AIRCRAFT REMOTE SENSING OF SOIL MOISTURE AND HYDROLOGIC PARAMETERS

Chickasha, Okla., and Riesel, Tex.,
1978 Data Report

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CONTENTS

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CHICKASHA, OKLA., AND RIESEL, TEX., 1978 DATA REPORT[1]

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ABSTRACT

Experiments were conducted to evaluate aircraft remote sensing techniques for hydrology in a wide range of physiographic and climatic regions using several sensor platforms. The data collected on May 1, 12, and 30, 1978, in two semiarid areas-- Chickasha, Okla., and Riesel, Tex., are reported. Soil moisture observations, climatic data, and the remote sensing data collected using thermal infrared, passive microwave, and active microwave systems are reported.

INTRODUCTION

Cooperative investigations were conducted during May 1978 by the National Aeronautics and Space Administration (NASA) and the U.S. Department of Agriculture (USDA) as part of a project to evaluate remote sensing in hydrologic studies with primary emphasis on measurements. Participants in the study were the NASA Goddard Space Flight Center and the USDA-SEA-AR Hydrology Laboratory, Southern Plains Watershed and Water Quality Laboratory and the Grassland, Soil, and Water Laboratory.

Experiments were planned to evaluate aircraft remote sensing techniques in a wide range of physiographic and climatic regions using several sensor platforms. This report deals with ground observations and aircraft remote sensing experiments conducted in two semiarid areas-- Chickasha, Okla., and Riesel, Tex.

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EXPERIMENTAL DESIGN

General

Experiments were designed to collect remote sensing data concurrent with ground observations of hydrologically significant parameters and phenomena, primarily soil moisture within several surface layers. An important feature was the observations made on intensively monitored watersheds. In some cases the watershed size was approximately the same size as the sensor ground resolution element.

In 1978 three successful flights were made on May 1, 12 and 30, over the test sites in Chickasha, Okla., and Riesel, Tex. The following sections describe the ground sampling procedures, general climatological observations and the remote sensing systems that were employed.

Ground Sampling Procedure

Chickasha. Okla., test site

The study sites and watersheds in Oklahoma were in the Washita River Experimental Watershed, Chickasha, area which is monitored by the USDA-SEA-ARS Southern Plains Watershed and Water Quality Laboratory. A general location map is shown in figure 1 and soil description given in table 1. Six flightlines were flown on May 1, 12, and 30, 1978. Two different approaches were used in soil moisture sampling.

Along flightline 6, two rows of samples were collected perpendicular to the flightline at the indicated locations. Figure 2 illustrates the spacing and layout of the eight points in the traverse moisture sampling scheme. Samples were obtained for the 0 to 2.5 cm, 2.5 to 5.0 cm, and the 5.0 to 15.0 cm depths. As shown in figure 1, each of these sites was located in proximity to a recording raingage. Table 2 lists the soil types and the land cover on each date. On flightlines 1 to 5 the data collected were on watershed units and soil moisture samples obtained generally on a grid.

Flightline 1 included 5 cropland or C watersheds (fig. 3, A). Descriptions of the land cover on these watersheds are given in table 3. Soil maps, sampling points and topography are presented in the Appendix. Soil descriptions are presented in table 1.

Flightlines 3 and 4 were flown over four rangeland or R watersheds (figure 3, B). Descriptions of the land cover of the R watersheds are listed in table 3. Soil maps, sampling sites and topography are presented in the Appendix. Soil descriptions are presented in table 1.

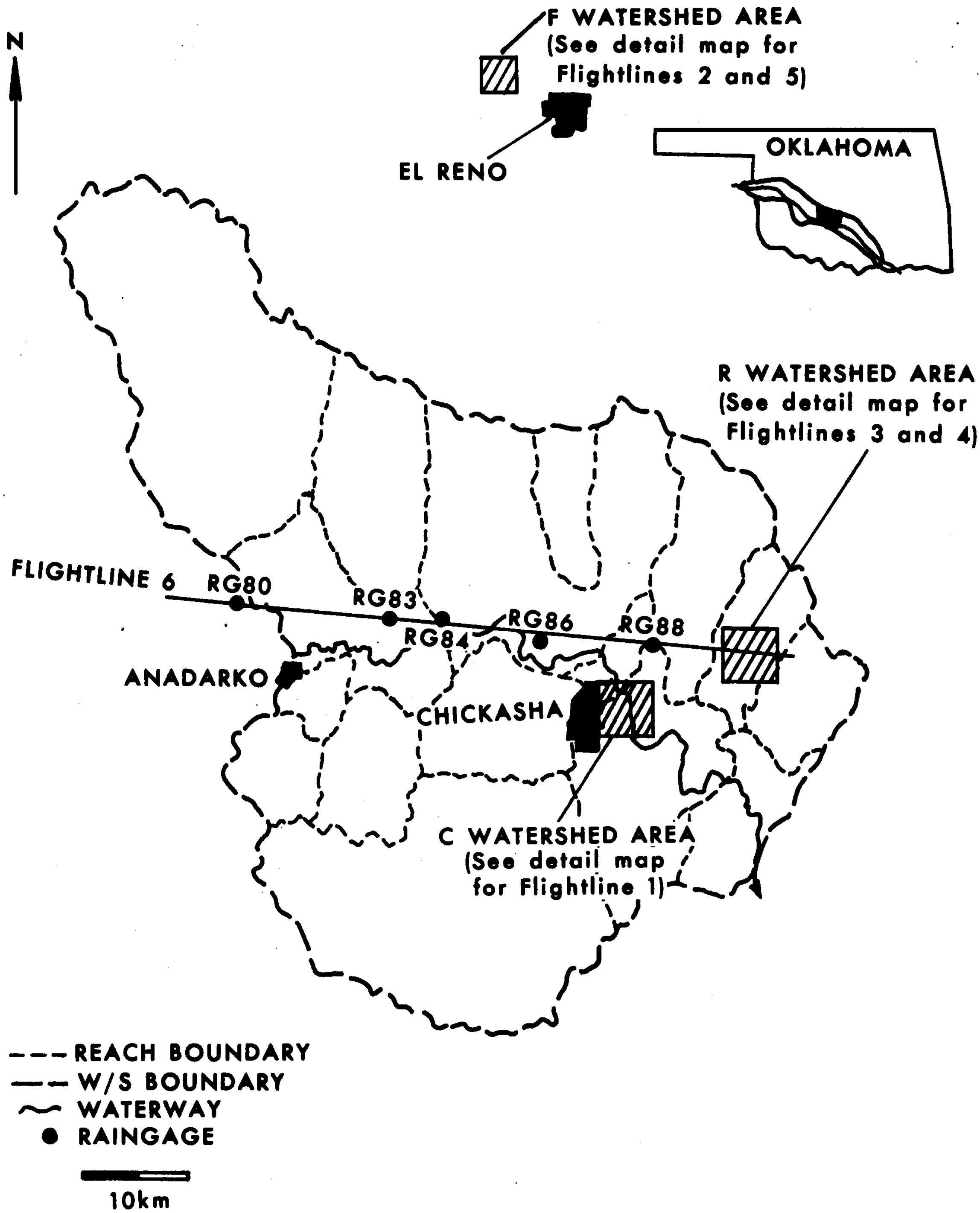


Figure 1.--General location map of the Washita River Experimental Watershed, Chickasha, Okla.

Table l.--Chickasha, Okla., soils descriptions

Soil type	Depth[1/]	Internal drainage[2/] and Permeability[3/]	Location[4/]	Available water capacity	Slope	Erosion
					Percent	
Aydelotte silt loam	D	M/SP	UP	---	---	No
Bethany silt loam	D	M/SP	UP	0.18 to 0.	0 to 1	No
Cobb fine sandy loam	D	M/MP	UP	.14	3 to 5	No
Dale silt loam	D	M/MP	FP	.15 to .24	0 to 1	No
Grant Port complex	D	M/MP	UP	.15 to .20	0 to 12	No
Kirkland silt loam	D	M/VSP	UP	.16 to .24	0 to 1	No
McLain silt loam	D	M/MSP	FP	.15 to .22	0 to 1	No
McLain silty clay loam	D	S/MSP	FP	---	0 to 1	No
Milan loam	D	M/MP	UP	---	---	No
Minco very fine sandy loam	D	M/MP	UP	.14	3 to 8	No
Pond Creek silt loam	MD	M/MP	UP	.12	1 to 3	Yes
Port silt loam	MD	M/MP	UP	.14	1 to 3	No
Quinlan-Woodward complex	MD	S/SP	UP	.14	5 to 12	No
Reinach silt loam	D	M/MP	FP	.13 to .24	0 to 1	No
Renfrow silt loam	D	S/MP	UP	.15 to .24	2 to 5	Yes
Teller loam	D	M/MP	UP	.12 to .16	2 to 5	Yes
Zaneis loam	D	M/SP	UP	.11 to .20	2 to 5	Yes

1/ Depth codes: D=deep, MD=moderately deep.
2/ Internal drainage codes: S=slow, M=moderate.
3/ Permeability codes: VSP=very slow, SP=slow, MSP=moderately slow, MP=moderate.
4/ Location code: FP=floodplain, UP=uplands.

