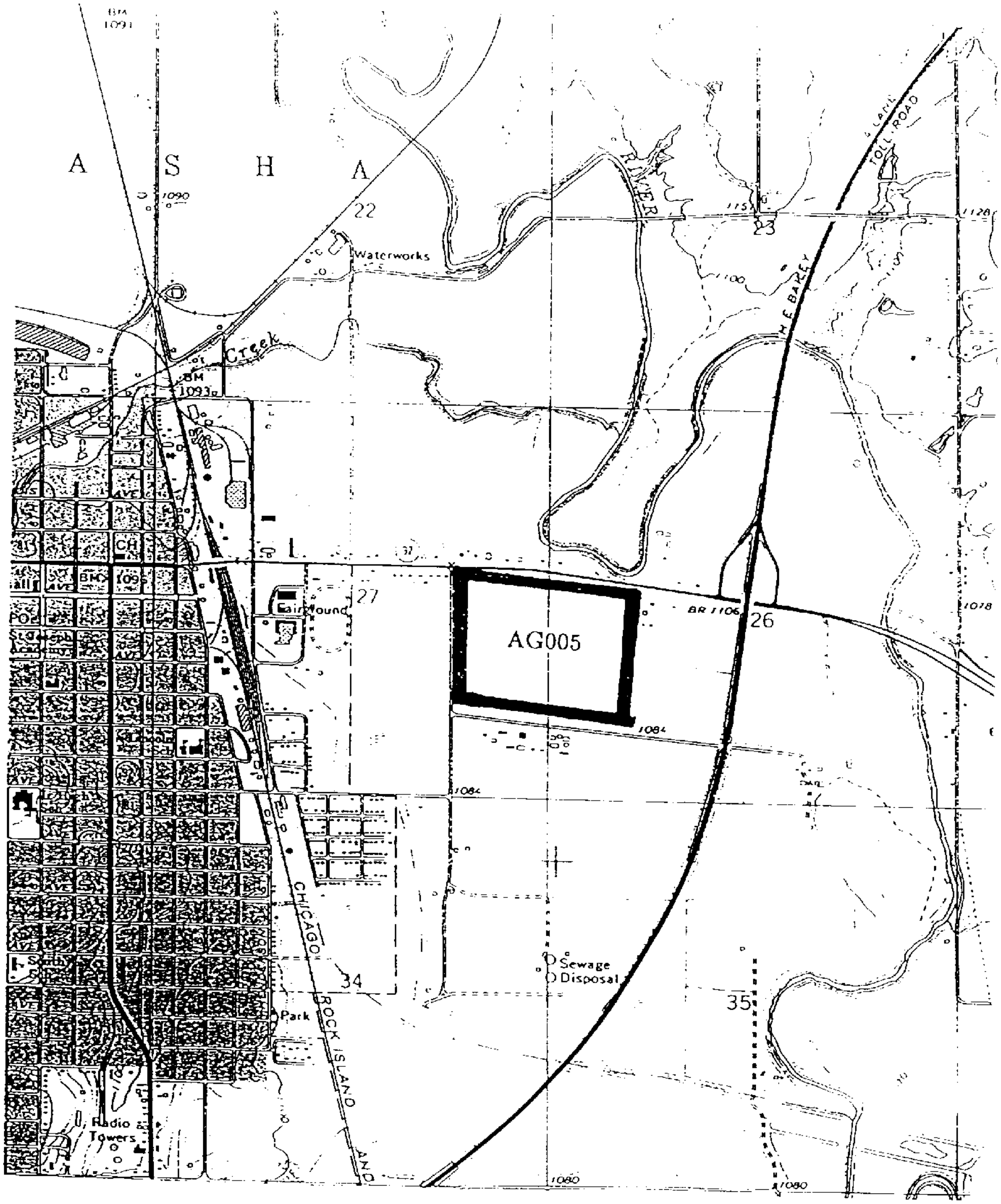

Figure IX-7 *Map showing site AG005 and surrounding area, located at approximately 35° 03 latitude, 97° 55′ longitude.*

Figure IX-8. Bare surface of site AG005 showing rough surface characteristics. Note six inch ruler in center of photo.