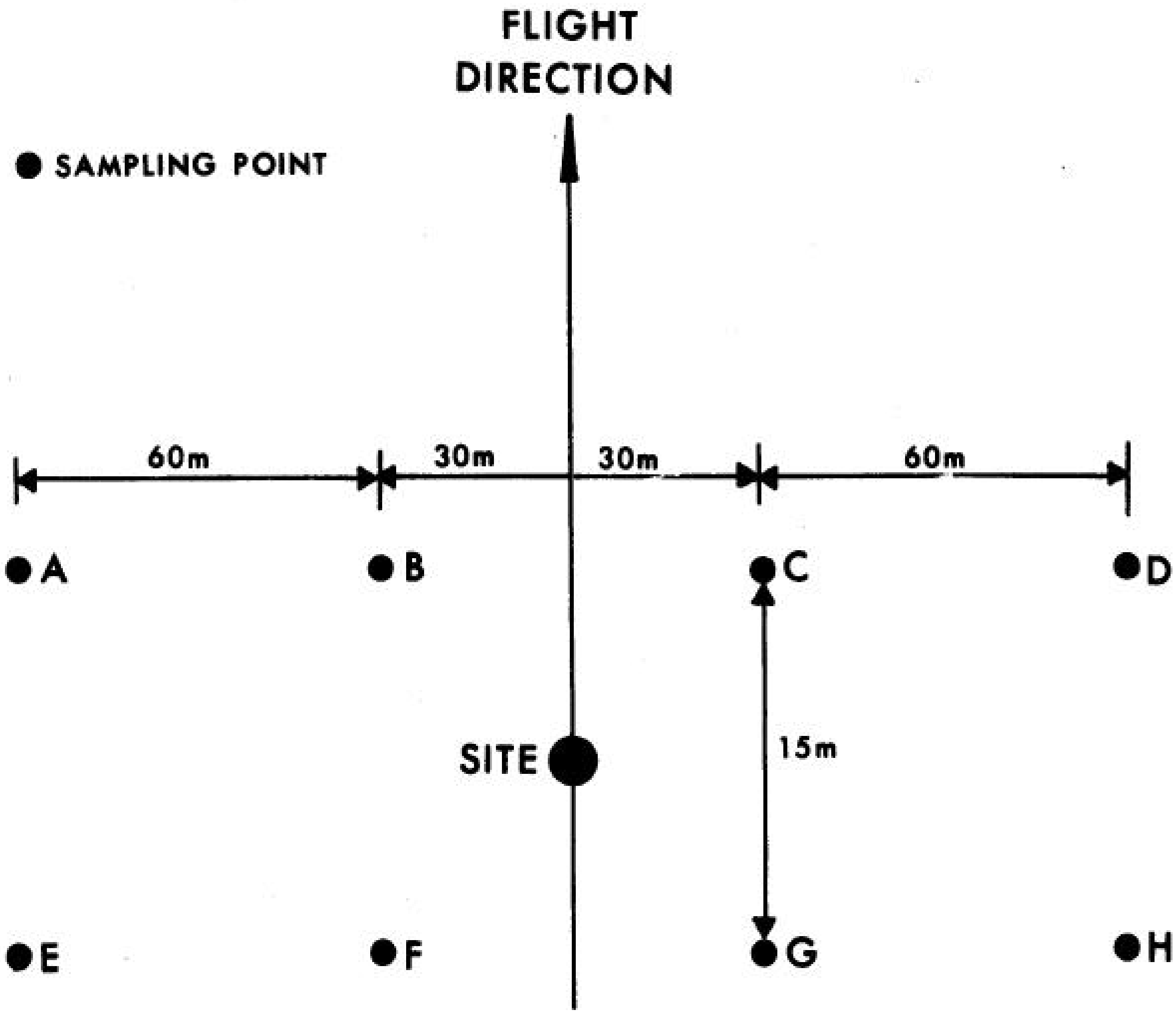


Figure 2.--Traverse soil moisture sampling scheme.

Table 2.--Chickasha, Okla., flightline 6 soil types land cover

Site	Soil type	Land cover on May 1, 1978	May 12, 1978	May 30, 1978
RG80	Cobb fine sandy loam	Alfalfa	Alfalfa	Alfalfa
RG83	Pond Creek silt loam	Fallow	Fallow	Fallow
RG84	Teller loam	Wheat	Wheat	Wheat
RG86	Port silt loam	Pasture	Pasture	Pasture
RG88	Grant Port Complex	Fallow	Fallow	Fallow

Table 3.--C and R watershed land cover, Chickasha, Olka.

Watershed site	Land cover on -- May 1, 1978	May 12, 1978	May 30, 1978
C3	Fallow	Fallow	Fallow
C4	Fallow	Fallow	Fallow
C5	Winter wheat	Winter wheat	Winter wheat
C6	Winter wheat	Winter wheat	Winter wheat
C8	Alfalfa	Alfalfa	Fallow
R5	Well managed Pasture	Well managed pasture	Well managed pasture
R6	Well managed pasture	Well managed pasture	Well managed pasture
R7	Poorly managed pasture	Poorly managed pasture	Poorly managed pasture
R8	Poorly managed pasture	Poorly managed pasture	Poorly managed pasture

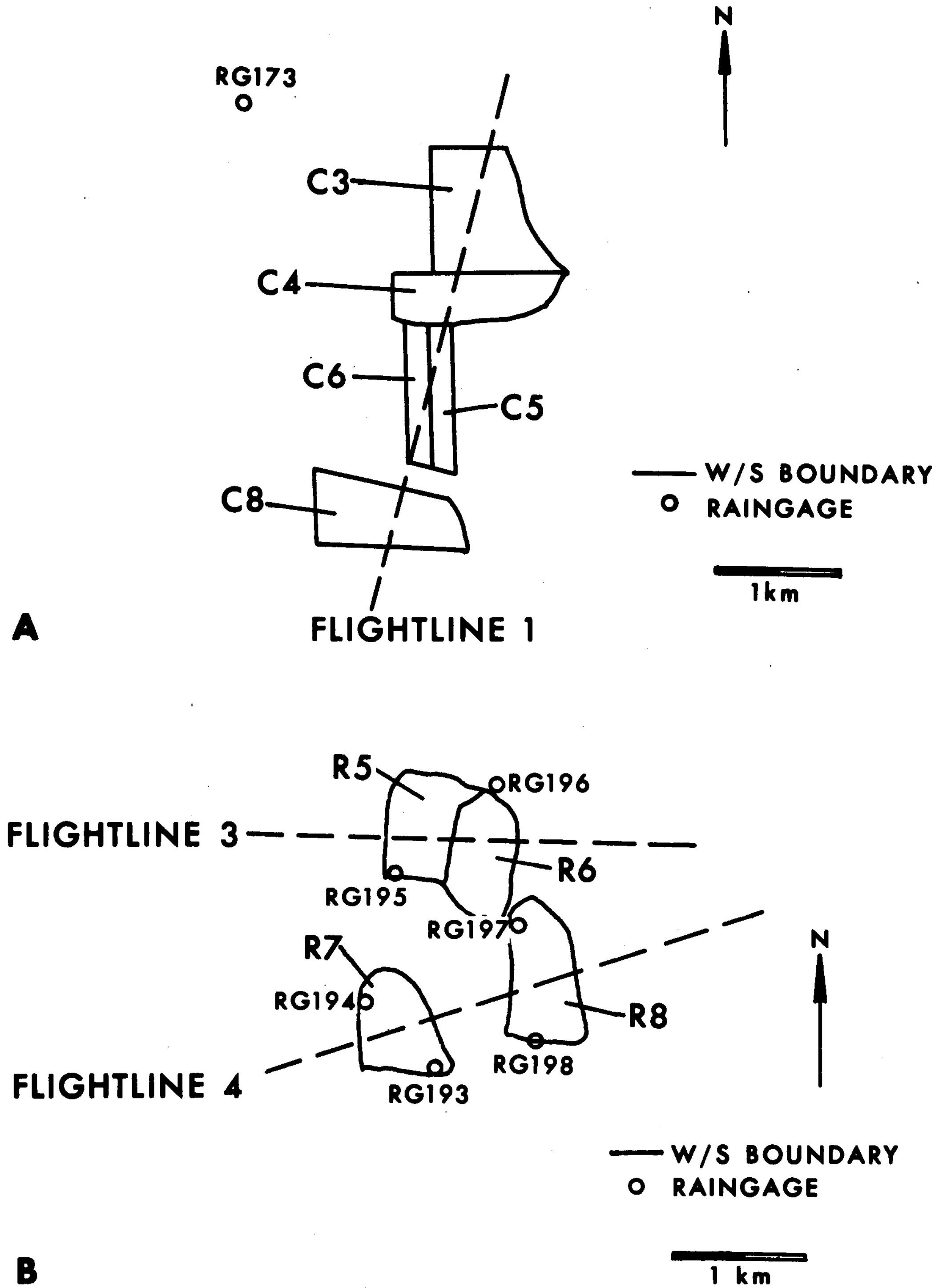


Figure 3.--Chickasha, Okla., watershed flightlines: A, C watershed area; B, R watershed area.

Flightlines 2 and 5 were flown over a group of eight watersheds located near El Reno, Okla., (fig. 4, A). These watersheds were all very small and for the purposes of this study were combined into two groups -- Fl and F2. All watersheds had a dense grass cover. Soils and sampling sites are presented in figure 4, A; soil descriptions in table 1. A topographic map of the area is shown in figure 4, B.

All soil moisture samples were weighed, oven-dried and weighed again to determine their gravimetric soil moisture. Bulk density samples from each field (table 4) were then used to determine the volumetric soil moisture. All samples were collected within ± 2 hours of the overflight and stored in oven cooking bags.

Table 4.--Bulk density of remote sensing soil moisture sites, Chickasha, Okla.

Site	Bulk density
	Gm/cm^3
C3	1.6
C4	1.4
C5	1.5
C6	1.3
C8	1.5
Fl	1.3
F2	1.3
R5	1.4
R6	1.4
R7	1.5
R8	1.5
RG80	1.3
RG83	1.6
RG84	1.3
RG86	1.4
RG88	1.6
RG92	1.6

Climatological data were collected during the experimental period as part of the regular data collection program. Table 5 presents the pan evaporation, daily maximum and minimum air temperatures, and the daily rainfall at a number of gages. The gage locations are shown in figures 1, 3, and 4.

Riesel, Tex., test site

The study site located in the central part of Texas near Riesel was on an experimental watershed area operated by the USDA-SEA Grassland, Soil, and Water Laboratory. Fifteen sampling sites were identified along a 9 km

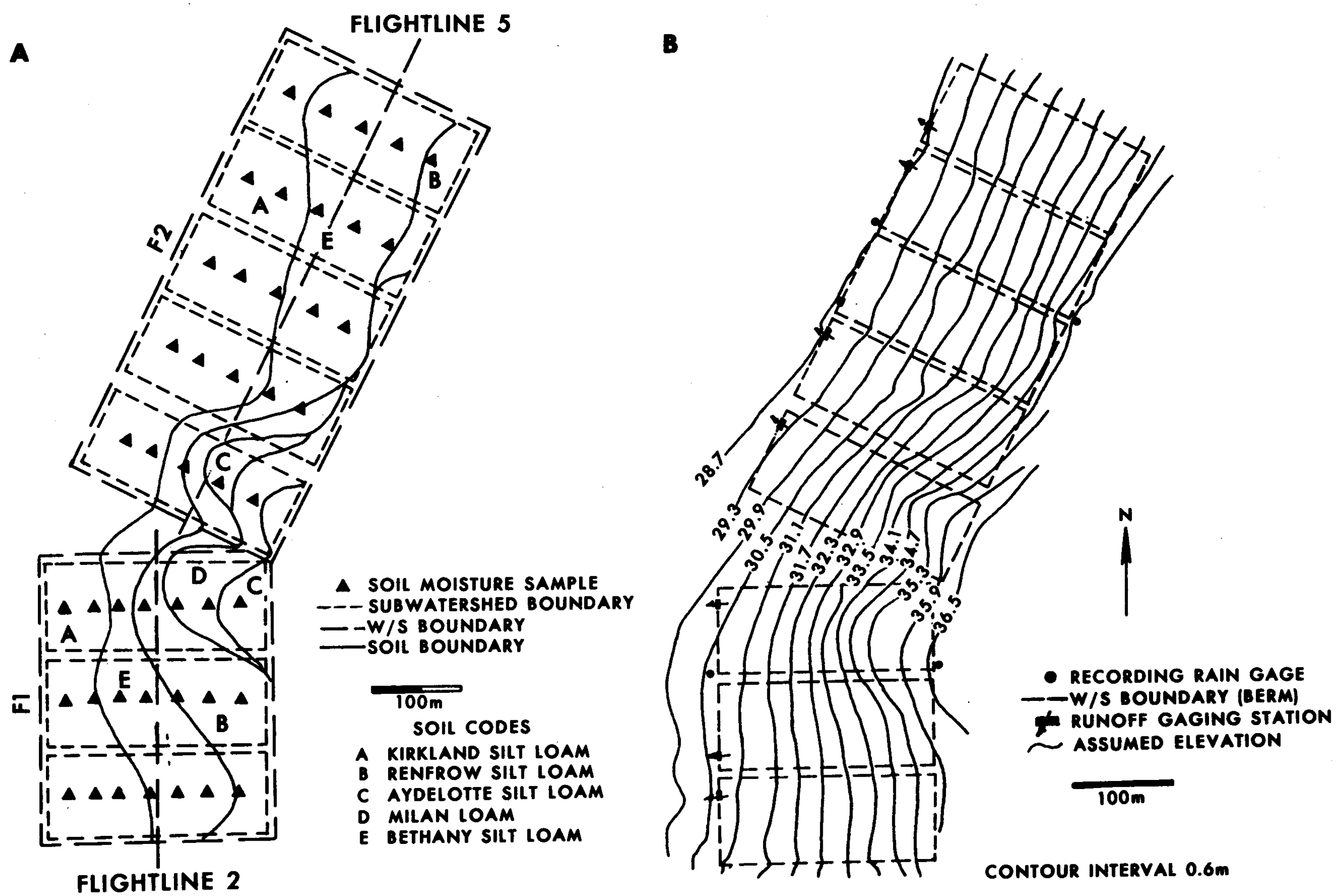


Figure 4.--F watershed area, El Reno, Okla.: A; Soils, sampling locations and flightlines; B, topographic map.

Table 5.--Chickasha, Okla., climatological data

DATE	PAN EVAP	DAILY TEMP MAX	DAILY TEMP MIN	RAINFALL AT RAINGAGE 80	83	84	86	88	92	173	230	193	194	195	196	197	198	331	332	333	334
	-CM-	-DEG K--		CM																	
41678	0.28	300	287	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41778	.63	303	283	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
41878	.66	300	280	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
41978	.71	296	279	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42078	.41	290	276	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42178	.63	295	277	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42278	.43	299	285	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42378	.43	299	276	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42478	.56	298	282	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42578	.43	297	279	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42678	.36	296	278	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42778	.66	300	283	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
42878	.28	300	286	.13	.10	.15	.20	.18	.51	.36	.38	.25	.20	.18	.23	.25	.25	.00	.00	.00	.00
42978	.20	303	288	.00	.00	.00	1.70	.00	.03	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
43078	.20	302	289	.38	2.90	2.51	.00	.97	.36	.89	.84	1.30	1.32	1.40	1.40	1.30	1.27	.38	.41	.36	.38
50178	.20	300	283	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
50278	.28	294	279	3.30	3.10	3.35	3.12	2.95	3.15	3.43	3.07	3.07	2.92	3.12	3.07	3.12	3.12	3.30	3.56	3.23	3.23
50378	.05	281	276	.15	.05	.23	.08	.10	.25	.00	.00	.05	.05	.05	.03	.05	.08	.20	.36	.38	.30
50478	.15	288	277	.10	.13	.10	.05	.08	.15	.00	.00	.05	.05	.03	.03	.03	.03	.00	.00	.00	.00
50578	.05	290	281	.05	.13	.08	.23	.13	.46	.46	.51	.28	.25	.23	.25	.25	.25	.00	.00	.00	.00
50678	.18	293	287	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.53	.53	.53	.46
50778	.08	296	282	.00	.00	.00	.00	.23	.10	.08	.05	.13	.13	.18	.15	.15	.13	.00	.00	.00	.00
50878	.30	298	280	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
50978	.28	298	279	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
51078	.30	300	282	.00	.13	.25	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
51178	.61	307	290	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
51278	.51	306	290	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
51378	.46	300	280	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
51478	.46	306	281	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
51578	.46	306	285	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
51678	.51	303	285	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
51778	.30	298	288	.00	.00	.00	.05	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.25	.00	.00	.00
51878	.20	306	288	1.93	2.31	2.16	.00	.13	.00	.00	.00	.15	.18	.10	.08	.13	.15	.00	.00	.00	.00
51978	.30	306	290	1.12	1.88	1.22	1.02	1.65	.00	1.37	1.07	.00	.00	.00	.00	.00	.00	6.60	6.60	6.07	5.84
52078	.05	305	288	.53	1.68	1.57	2.67	2.08	2.87	2.62	2.49	2.44	2.26	2.21	2.03	2.18	2.31	.63	.63	.61	.61
52178	.05	299	289	.18	.38	.43	4.47	4.67	3.43	1.47	1.93	5.08	4.60	4.32	4.19	4.37	5.21	1.68	2.29	1.70	2.03
52278	.43	303	290	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
52378	.56	304	290	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
52478	.51	304	290	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
52578	.43	304	290	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
52678	.56	304	289	1.52	2.34	2.34	1.78	1.60	2.03	1.88	1.70	1.90	1.90	2.03	1.88	1.90	1.98	1.35	1.50	1.37	1.37
52778	.00	300	288	8.18	11.73	9.17	5.23	7.75	10.62	8.43	8.05	9.83	9.27	9.47	9.27	9.60	9.65	9.78	10.62	9.80	9.91
52878	.00	297	286	.03	.38	.53	.30	.38	.53	.58	.97	.71	.63	.69	.76	.43	.58	.30	.28	.30	.33
52978	.58	301	286	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
53078	.56	304	289	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.10	.08	.10	.10

flightline. A map of the study area (fig. 5) shows the location of each sampling site. Flights were made on May 1, 12, and 30, 1978. All sites were sampled by using the scheme illustrated in figure 2, which involved 8 samples per site.

The land cover varied from almost bare soil to a very dense vegetative cover. Some sites experienced considerable vegetation growth between the first flight and the last flight. The soils and vegetation on each site and for each flight date are presented in table 6.

Along the flightline, the soils, characteristic of those in the Blackland Prairie of Texas, are deep, dense, slowly permeable, montmorillonitic clays with pronounced shrink-swell characteristics. General descriptions are given in table 7.

Gravimetric soil moisture samples were obtained at each site within ± 2 hours of the flight time on each of the three dates. At each location, soil samples of 200 to 1,000 gm were collected from the following depths: 0 to 2.5 cm, 2.5 to 5 cm, 5 to 10 cm, and 10 to 15 cm. Each sample was placed in a plastic bag and sealed for later weighing and analysis. The type and condition of the land cover was recorded at each location. The soil temperature at the 1 cm depth was recorded at selected locations.

The soil samples were weighed on the same day they were obtained. Over the next several days the samples were ovendried, the dry weights obtained, and the gravimetric water contents were computed. After the last flight date, soil bulk density samples were obtained by depths at each site. The bulk density for each site and each depth is given in table 8. The bulk densities were used to convert the gravimetric water contents to volumetric water contents.

Table 9 presents the pan evaporation, daily maximum and minimum temperatures, and the daily rainfall at each gage. The locations of the raingages in the immediate area of the sites are shown in figure 5.

Remote Sensing Systems

The NASA 929 (C-130B) aircraft was the sensor platform used in these experiments. A nominal altitude of 305 m (1,000 ft) and a ground speed of 278 kilometers per hour, kph, (150 knots) were chosen. The systems used were: Color infrared photography, a modular multispectral scanner, a thermal infrared radiometer, multifrequency microwave radiometers,(a passive microwave scanner and multifrequency active microwave scatterometers).

Color infrared photography was obtained by using a Zeiss 23 (9 in) camera with Kodak 2443 film. A 15 cm (6 in) focal length at the specified altitude resulted in a nominal scale of approximately 1:2000 on products. Forward overlap of 10 percent was used.

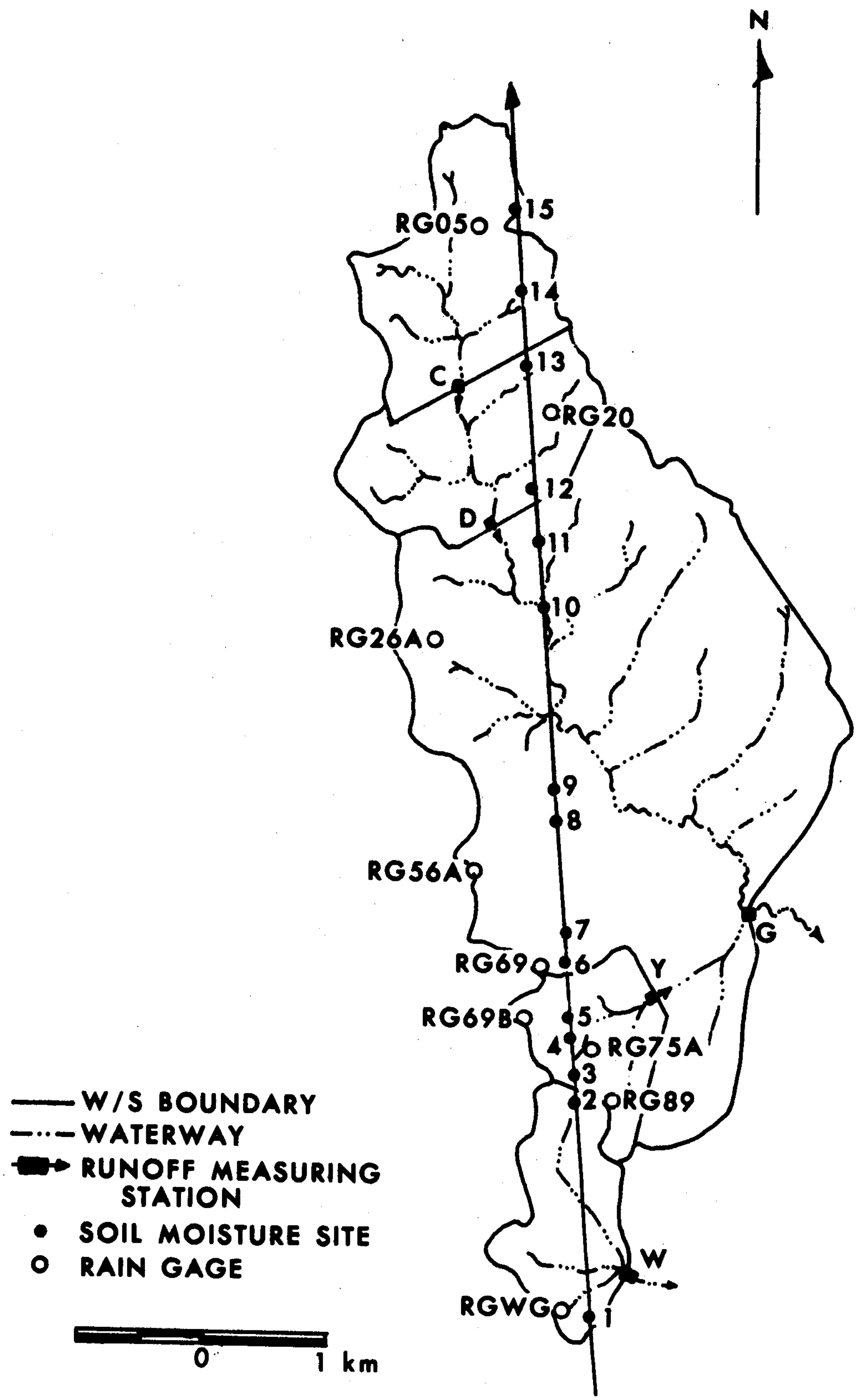


Figure 5.--General location map and soil moisture sampling sites, Riesel, Tex.