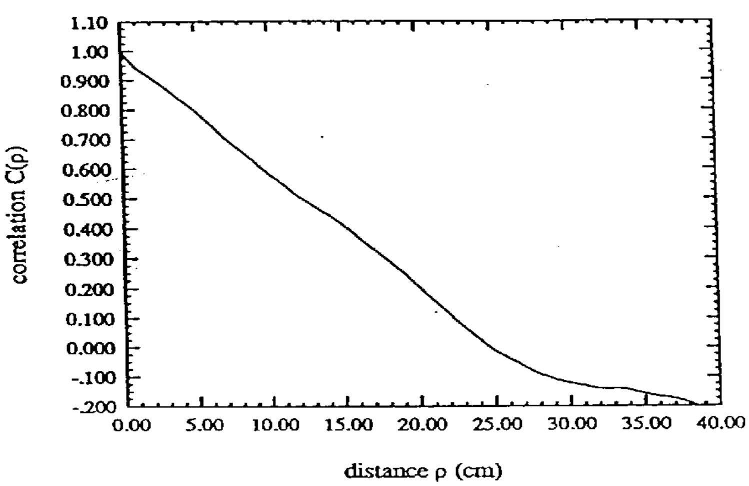

Figure IX-9 *Estimated correlation function of bare soil surface located at site AG005.*

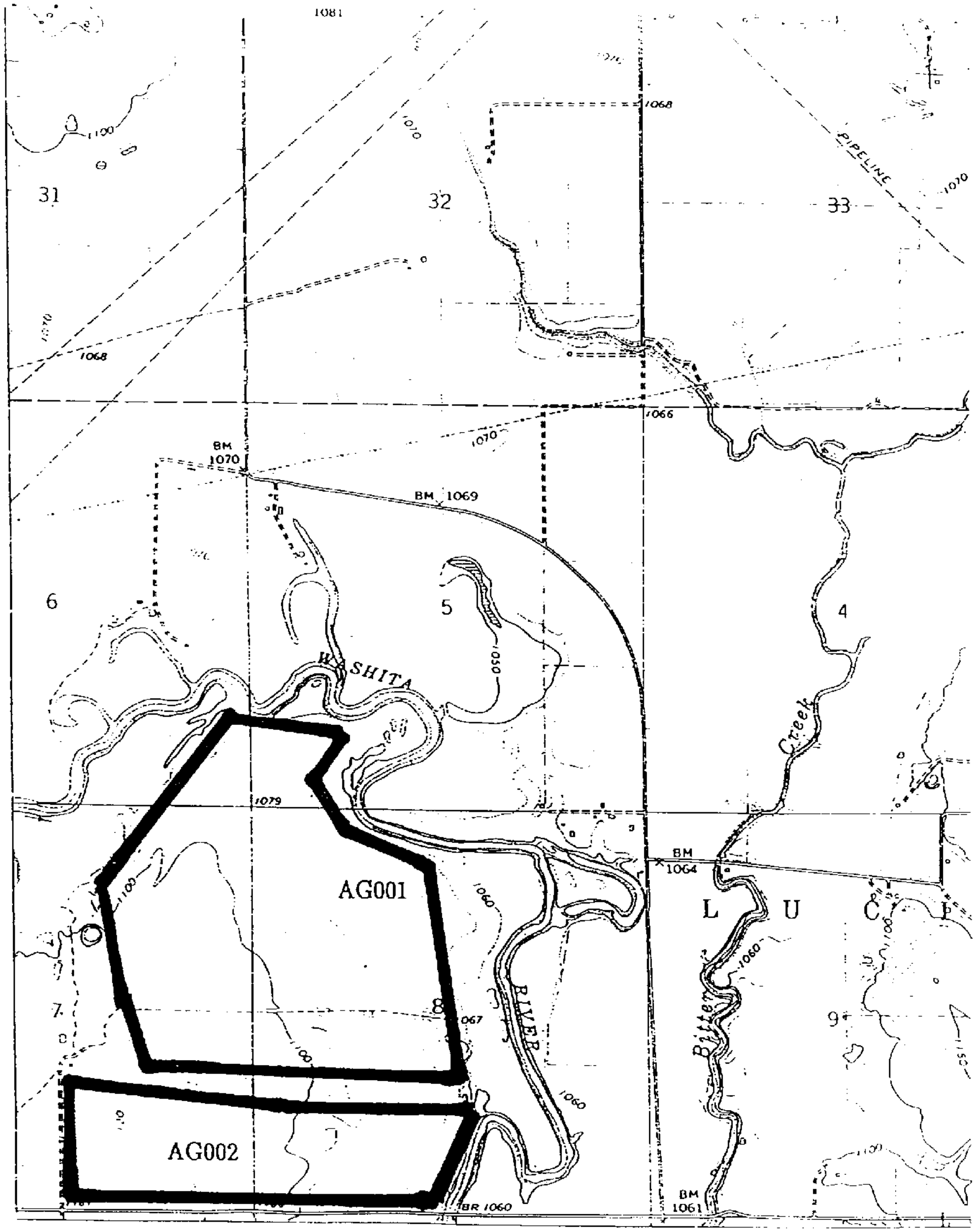

Figure IX-10 *Map showing sites AG001, AG002 and surrounding area, located at approximately 35° 00′ latitude, 97° 52′ longitude.*