Table 6.--Soil type and land cover by site, Riesel, Tex., May 1, 12, and 30, 1978

Site	Soil Type	Land cover on---		
		May 1, 1978	May 12, 1978	May 30, 1978
1	Houston black clay	Bermudagrass, 6 cm high, dense cover	Bermudagrass, 10 to 15 cm high, dense cover	Bermudagrass, 20 cm high, dense cover
2	do.	Hardingrass, 5 cm high, very sparse stand	Hardingrass and Johnsongrass, 5 to 10 cm, very sparse	Hardingrass and Johnsongrass, 30 to 40 cm, sparse stamd
3	do.	Grain sorgham, 15 cm high planted in 90 cm rows	Grain sorgham, 30 cm high	Grain sorgham, 50 to 60 cm high
4	do.	Pasture-Bermudagrass, 10 cm high	Pasture-Bermudagrass, 15 to 20 cm high	Pasture-Bermudagrass, 20 cm high
5	do.	Kliengrass, 30 cm high	Kliengrass, 30 to 60 cm high	Kliengrass, 90 cm high, headed
6	do.	Native grass meadow, 45 cm high, very dense cover	Native grass meadow, 30 to 40 cm high, very dense cover	Native grass meadow, 30 to 50 cm high, very dense cover
7	do.	Oats, 40 cm high, grazed	Oats, 40 to 50 cm high, grazed	Oats, harvested, stubble left
8	do.	Grain sorgham, 15 cm high planted in 90 cm rows	Grain sorgham, 30 to 40 cm high	Grain sorgham, 50 to 60 cm high
9	Houston clay	Pasture-Bermudagrass, heavily grazed, 4 cm high	Pasture-Bermudagrass, heavily grazed, 5 to 10 cm high	Pasture-Bermudagrass, heavily grazed, 5 cm high
10	Catalpa clay	Grass, 20 cm high under a tree canopy near a stream	Grass, 40 to 50 cm high under a tree canopy near a stream	Grass, 40 to 60 cm high under a tree canopy near a stream
11	Wilson clay loam	Corn, 45 cm high	Corn, 70 to 80 cm high	Corn, 150 cm high
12	Burleson Houston clay	Wheat, 90 cm high	Wheat, 90 cm high, maturing	Wheat, 90 cm high, matured
13	do.	Wheat, 50 to 10 cm high, grazed	Wheat, 5 to 15 cm high, grazed	Wheat, 5 cm high, grazed
14	Catalpa clay	Forage sorgham, 15 cm high	Forage sorgham, 20 to 40 cm high	Forage sorgham, 60 to 90 cm high
15	Burleson Houston clay	Pasture, heavily grazed, grass, 15 cm high	Pasture, heavily grazed, grass, 20 cm high	Pasture, heavily grazed, grass, 15 to 30 cm high

Table 7.--Riesel9 Tex., soils descriptions.

Soil type	Depth[1/]	Internal drainage-[2/] and Permeability[3/]	Location[4/]	Available water capacity	Slope	Erosion
					Percent	
Burleson-Houston clay	D	S/VSP	UP	0.05	1 to 3	No
Calalpa clay	MD	M/SP	FP	---	0 to 1	No
Houston Black clay	D	S/MP	UP	.05-.08	1 to 4	No
Houston clay	MD	S/MP	UP	.05-.10	1 to 4	No
Wilson clay loam	D	S/VSP	UP	.05-.10	0 to 1	No

[1/]Depth codes: D=deep, MD=moderately deep.
[2/]Internal drainage codes: S=slow, M=moderate.
[3/]Permeability codes: VSP=very slow, SP=slow, MSP=moderately slow, MP=moderate.
4/Location codes: FP=floodplain, UP=uplands.

Table 8.--Bulk density of soil samples by depth, Riesel, Tex.

Site	Soil samples collected at depth of--			
	0 to 2.5 cm	2.5 to 5 cm	5 to 10 cm	10 to 15 cm
	----Gm/cm³----			
1	1.2	1.4	1.5	1.5
2	1.1	1.4	1.4	1.6
3	1.2	1.5	1.4	1.5
4	1.1	1.3	1.4	1.5
5	1.3	1.4	1.4	1.4
6	1.0	1.2	1.2	1.3
7	1.2	1.2	1.3	1.3
8	1.2	1.5	1.4	1.5
9	1.4	1.4	1.5	1.6
10	1.3	1.3	1.4	1.4
11	1.1	1.4	1.4	1.5
12	1.1	1.2	1.2	1.3
13	1.1	1.2	1.2	1.3
14	1.2	1.4	1.4	1.6
15	1.5	1.7	1.6	1.6

Table 9.—Riesel, Tex., climatological data

DATE	PAN EVAPORATION	DAILY TEMPERATURE MIN	DAILY TEMPERATURE MAX	RAINFALL AT RAINGAGE 5	20	26A	56A	69	69B	75A	89	W6
	--CM--	---DEG K---		--------------------------CM--------------------								
41678	0.71	298	289	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
41778	.74	299	289	- 13	.15	.10	.18	.15	. 15	.25	.20	. 18
41878	.13	298	284	.00	.00	.00	.00	.00	.00	CO	.00	.00
41978	1.04	299	285	.00	.00	.00	.00	.00	.00	.00	.00	.00
42078	.97	295	280	.00	.00	.00	.00	.00	.00	.00	.00	.00
42178	.46	294	281	.00	.00	.00	.00	.00	.00	.00	.00	.00
42278	.94	297	285	.15	.08	.10	.13	.18	.25	.41	.36	.51
42378	.05	295	286	.00	.00	.00	.00	.00	.00	.00	.00	.00
42478	.66	300	288	.05	.15	.25	.25	.20	.15	.23	.20	.10
42578	.13	303	288	.00	.00	.00	.00	.00	.00	.00	.00	.00
42678	1.30	296	281	.00	.00	.00	.00	.00	.00	.00	.00	.00
42778	.43	296	287	.00	.00	.00	.00	.00	.00	.00	.00	.00
42878	1.12	299	285	.00	.00	.00	.00	.00	.00	.00	.00	.00
42978	1.04	300	289	.00	.00	.00	.00	.00	.00	.00	.00	.00
43078	.46	300	292	.00	.00	.00	.00	.00	.00	.00	.00	.00
50178	.66	302	292	.79	.48	.00	.00	.00	.00	.00	.00	.00
50278	.69	301	288	2.01	2.59	2.26	2.18	2.08	1.90	2.57	2.03	2.06
50378	1.27	292	282	.00	.00	.00	.00	.00	.00	.00	.00	.00
50478	.33	289	280	.00	.00	.00	.00	.00	.00	.00	.00	.00
50578	.58	294	281	.00	.00	.00	.00	.00	.00	.00	.00	.00
50678	.89	302	288	.00	.00	.00	.00	.00	.00	.00	.00	.00
50778	.20	299	294	.00	.00	.00	.00	.00	.00	.00	.00	.00
50878	.13	304	291	.00	.00	.00	.00	.00	.00	.00	.00	.00
50978	.58	304	287	.00	.00	.00	.00	.00	.00	.00	.00	.00
51078	.74	302	288	.00	.00	.00	.00	.00	.00	.00	.00	.00
51178	.84	303	291	.28	.20	.18	.71	.46	.36	.38	.30	.20
51278	.58	300	291	.28	.25	.56	.76	.81	.76	.89	.76	.41
51378	1.47	306	286	.00	.46	.81	.00	.00	.00	.00	.00	.00
51478	1.02	300	286	.00	.00	.00	.00	.00	.00	.00	.00	.00
51572	1.09	304	288	.00	.00	.00	.00	.00	.00	.00	.00	.00
51678	1.09	305	291	.00	.00	.00	.00	.00	.00	.00	.00	.00
51778	.94	306	294	.00	.00	.00	.00	.00	.00	.00	.00	.00
51878	.71	304	294	.00	.00	.00	.00	.00	.00	.00	.00	.00
51978	.79	305	294	.00	.00	.00	.00	.00	.00	.00	.00	.00
52078	.97	306	292	2.44	2.59	1.96	2.16	2.08	2.06	2.26	2.11	2.06
52178	.81	302	292	1.04	1.55	1.27	1.27	1.37	1.30	1.65	1.42	1.45
52278	.20	301	292	.00	.00	.00	.00	.00	.00	.00	.00	.00
52378	.74	302	293	.00	.00	.00	.00	.00	.00	.00	.00	.00
52478	.56	304	292	.00	.00	.00	.00	.00	.00	.00	.00	.00
52578	.76	304	292	.51	.30	.00	.00	.00	.00	.00	.00	.00
52678	.79	303	295	.00	.00	.00	.00	.00	.00	.00	.00	.00
52778	1.40	305	294	.00	.00	.00	.00	.00	.00	.00	.00	.00
52878	.76	304	294	.00	.00	.00	.00	.00	.00	.00	.00	.00
52978	.53	304	292	.00	.00	.00	.00	.00	.00	.00	OC	.00
53078	1.19	304	291	.00	.00	.00	.00	.00	.00	.00	OC	.00

The modular multispectral scanner (MMS) used on the NASA 929 senses visible and infrared energy in 11 spectrometer channels or bands (table 10**).** The scanner has a total field of view of 100° and an instantaneous field of view of 2.5 mrad (milliradians) for each band. This system was flown at an altitude of 610 m (2,000 ft) at which the ground resolution element was approximately 5 m (16 ft).

Table 10.--Modular multispectral scanner wavelength bands

Band	Wavelength Low	High	Peak Output
	----------	um	----------
1	0.419	0.456	0.442
2	.458	.500	.481
3	.502	.545	.522
4	.546	.583	.563
5	.584	.621	.598
6	.622	.662	.641
7	.662	.701	.682
8	.703	.747	.727
9	.770	.863	.789
10	.959	1.039	.981
14	8.000	12.080	8.100

Thermal infrared radiometer data were also obtained by using a Barnes precision radiation thermometer (PRT5) with a spectral range from 8 to 14 microns. This is a fixed beam sensor with a field view of 2°. The ground swath width at the flight altitude was 24 m (79 ft).

The multifrequency microwave radiometer (MFMR) is a collection of 5 separate radiometers operating over the frequency range of from 1.414 to 37 GHz. The characteristics of these radiometers are described in table 11. Since the L and C band radiometers shared a rotatable mount in the nose of the aircraft only one was usable at a particular time. They also operate through a dielectric radome which contributes to the calibration problems for these radiometers. The three K band radiometers operate through the open cargo door at the rear of the aircraft. The instruments are basically Dieke radiometers in which the incoming radiation is compared with internal reference sources at known temperatures to obtain the quantitative values of the brightness temperature of the incoming radiation.

The swath widths listed in table 11 are for the 3 dB or half power points of the antenna pattern. This means for the L-Band system at $\pm$ 7.50 off from the beam center the sensitivity is one-half that at the beam center. The first nulls or minimums in the antenna pattern are generally 2.5 times further out producing a beam width between nulls, called the main beam, of 37.5° for

L-Band and 15° for the others. Generally over 90 percent of the energy received by the radiometer comes through the main beam and of that energy 60 to 65 percent is received within the 3 dB points.

Table ll.--Passive microwave sensor systems

System designation	Center frequency	Wavelength	Receiver bandwidth	Antenna beamwidth	Swath width for 305 m altitude: 0° look angle	Swath width for 305 m altitude: 40° look angle
	GHz	Cm	MHz	Degrees	M	M
L band	1.41	21.00	27	15	75	120
C band	5.00	6.00	50	6	30	50
Ku band	18.00	1.67	200	6	30	50
K band	22.00	1.35	200	6	30	50
Ka band	37.00	.81	200	6	30	50

Look angles of 0° and 40° were used for the C, L, and K band radiometers. A forward look angle was used for the C and L bands, and a backward look angle for the K bands. Horizontal and vertical polarization data were collected for the C and K bands and only horizontal polarization data for the L band.

The passive microwave imaging system (PMIS), a scanning radiometer sensing at a 2.8 cm wavelength, consisted of three basic components: a phased array antenna, a beam steering computer, and the microwave receivers for the horizontal and vertical channels. The antenna is a dual polarized, electrically scanned, phased array which consists of 51 linear slotted waveguide sections forming a 109 by 91 cm aperture. The magnitudes of the resulting brightness temperatures are determined by comparison with internal blackbodies at 323 K and 403 K.

The data for the 2.8 cm scanning radiometer were recorded at 44 beam positions for each scan. The scan rate was adjusted to provide contiguous coverage, which for the altitude and velocity of these flights was one scan per second. A backward look angle of approximately 49.2° was used for this sensor. The ground resolution element is approximately 21 by 34 m (69 by 112 ft).

During missions over Oklahoma and Texas, three scatterometers were on the aircraft operating at frequencies listed in table 12. Data for HH and HV polarizations were available. The scatterometer antenna pattern is fan-shaped which covers the 0 range, along the aircraft flight path of approximately 5° to 60° for the radar direction. The scatterometer receives the backscattered signal at all angles of incidence simultaneously. As a result of the aircraft's forward motion, different Doppler frequency shifts are introduced in the return signals for different incidence angles.

Table 12. --Scatterometer frequencies

System designation	Frequency	Wavelength
	GHz	Cm
C band	4.75	6.3
L band	1.60	18.9
P band	.40	74.9

The ground spot sizes of the scattermeter data are processed to approximately 35 m along track using the Doppler information for all three frequencies. The cross-track resolution is mainly based on the beamwidth for each individual instrument. When the aircraft altitude is 450 m the crosstrack spot size is 50 m for the C band, 70 m for the L band, and 110 m for the P band.

Table 13 summarizes the systems and data collected. Additional details on data preparation and processing are presented in the next section.

Table 13.--System run numbers

System	Operating during runs (look angle)
Photography	1,2,3,4,5
PRT5	1,2,3,4,5
L band	2 (0°), 4(40°)
C band	3(0°), 5(40°)
K bands	2(0°), 3(0°), 4(40°), 5(40°)
PMIS	2,3,4,5
Scatterometers	1

DATA AND PROCESSING

Soil Moisture Observations

Gravimetric soil moistures were converted to percent by volume by using the bulk density values. Samples collected within each site at each depth are summarized in table 14. If for some reason remote sensing measurements were not obtained at a site or if they were not reliable, the soil moisture data were not included in table 14.

Table 14.--Soil.moisture observations

		VOLUMETRIC SOIL MOISTURE (%)					
		0 - 2.5 CM DEPTH		2.5 - 5 CM DEPTH		5 - 15 CM DEPTH	
DATE	SITE	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
50178	C3	0.300	0.032	0.260	0.033	0.276	0.032
50178	C4	-306	.045	.272	.035	.280	.038
50178	C5C6	.283	.041	.250	.039	.149	.042
50178	F1	.236	.066	.152	.031	.136	.038
50178	RG83	.274	.055	.237	.027	.220	.033
50178	RG88	.267	.033	.206	.032	.129	.038
50178	R5	.307	.059	.243	.050	.156	.041
50178	R6	.319	.046	.258	.041	.169	.040
50178	R7	.284	.043	.232	.051	.191	.058
50178	P8	.323	.070	.274	.055	.203	.061
50178	TX 3	.240	.093	.349	.069	.386	.030
50178	TX 4	.175	.027	.238	.024	.279	.019
51278	C3	.140	.046	.254	.058	.306	.052
51278	C4	.167	.088	.230	.042	.266	.063
51278	C5C6	.192	.053	.221	.046	.218	.040
51278	F1	.286	.027	.237	.023	.228	.028
51278	F2	.253	.029	.225	.023	.223	.020
51278	RG83	.042	.009	.105	.025	.135	.029
51278	RG88	.115	.047	.165	.030	.208	.048
51278	R5	.220	.068	.194	.042	.201	.027
51278	R6	.226	.068	.202	.029	.210	.017
51278	R7	.184	.036	.219	.044	.250	.031
51278	R8	.189	.076	.218	.043	.248	.040
51278	TX 3	.159	.047	.348	.045	.392	.017
51278	TX 4	.210	.014	.257	.022	.287	.021
51278	TX 8	.239	.021	.343	.034	.367	.029
51278	TX 9	.274	.024	.206	.040	.199	.053
51278	TY10	.280	.056	.222	.057	.208	.053
51278	TX11	.091	.016	.150	.031	.265	.027
51278	TX12	.112	.019	.134	.016	.128	.016
51278	TX13	.114	.011	.152	.013	.178	.019
51278	TX15	.182	.025	.212	.019	.225	.011
53078	C3	.286	.090	.323	.058	.315	.032
53078	C4	.224	.053	.311	.066	.310	.037
53078	C5C6	.334	.086	.347	.067	.356	.066
53078	F1	.537	.079	.424	.065	.348	.053
53078	F2	.509	.043	.382	.036	.331	.025
53078	RG83	.264	.132	.224	.053	.223	.035
53078	RG88	.404	.065	.291	.025	.285	.011
53078	R5	.437	.083	.335	.051	.313	.025
53078	R6	.412	.098	.324	.042	.303	.034
53078	R7	.289	.034	.287	.029	.292	.022
53078	R8	.341	.093	.305	.037	.299	.033
53078	TX 3	.220	.019	.362	.035	.358	.026
53078	TX 4	.142	.016	.214	.011	.253	.010
53078	TX 8	.116	.028	.287	.050	.339	.059
53078	TX 9	.102	.011	.162	.029	.214	.043
53078	TX10	.133	.056	.168	.061	.180	.057
53078	TY11	.047	.021	.136	.035	.199	.035
53078	TX12	.065	.018	.142	.048	.201	.027
53078	TX13	.085	.009	.145	.023	.186	.069
53078	TX15	.157	.029	.214	.027	.214	.017

Table 15.--NERDAS data

SAL LAB(BLD 15) CORRECTED CAMERA CORRELATION 18-APR-79 19:50:42
SCALE 2069.00 ZEISS 1 ROLL 2 LENGTH 6.00 FILM TYPE 2443 FILM SIZE 9.5
COMMENTS WRITTEN ON TAPE : DPAR 379-077-2 TAPE #5279
AIRCRAFT 929 DATE 05/01/78 MISSION 379 SITE 184 FLT 01 LINE 01 RUN 2