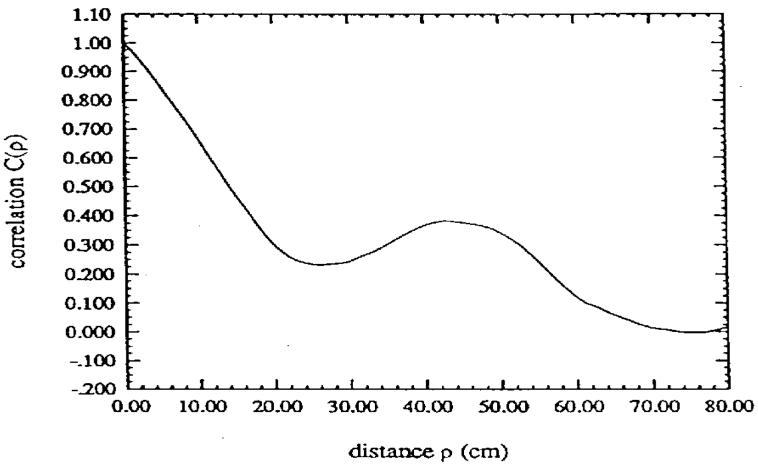

Figure IX-11 *Estimated correlation function of bare soil surface located at site AG002.*

Figure IX-12. Profilometer system operating in the corn field of site AG001.

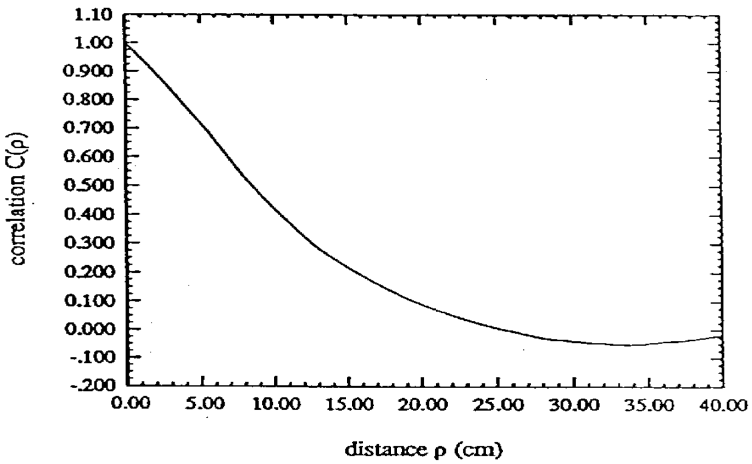

Figure IX-13 *Estimated correlation function of soil surface located at site AG001.*

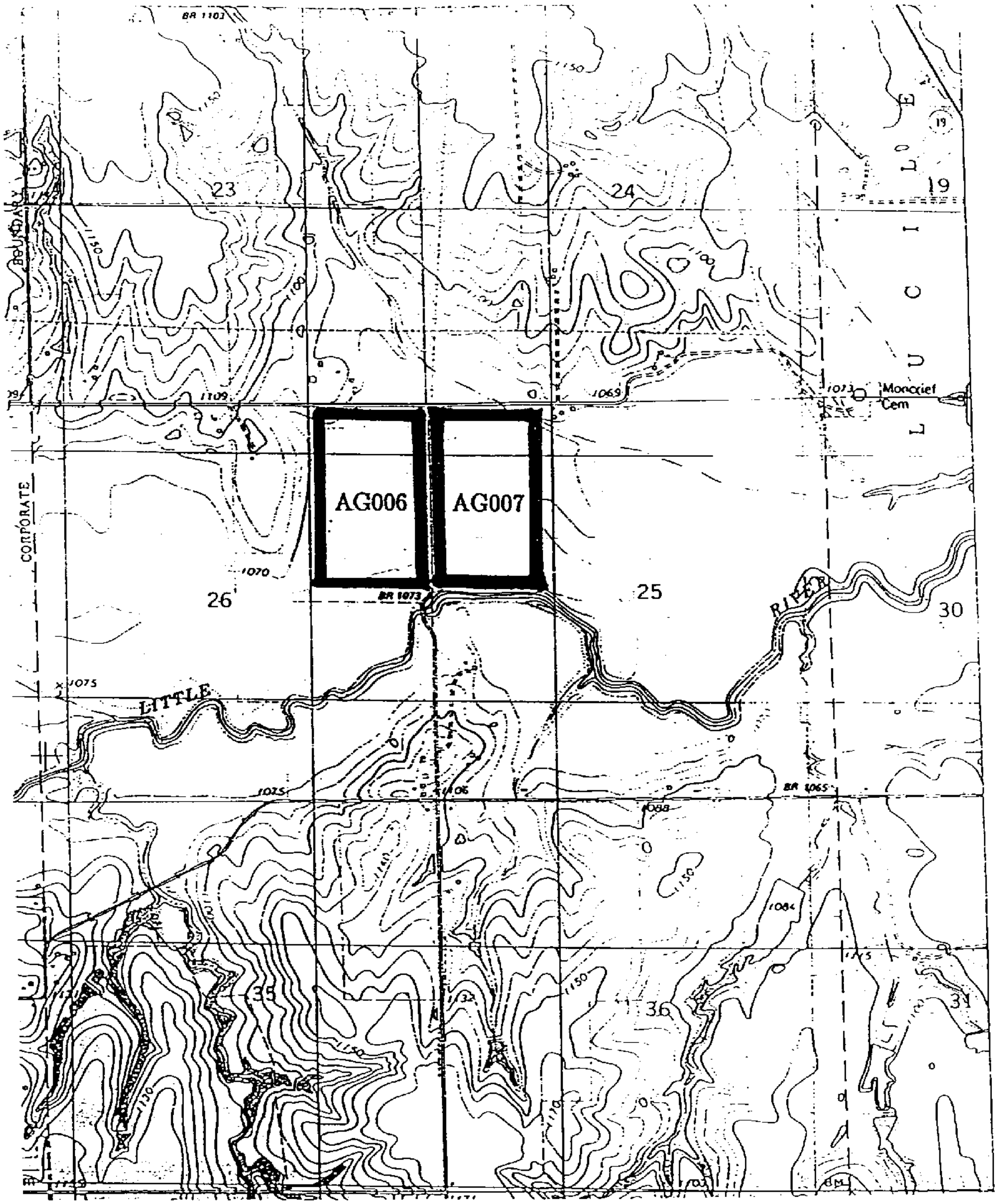

Figure IX-14 *Map showing sites AG006 and AG007, located at approximately* 34° 58′ *latitude,* 97° 54′ *longitude.*

Figure IX-15. Whheat vegetation of site AG006.

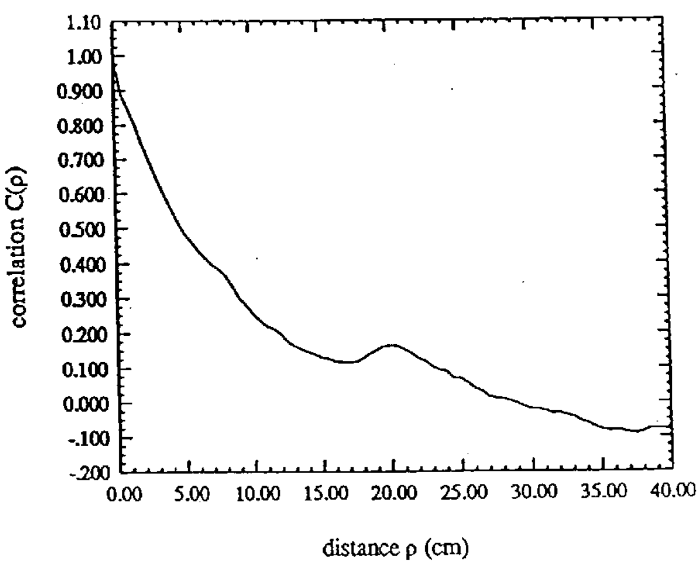

Figure IX-16 *Estimated correlation function of soil surface located at site AG006.*

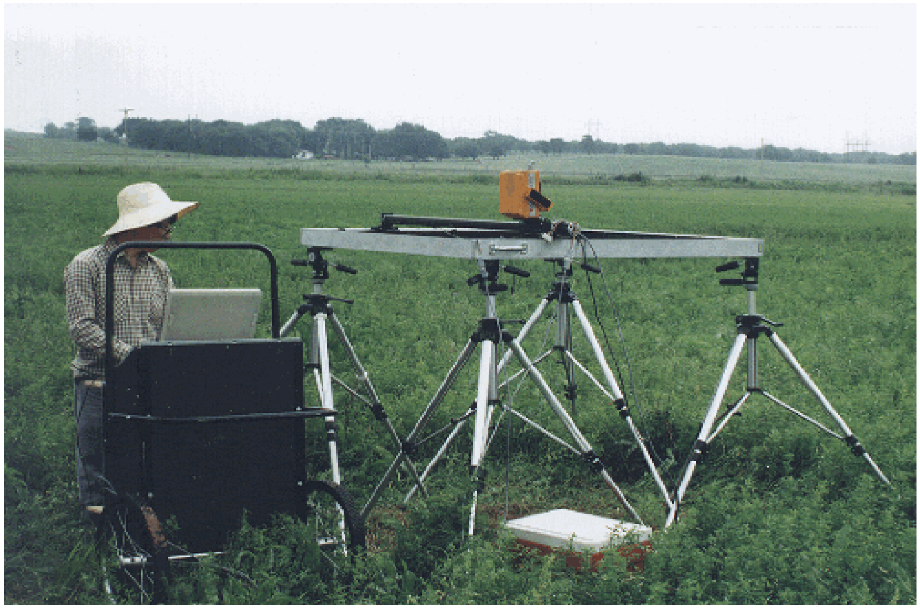

Figure IX-17. Alfalfa vegetation of site AG007.