TIME	LAT	LONG	ALT	TAS	HDG	DRIFT	ROLL	PITCH	GDS	VTACC	WDS	WD<	DTTG	TTG	CTD	DTK	TRK<	FRAME
18:53:55.5	+34’59.4	-097’55.5	00,960	158	014.2	-03.1	+01.4	-00.2	149	+0.98	013	056	0006.4	002.6	000.5	027.5	-000.3	136
18:54:00.5	+34’59.6	-097’55.4	00,980	159	014.2	-02.8	-01.7	+00.2	150	+0.98	012	051	0006.3	002.5	000.5	027.5	+000.4	137
18:54:05.5	+34’59.9	-097’55.3	00,980	159	012.6	-02.2	-02.6	+00.1	150	+1.17	012	044	0006.1	002.4	000.5	027.5	-000.5	138
18:54:10.5	+35’00.0	-097’55.3	00,980	159	012.1	-02.0	+00.5	+00.1	150	+0.98	012	046	0005.8	002.3	000.4	027.5	-001.6	139
18:54:15.5	+35’00.1	-097’55.2	01,020	159	012.0	-02.9	-00.9	-00.3	151	+1.19	013	050	0005.6	002.2	000.3	027.5	-001.8	140
18:54:20.5	+35’00.4	-097’55.2	01,050	159	013.4	-03.3	+01.3	+00.5	152	+1.19	013	062	0005.4	002.2	000.4	027.5	-001.6	141
18:54:25.5	+35’00.6	-097’55.2	01,040	161	012.3	-02.4	+00.2	+00.4	151	+1.19	011	041	0005.1	002.0	000.4	027.5	-000.7	142
18:54:30.5	+35’00.9	-097’55.1	01,050	161	011.7	-00.8	+00.2	+00.4	150	+1.16	012	025	0005.0	002.0	000.5	027.5	-000.6	143
18:54:35.5	+35’01.1	-097’55.1	01 060	160	012.7	-01.8	+03.7	-00.2	150	+1.19	013	036	0004.8	001.9	000.4	027.5	-000.5	144
18:54:40.6	+35’01.3	-097’55.1	01,050	159	016.0	-03.4	-00.7	+00.2	150	+1.13	015	054	0004.6	001.8	000.5	027.5	+001.3	145
18:54:45.6	+35’01.5	-097’54.8	01,040	160	013.8	-02.1	-00.6	+01.1	149	+0.95	014	037	0004.3	001.8	000.3	027.5	+000.7	146
18:54:50.6	+35’01.6	-097’55.3	01,040	158	014.2	-03.1	-05.1	+00.5	148	+0.91	016	050	0004.2	001.7	000.5	027.5	+000.0	147
18:54:55.6	+35’01.9	-097’54.8	01,040	159	011.6	-01.9	+02.6	+00.9	149	+1.10	012	035	0004.0	001.6	000.4	027.5	-001.5	148
18:55:00.6	+35’02.1	-097’54.7	01,060	159	011.9	-01.9	-00.7	+00.2	147	+0.79	013	031	0003.7	001.5	000.5	027.5	-001.0	149
18:55:05.6	+35’02.3	-097’54.7	01,070	160	011.7	-02.8	-01.0	-00.1	148	+1.16	014	037	0003.5	001.4	000.5	027.5	-001.5	150
18:55:10.6	+35’02.6	-097’54.7	01,060	159	012.1	-02.9	+01.5	-00.2	149	+0.98	013	046	0003.2	001.3	000.5	027.5	-002.0	151
18:55:15.5	+35’02.7	-097’54.7	01,060	159	012.0	-02.3	+01.0	+00.1	149	+1.14	013	042	0003.2	001.3	000.5	027.5	-001.4	152
18:55:20.6	+35’02.9	-097’54.6	01,050	159	012.3	-02.0	+01.7	+00.2	150	+0.98	012	039	0003.0	001.2	000.4	027.5	-001.0	153
18:55:25.6	+35’03.2	-097’54.6	01,050	159	013.5	-02.5	+00.5	+00.6	150	+0.95	012	050	0002.8	001.1	000.5	027.5	+000.0	154
18:55:30.6	+35’03.3	-097’54.5	01,040	158	013.5	-01.8	+00.8	+00.3	149	+0.95	013	040	0002.4	001.8	000.4	027.5	+000.6	155

Remote Sensing Data

Five runs were made on each of the flightlines on May 1, 1978. On May 12 and May 30, 1978, only runs 2 and 4 were made on flightline 6 at Chickasha, Okla. The aircraft encountered several problems in locating some sites; consequently, no remote sensing data were obtained. Also, errors in judgment on the selection of test sites resulted in the deletion of sites.

All data were preprocessed by the NASA Johnson Space Center and supplied to the NASA Goddard Space Flight Center and the USDA-SEA-AR Hydrology Laboratory for further processing. An important part of this additional processing was the time location of sensor coverage of each site. This was done by using the Navigational Engineering Recording Data Analysis System (NERDAS) data which related photo center times to instrument recording times. An example of the NERDAS data is shown in table 15. By locating the field or site boundaries on the photos, the start and stop times of sensor coverage were determined. This section describes the procedures used for time locating each sensor system and presents the sensor data.

Color infrared photography

NERDAS data included the frame center time for each photo as well as distortion parameters, altitude and ground speed. Although constant altitude and ground speed and zero distortion were desired, there were variations. Distortions were considered minor and no correction was made for these. Photo scales for the 23 cm (9 in) products for various altitudes are listed in table 16.

Table 16.--Photo scale-altitude relationships

Altitude	Scale
M	
245	1:1600
275	1:1800
305	1:2000
335	1:2200
365	1:2400

Modular multispectral scanner

The modular multispectial scanner (MMS) was operated only on May 30, 1978, over flightlines 1 and 3 at Chickasha, Okla. at an altitude of 610 m (2,000 ft). Raw data were only processed for flightline 1. Gray scale imagery for each of the channels is shown in figure 6.

Thermal Infrared radiometer

Data collected by the precision thermal radiometer (PRT5) sensor were averaged for the time frames of sensor coverage. In most cases several sets of data collected during different runs were averaged for each site. Table 17 lists temperatures and soil temperatures measured by the ground observers in the top 2.5 cm (1 in).

K band radiometers

Data obtained at 0° can be related to the photos by using the photo center times, altitudes, and ground speeds listed on the NERDAS printout, not the photo clock times. To determine the time frame of 0° coverage of a particular line-run-site-day combination, the NERDAS printout for the line, run and day is used to identify the film roll. The frames that cover the site are then located and the photo distance from the starting photo center to the beginning of the site is measured. Next, the distance from the last photo center to the end of the site is measured. Distances measured in the flight direction are positive and distances in the opposite direction are negative.

Photo center times of the first and last coverage frames as well as the altitude and ground speed are determined. For each of the frames the ground speed in meters per second is computed. Next, the scale of each photo is determined. This is the conversion from centimeters to meters and is computed by dividing the altitude in meters by the focal length in centimeters. In this case the focal length is 15.25 cm (6 in).

The start and stop times are then determined by multiplying the scale factor in m/cm by the distance in centimeters measured off the photo and then dividing by the ground speed in m/sec. This correction is applied to the photo center time. Typical values are listed in table 18.

In order to use the 40° look angle data, a time correction must be applied to the start and stop-degree times determined following the zero-degree procedure. This is necessary because the sensor covers the location on a photo after the camera does. The system geometry is shown in figure 7, A. The distance behind the NASA 929 plane is called S and depends on the altitude (H) as described in the following equation:

$$S = 0.8391 * H$$

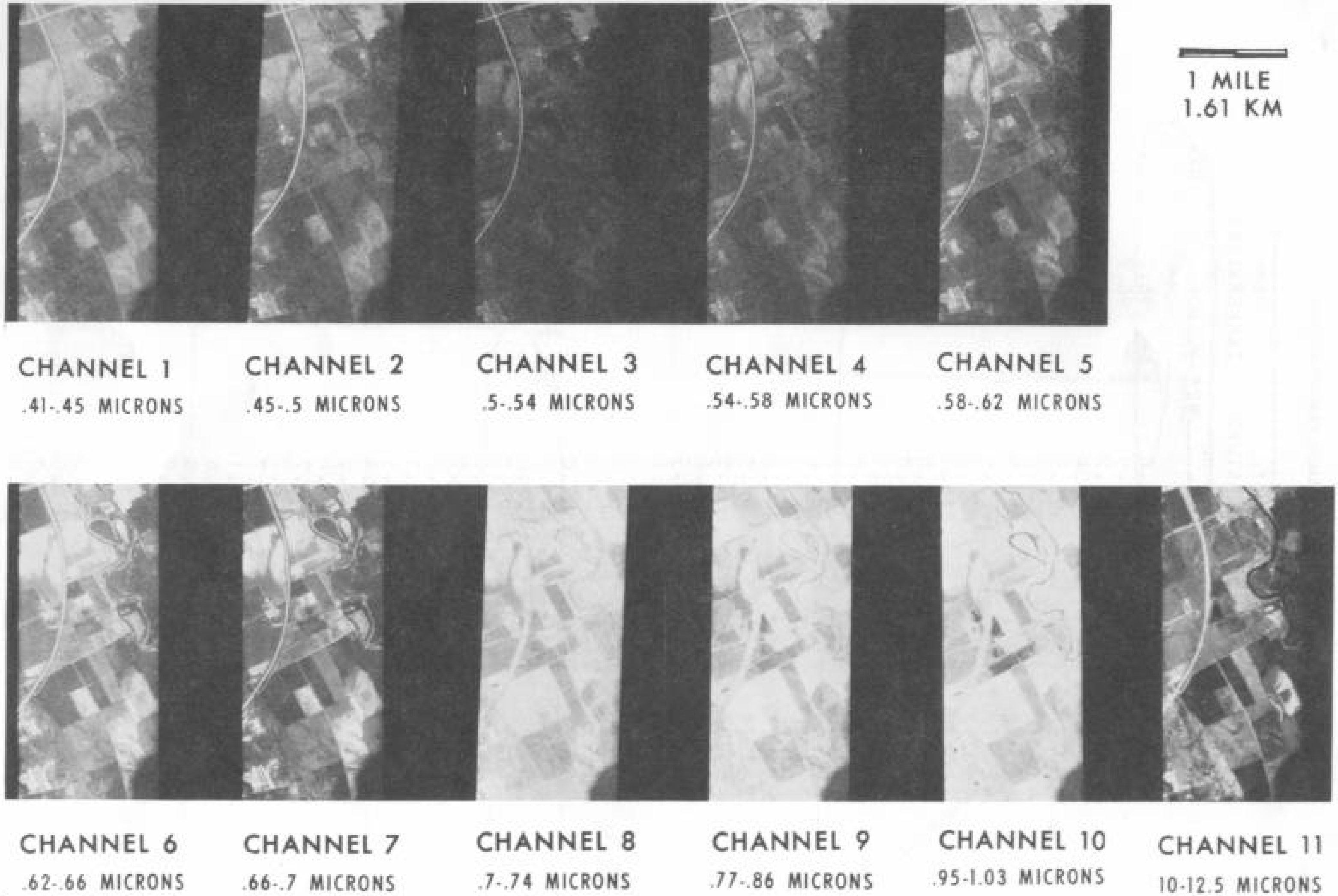


Figure 6.--Multispectral scanner imagery, Chickasha, Okla., flightline 1, May 30, 1978.