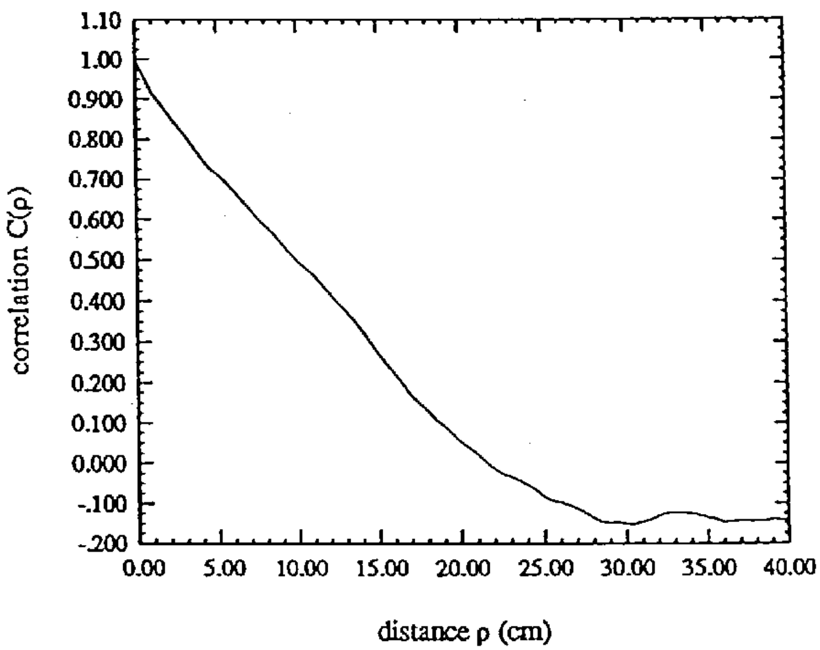

Figure IX-18 *Estimated correlation function of soil surface located at site AG007.*