Table 17.--Temperature observations

DATE	SITE	SOIL TEMPERATURE	PRT5 TEMPERATURE
		-----DEG K-----	
50178	C3	293.6	296.7
50178	C4	291.9	296.8
50178	C5C6	296.2	295.2
50178	F1	290.9	289.5
50178	RG83	295.5	291.6
50178	RG88	300.2	294.9
50178	R5	293.4	298.3
50178	P6	295.4	298.7
50178	R7	295.3	294.6
50178	R8	295.1	294.5
50178	TX 3	300.0	---
50178	TX 4	291.0	---
51278	C3	296.9	299.0
51278	C4	296.8	300.2
51278	C5C6	294.7	296.0
51278	F1	292.4	---
51278	F2	293.6	---
51278	FG83	295.8	299.0
51278	RG88	298.7	299.4
51278	R5	294.5	301.6
51278	R6	295.6	302.0
51278	F7	297.3	300.5
51278	R8	295.8	301.4
51278	TX 3	307.0	313.3
51278	TX 4	307.0	313.0
51278	TX 8	307.0	310.9
51278	TX 9	307.0	307.6
51278	TX10	307.0	309.0
51278	TX11	307.0	309.7
51278	TX12	307.0	309.6
51278	TX13	307.0	311.2
51278	TX15	307.0	311.3
53078	C3	302.8	302.0
53078	C4	302.1	303.6
53078	C5C6	304.5	306.6
5307B	F1	297.4	301.9
53078	F2	297.6	302.5
53078	RG83	302.4	300.3
53078	RG88	304.7	300.3
53078	R5	302.2	305.1
53078	R6	301.7	305.5
53078	R7	304.1	305.9
53078	R8	302.6	305.1
53078	Tx 3	307.0	309.4
53078	TX 4	304.0	314.0
53078	TX 8	307.0	309.6
53078	TX 9	304.0	314.6
53078	TX10	300.0	309.5
53078	TX11	300.0	310.4
53078	TX12	304.0	314.9
53078	TX13	300.0	314.9
53078	TX15	300.0	314.0

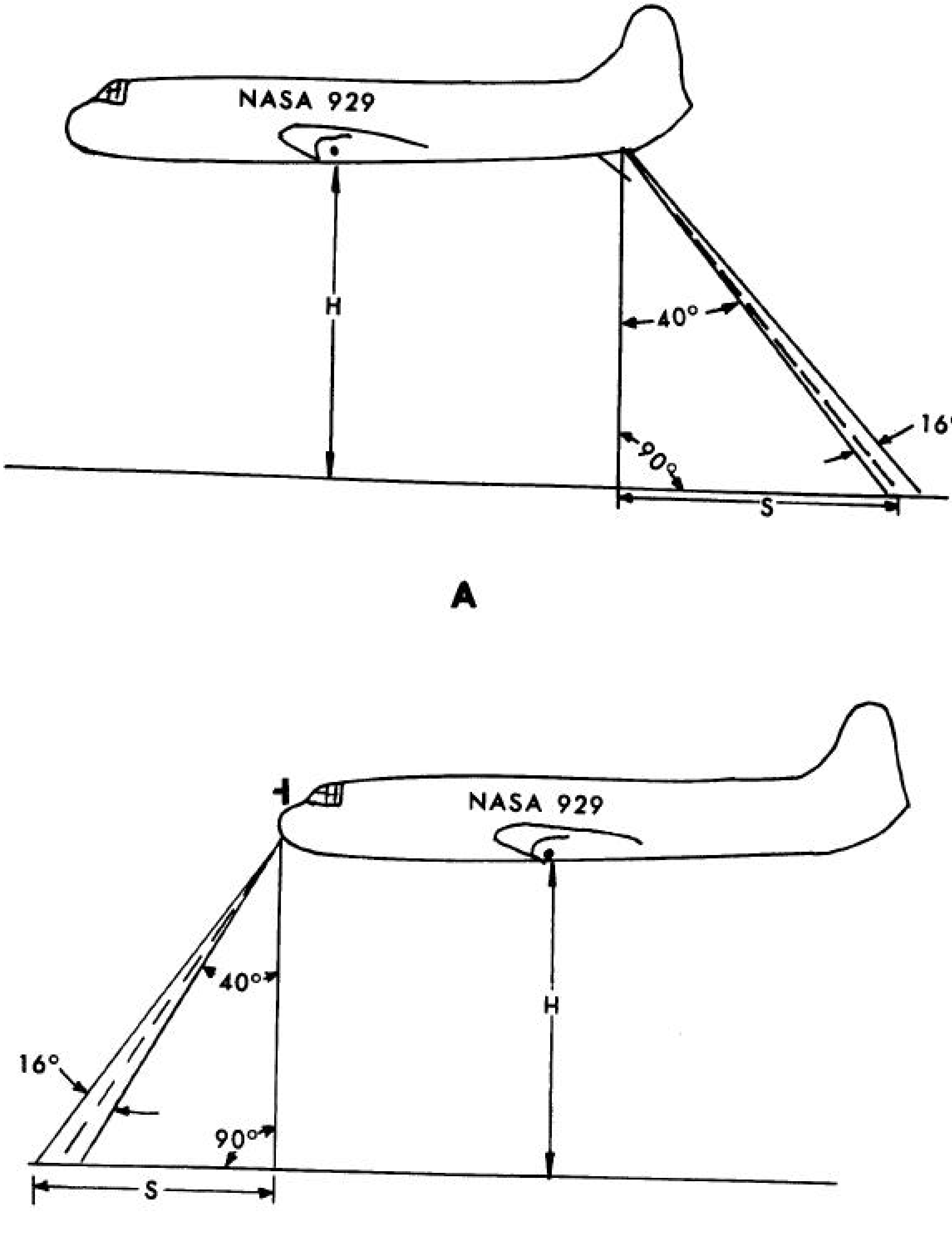


Figure 7.--Radiometer 40 degree look angle geometry: A, K band; B, C and L bands.

Table 18.--Time corrections for correlation of NERDAS and camera time data at O-degree look angles

Altitude	Time correction factors for ground speeds				
	224 kph	245 kph	261 kph	280 kph	299 kph
M	Sec/cm				
245	0.26	0.24	0.22	0.21	0.19
275	.29	.27	.25	.23	.22
305	.32	.30	.28	.26	.24
335	.36	.33	.31	.28	.27
365	.39	.36	.33	.31	.29

The time correction ΔT is computed by using S and the plane's ground speed as follows:

$$\Delta T = S(m) / (G \left(\frac{km}{hr} \right) * 1000 \left(\frac{m}{km} \right) * \frac{1}{3600} \left(\frac{sec}{hr} \right)) \qquad (2)$$

Typical values are listed in table 19. The correction is added to the NERDAS determined start and stop times. Average radiometer brightness temperatures and standard deviations for each site are obtained using a NASA program. Site average brightness temperatures for the K-band are listed in tables 20,21,and 22.

Table 19.--Time corrections for 40° look angles

Altitude	S	Time corrections for ground speeds				
		205 kph	224 kph	243 kph	280 kph	299 kph
M	M	Sec				
245	205	3.62	3.32	3.06	2.84	2.65
275	230	4.07	3.73	3.44	3.20	2.98
305	256	4.52	4.15	3.83	3.55	3.32
335	282	4.97	4.56	4.21	3.91	3.65
365	307	5.43	4.97	4.59	4.26	3.98

Table 20. -- Ka band radiometer data

DATE	SITE	BRIGHTNESS TEMPERATURES 0 DEG LOOK ANGLE HORIZONTAL POLARIZATION	0 DEG LOOK ANGLE VERTICAL POLARIZATION	40 DEG LOOK ANGLE HORIZONTAL POLARIZATION	40 DEG LOOK ANGLE VERTICAL POLARIZATION
		DEG K			
50178	C3	275.2	274.4	275.6	279.7
50178	C4	276.3	277.0	-	-
50178	C5C6	288.2	286.9	290.4	291.3
50178	F1	285.1	283.7	286.8	289.2
50178	RG83	279.4	278.0	278.2	282.6
50178	RG88	278.7	277.7	-	-
50178	R5	289.9	289.4	291.4	291.9
50178	R6	287.6	288.2	288.4	290.4
50178	R7	280.3	278.2	283.6	287.3
50178	R8	279.4	278.7	282.1	286.3
50178	TX 3	301.9	301.6	296.6	299.1
50178	TX 4	300.2	301.8	303.7	305.7
51278	C3	285.8	295.6	284.7	290.9
51278	C4	283.2	281.8	-	-
51278	C5C6	289.5	288.8	292.8	293.7
51278	F1	291.6	291.1	293.5	293.8
51278	F2	294.0	292.5	294.8	295.5
51278	RG83	286.8	287.0	-	-
51278	RG88	290.6	290.4	-	-
51278	R5	295.9	293.8	296.4	296.3
51278	R6	292.7	292.3	294.8	295.1
51278	R7	291.2	291.1	-	-
51278	R8	290.8	292.1	292.0	294.9
51278	TX 3	298.3	298.3	298.1	302.4
51278	TX 4	303.9	302.7	304.8	305.2
51278	TX 8	299.2	298.3	296.7	300.2
51278	TX 9	299.4	299.2	300.0	301.1
51278	TX 10	296.3	295.7	300.7	300.2
51278	TX 11	297.8	295.8	300.6	301.8
51278	TX 12	304.6	303.3	307.0	307.2
51278	TX 13	303.0	302.2	302.7	305.1
51278	TX 15	304.0	303.5	304.8	306.3
53078	C3	-	-	-	-
53078	C4	-	-	-	-
53078	C5C6	293.1	292.5	295.6	303.3
53078	F1	297.0	295.9	297.6	297.3
53078	F2	298.1	296.9	298.9	299.2
53078	RG83	289.5	289.0	-	-
53078	RG88	294.7	294.4	-	-
53078	R5	298.1	298.0	300.3	301.5
53078	R6	296.4	295.8	298.7	302.2
53078	R7	293.2	293.0	297.9	301.3
53078	R8	291.9	291.6	294.3	297.8
53078	TX 3	299.1	298.7	297.1	300.0
53078	TX 4	308.6	308.1	311.6	309.8
53078	TX 8	297.6	296.7	292.7	294.6
53078	TX 9	309.7	309.6	311.6	312.9
53078	TX 10	301.6	299.7	303.9	303.4
53078	TX 11	295.4	294.8	290.5	293.5
53078	TX 12	304.0	302.7	307.5	308.8
53078	TX 13	310.1	308.3	311.7	313.1
53078	TX 15	310.2	310.8	311.3	311.9