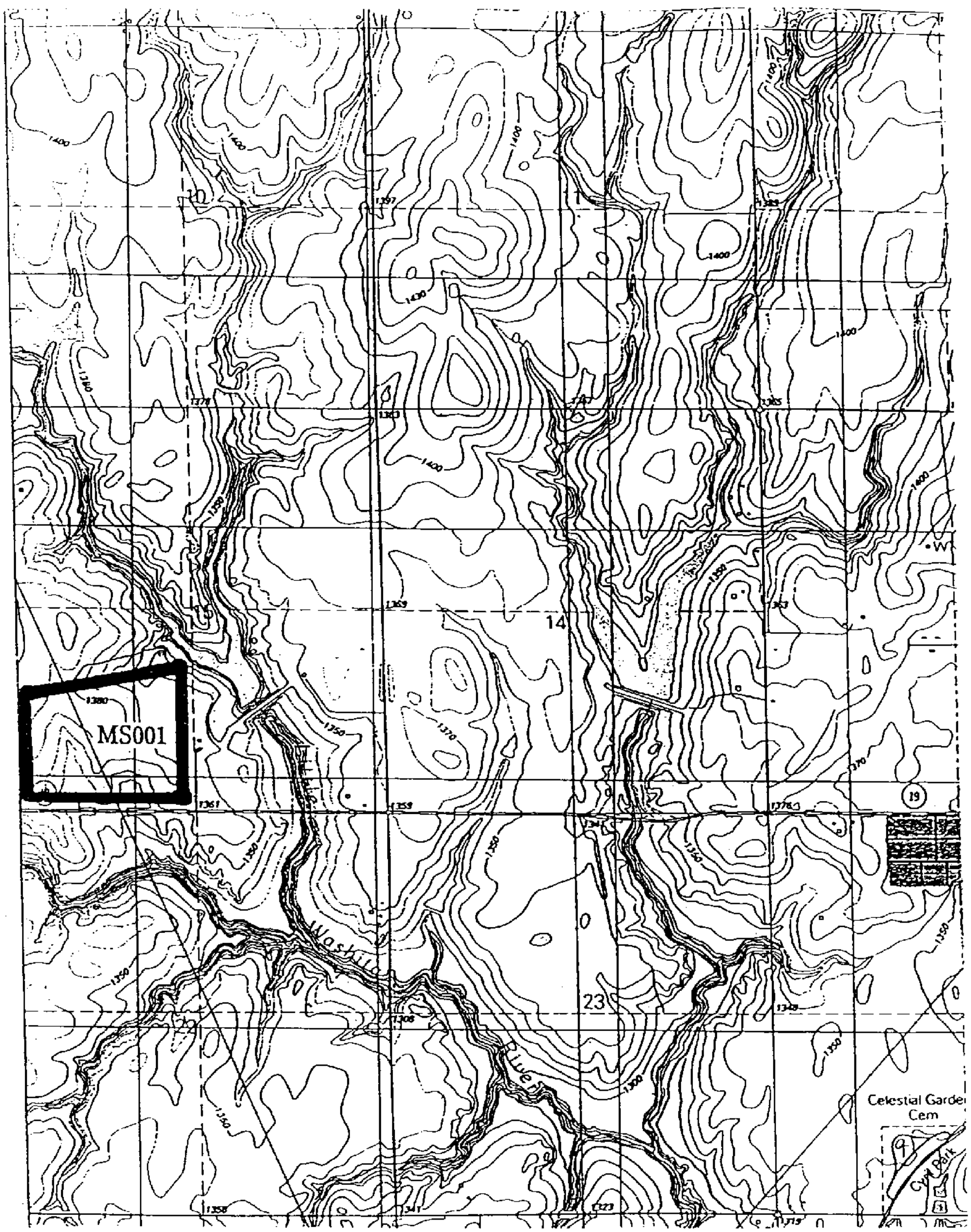

Figure IX-19 *Map showing site MS001 and surrounding area, located at approximately* 34° 54′ *latitude,* 98° 15′ *longitude.*

Figure IX-20. Vegetation of rangeland site MS001.

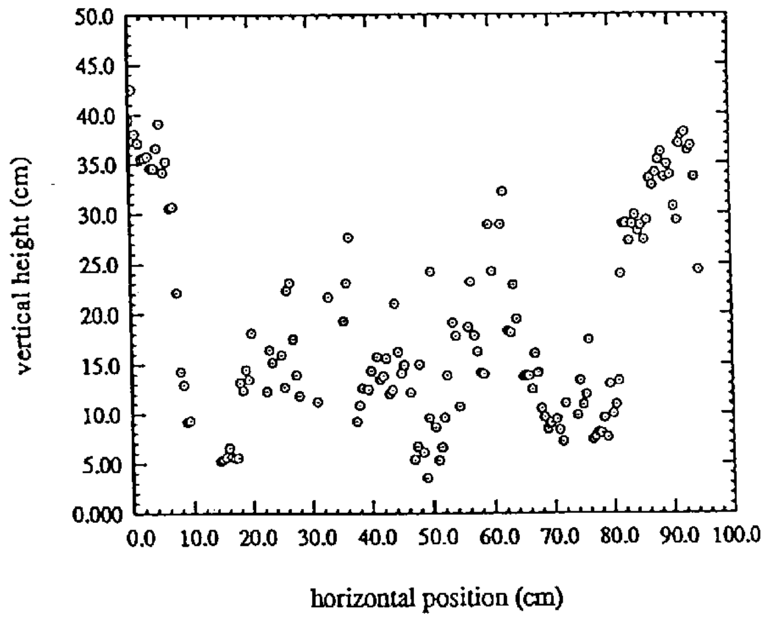

Figure IX-22 *Vertical profile of vegetation at site MS001 as determined by the laser profilometer (data is normalized to lowest data point).*

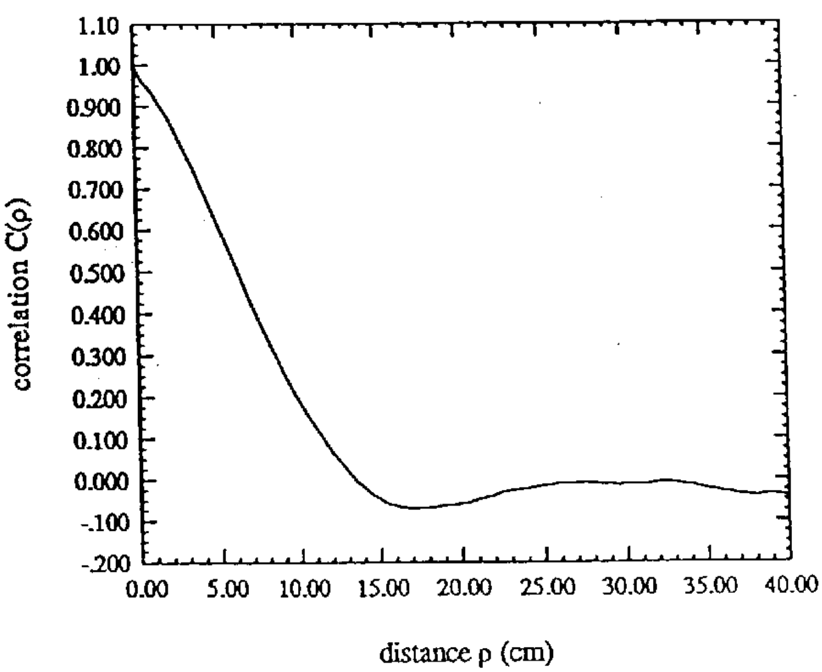

Figure IX-21 *Estimated correlation function of soil surface located at site MS001.*

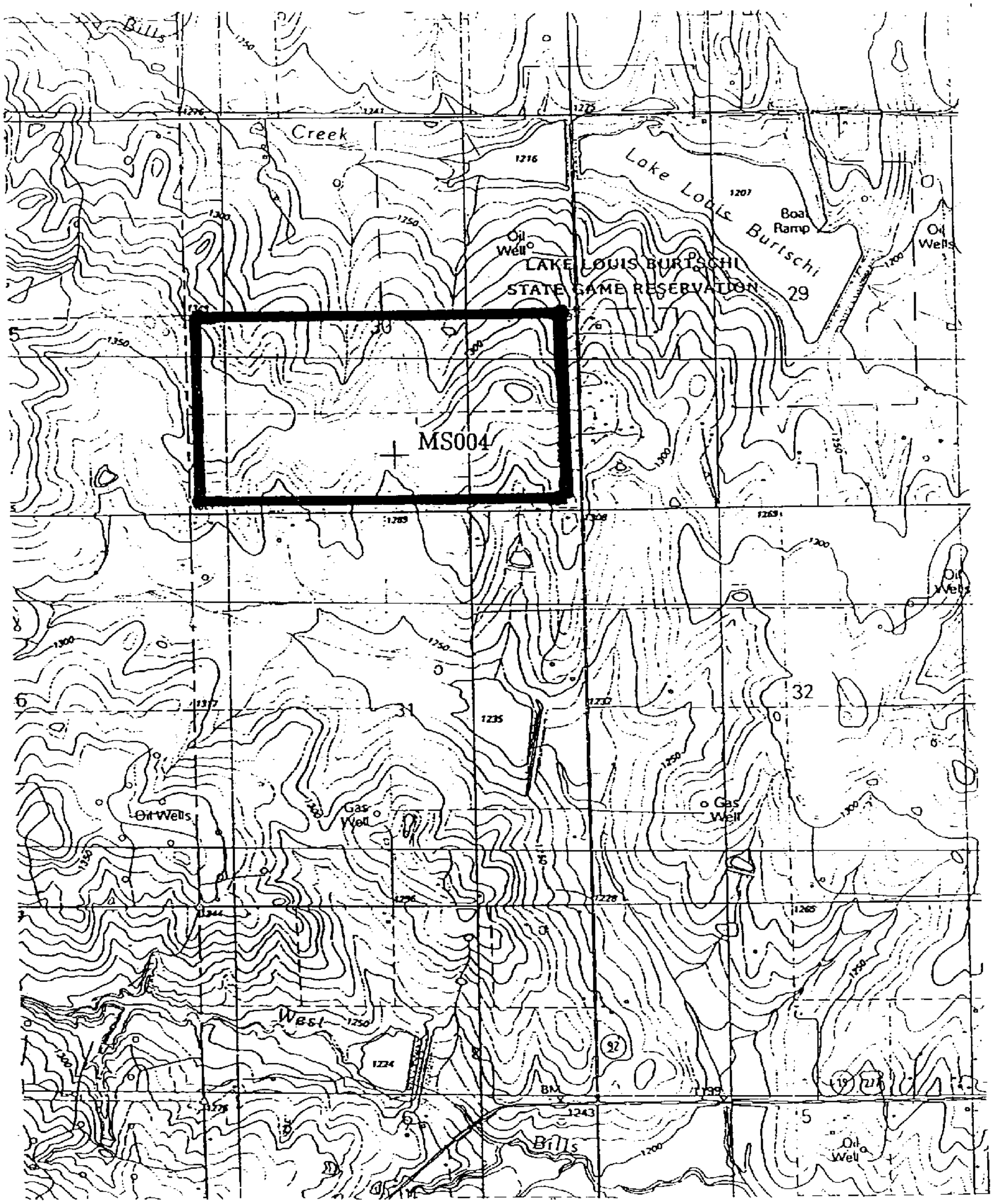

Figure IX-23 *Map showing site MS004 and surrounding area, located at approximately* 34° 58′ *latitude,* 97° 54′ *longitude.*

Figure IX-24. Vegetation of rangeland site MS004.

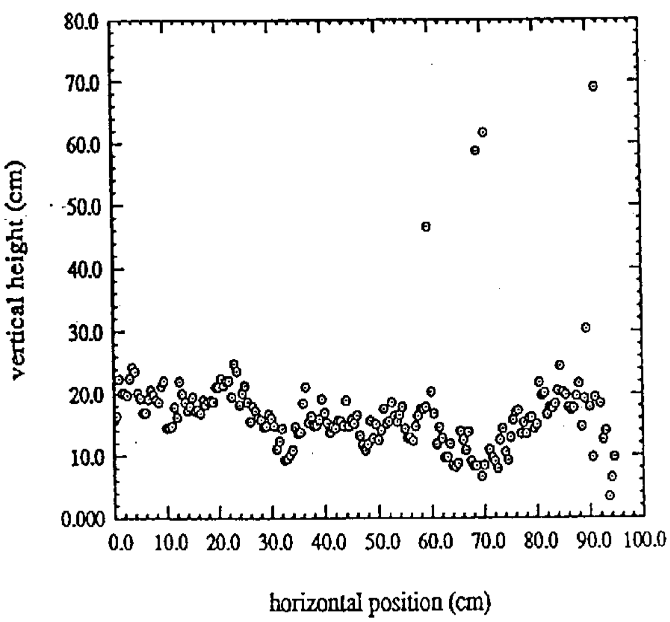

Figure IX-25 *Vertical profile of vegetation at site MS004 as determined by the laser profilometer (data is normalized to lowest data point).*

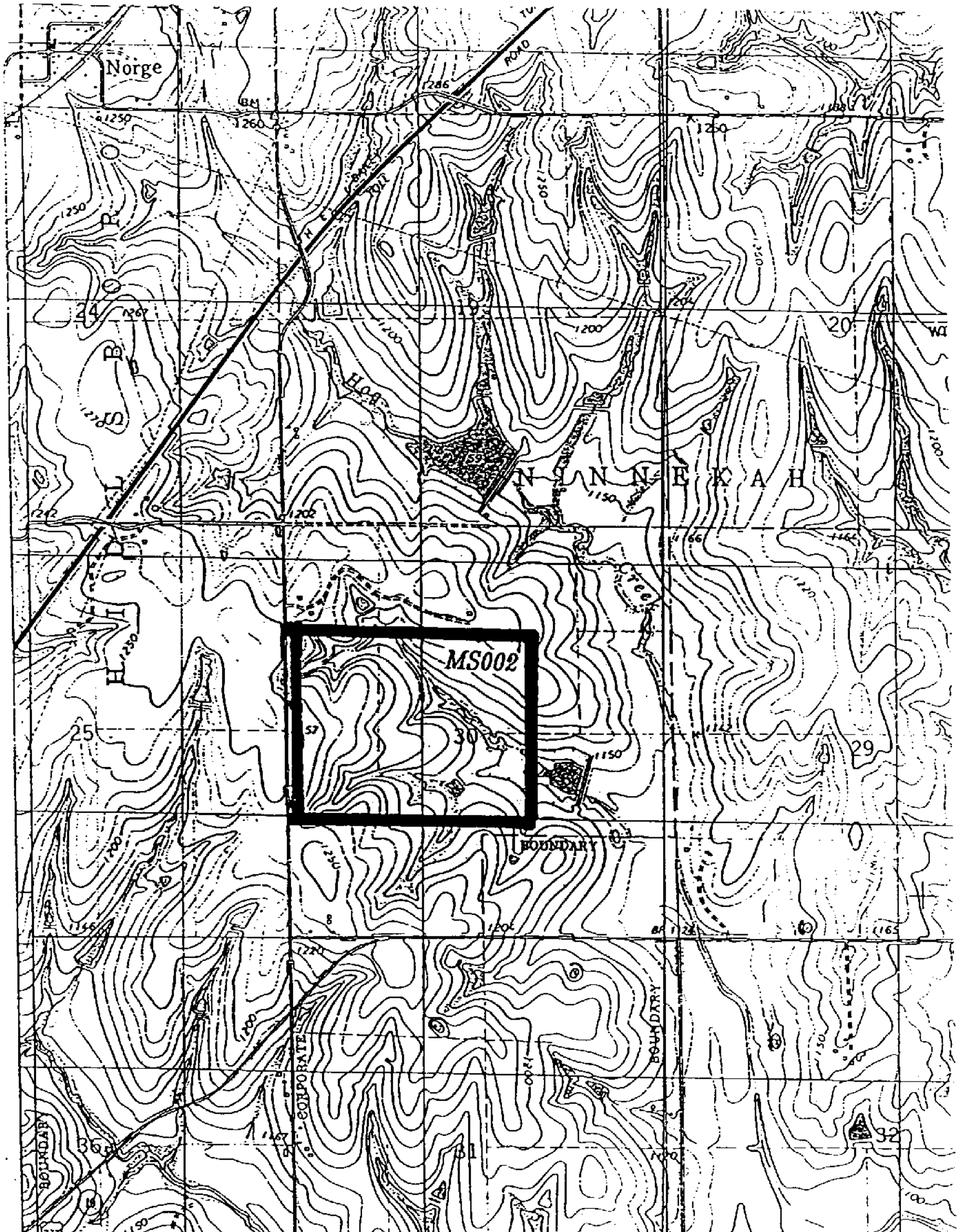

Figure IX-26 *Map showing site MS002 and surrounding area, located at approximately* 34° 58′ *latitude,* 97° 54′ *longitude.*

Figure IX-27. Vegetation of rangeland site MS002.