Table 21.-- K band radiometer data

DATE	SITE	BRIGHTNESS TEMPERATURE 0 DEG LOOK ANGLE HORIZONTAL POLARIZATION	BRIGHTNESS TEMPERATURE 0 DEG LOOK ANGLE VERTICAL POLARIZATION	BRIGHTNESS TEMPERATURE 40 DEG LOOK ANGLE HORIZONTAL POLARIZATION	BRIGHTNESS TEMPERATURE 40 DEG LOOK ANGLE VERTICAL POLARIZATION
		---DEG K---			
50178	C3	272.6	274.2	273.0	280.0
50178	C4	275.2	277.7	-	-
50178	C5C6	287.2	288.7	288.4	292.2
50178	F1	282.4	283.8	285.0	287.6
50178	RG83	276.3	276.9	272.6	282.4
50178	RG88	276.6	277.2	-	-
50178	R5	286.6	288.3	286.6	292.0
50178	R6	283.6	285.3	282.3	289.3
50178	R7	274.6	276.2	278.7	286.9
50178	R8	273.6	275.5	276.9	286.0
50178	TX 3	299.9	300.9	296.1	298.0
50178	TX 4	298.5	301.9	301.6	305.5
51278	C3	284.7	285.5	283.4	291.1
51278	C4	280.0	282.8	-	-
51278	C5C6	288.5	290.2	290.6	295.0
51278	F1	289.8	291.8	291.1	294.1
51278	F2	291.5	293.0	293.7	296.1
51278	RG83	287.8	289.2	-	-
51278	RG88	289.6	290.2	-	-
51278	R5	294.7	295.7	294.3	296.6
51278	R6	292.0	293.9	292.1	295.4
51278	R7	289.9	292.2	-	-
51278	R8	290.5	292.4	290.3	295.5
51278	TX 3	297.0	297.1	294.9	302.3
51278	TX 4	300.6	301.9	301.9	305.1
51278	TX 8	296.1	297.3	292.9	300.9
51278	TX 9	297.2	299.6	296.9	301.5
51278	TX 10	295.6	297.6	298.1	301.3
51278	TX 11	296.7	298.2	297.8	304.5
51278	TX 12	301.7	303.8	304.7	307.0
51278	TX 13	300.3	302.5	299.3	305.6
51278	TX 15	300.9	303.0	301.1	306.2
53078	C3	-	-	-	-
53078	C4	-	-	-	-
53078	C5C6	289.0	289.6	288.0	295.8
53078	F1	291.7	292.9	293.0	294.7
53078	F2	291.6	292.8	293.0	295.3
53078	RG83	282.8	282.4	-	-
53078	RG88	289.0	289.6	-	-
53078	R5	290.9	292.8	293.3	296.8
53078	R6	288.0	288.7	292.6	298.1
53078	R7	286.2	287.6	289.8	296.9
53078	R8	283.8	285.5	285.5	294.7
53078	TX 3	295.3	296.5	293.5	299.6
53078	TX 4	301.6	304.0	305.3	307.7
53078	TX 8	294.2	295.4	290.1	295.1
53078	TX 9	303.9	305.9	304.4	309.2
53078	TX 10	297.1	299.3	298.3	301.0
53078	TX11	293.8	295.1	287.9	294.4
53078	TX12	298.7	300.6	300.6	306.1
53078	TX13	304.7	304.6	304.6	309.5
53078	TX 15	304.1	306.4	304.6	309.7

Table 22.--Ku band radiometer data

DATE	SITE	BRIGHTNESS TEMPERATURE 0 DEG LOOK ANGLE HORIZONTAL POLARIZATION	0 DEG LOOK ANGLE VERTICAL POLARIZATION	40 DEG LOOK ANGLE HORIZONTAL POLARIZATION	40 DEG LOOK ANGLE VERTICAL POLARIZATION
		DEG K			
50178	C3	261.5	262.3	263.2	272.0
50178	C4	264.5	265.3	-	-
50178	C5C6	279.2	280.0	282.6	286.7
50178	F1	275.0	276.6	280.2	284.4
50178	RG83	265.4	265.6	261.5	273.1
50178	RG88	263.6	264.2	-	-
50178	R5	276.6	277.6	280.4	285.8
50178	R6	272.8	273.8	273.6	282.7
50178	R7	262.3	263.4	267.5	279.1
50178	R8	261.2	262.2	265.5	277.4
50178	TX 3	291.7	293.8	289.8	293.3
50178	TX 4	291.6	295.4	295.0	298.4
51278	C3	275.0	275.5	275.9	285.3
51278	C4	272.9	273.4	-	-
51278	C5C6	281.4	282.0	286.3	289.8
51278	F1	283.1	283.4	286.3	289.6
51278	F2	284.8	284.6	289.0	291.1
51278	RG83	277.6	278.3	-	-
51278	RG88	279.7	281.1	-	-
51278	R5	285.3	285.9	288.4	291.6
51278	R6	282.8	282.3	287.9	290.8
51278	R7	282.0	282.2	-	-
51278	R8	282.4	283.1	284.1	290.7
51278	TX 3	285.6	285.8	286.7	295.3
51278	TX 4	290.5	291.8	294.4	299.1
51278	TX 8	285.8	285.7	285.1	293.7
51278	TX 9	288.5	289.6	290.7	296.3
51278	TX 10	287.8	288.4	293.1	296.3
51278	TX 11	287.5	288.9	291.0	297.6
51278	TX 12	294.8	294.5	299.5	301.9
51278	TX 13	292.1	292.5	292.9	298.3
51278	TX 15	293.2	292.9	295.0	300.6
53078	C3	-	-	-	-
53078	C4	-	-	-	-
53078	C5C6	-	-	-	-
53078	F1	-	-	-	-
53078	F2	-	-	-	-
53078	RG83	-	-	-	-
53078	RG88	-	-	-	-
53078	R5	-	-	-	-
53078	R6	-	-	-	-
53078	R7	-	-	-	-
53078	R8	-	-	-	-
53078	TX 3	-	-	-	-
53078	TX 4	-	-	-	-
53078	TX 8	-	-	-	-
53078	TX 9	-	-	-	-
53078	TX 10	-	-	-	-
53078	TX11	-	-	-	-
53078	TX12	-	-	-	-
53078	TX13	-	-	-	-
53078	TX 15	-	-	-	-

C and L band radiometers

These systems were mounted in the nose of the aircraft. Each was used at 0° and 40° forward look angles. The system geometry at the 40° angle is shown in figure 7, B.

Data preparation procedures are similar to those described for the K band system. Equation 1 is used to determine S and equation 2 is used to estimate ΔT as was done for the 40° K band data. However, in this case, the time correction is subtracted from the NERDAS determined zero degrees start and stop times since the sensor covers the spot before the plane does.

Typical values for S and ΔT are listed in table 19 and data are prepared in the same manner as described for the K bands. C and L band site averages and variances are listed in tables 23 and 24.

Passive microwave Imaging system

As shown in figure 8, A, the passive microwave imaging system (PMIS) sensor points out of the back of the aircraft at an angle of approximately 49.2°. The sensor scans 33.2° on each side of the aircraft moving from left to right. Data are recorded for overlapping spots as (figure 8, B). To define the factors illustrated in figure 8, A and B, geometric relationships can be used. Table 25 also lists some typical values for these factors.

Time Correction.--The distance between the plane and the sensor beam position (S) can be used in conjunction with the ground speed of the aircraft (G) to compute the time which elapsed between the time the plane passed over a ground location and the time at which the scanner beam did (ΔT). Equation 2 is used for this computation.

A photo center can be located on a PMIS printout by adding ΔT to the NERDAS time of the photo center. For example, suppose that photo frame 140 of the line described on the NERDAS list shown in table 15 was involved. From this printout the value of H is approximately 1,020 ft (311 m) and G is approximately 151 knots (280 kph) After conversion to metric and using the typical values illustrated in table 25, the value ΔT is approximately 4.6 second. This is added to the photo center time of 18:54:15.5 to obtain the sensor coverage time of 18:54:20.1.

To locate an experimental site, the procedure for identifying the start and stop times followed for zero degrees is used. Then, the H and G values of the relevant photos are used to determine ΔT and to correct the start and stop times.

Table 23.--C band radiometer data

DATE	SITE	BRIGHTNESS TEMPERATURE			
		0 DEG LOOK ANGLE		40 DEG LOOK ANGLE	
		HORIZONTAL POLARIZATION	VERTICAL POLARIZATION	HORIZONTAL POLARIZATION	VERTICAL POLARIZATION
		---------------------------------DEG K	---------------------------------DEG K	---------------------------------DEG K	---------------------------------DEG K
50178	C3	258.5	261.6	248.6	256.9
50178	C4	264.0	264.9	253.5	261.5
50178	C5C6	275.0	275.3	263.3	267.5
50178	F1	278.4	282.0	-	-
50178	RG83	256.9	259.1	228.3	246.5
50178	RG88	-	-	-	-
50178	R5	261.2	261.3	243.0	258.4
50178	R6	250.8	252.2	236.3	253.8
50178	R7	240.2	244.3	227.2	250.5
50178	R8	240.4	244.8	228.5	248.6
50178	TX 3	-	-	279.8	284.2
50178	TX 4	-	-	283.0	283.8
51278	C3	277.7	280.5	268.9	272.7
51278	C4	276.1	273.7	263.4	271.6
51278	C5C6	280.9	281.6	272.4	274.5
51278	F1	281.7	285.3	271.3	275.8
51278	F2	282.1	285.2	273.2	278.2
51278	RG83	276.8	278.0	-	-
51278	RG88	275.0	277.6	-	-
51278	R5	281.7	284.4	-	-
51278	R6	276.8	280.1	268.4	274.5
51278	R7	279.1	282.7	-	-
51278	R8	280.8	283.0	269.2	277.3
51278	TX 3	293.5	291.4	278.5	285.1
51278	TX 4	290.9	294.7	281.4	285.3
51278	TX 8	291.2	294.0	276.9	281.2
51278	TX 9	282.3	286.1	270.6	279.5
51278	TX 10	284.9	287.6	278.5	280.1
51278	TX 11	293.1	297.5	285.8	287.2
51278	TX 12	292.0	295.1	280.1	285.5
51278	TX 13	290.8	297.4	283.6	286.9
51278	TX 15	291.2	294.3	278.8	285.8
53078	C3	-	-	-	-
53078	C4	-	-	-	-
53078	C5C6	254.8	250.9	240.9	260.1
53078	F1	275.1	279.3	268.1	275.4
53078	F2	276.5	278.6	268.6	275.7
53078	RG83	-	-	-	-
53078	RG88	-	-	-	-
53078	R5	258.5	261.9	246.8	265.4
53078	R6	249.1	252.5	238.3	259.8
53078	R7	257.4	262.7	238.9	262.9
53078	R8	251.5	255.3	239.9	259.2
53078	TX 3	294.3	297.1	281.8	285.8
53078	TX 4	298.3	302.3	288.0	290.4
53078	TX 8	292.3	294.8	283.4	284.9
53078	TX 9	299.0	301.7	287.2	290.4
53078	TX 10	295.2	297.6	284.8	281.9
53078	TX11	293.9	296.4	282.3	283.2
53078	TX12	294.6	298.2	282.2	285.8
53078	TX13	296.4	298.4	282.5	289.1
53078	TX 15	297.4	301.0	283.1	288.6

Table 24.-- L band radiometer data, horizontal polarization

DATE	SITE	BRIGHTNESS TEMPERATURES O DEG LOOK ANGLE	BRIGHTNESS TEMPERATURES 40 DEG LOOK ANGLE
		DEG K	DEG K
50178	C3	250.9	224.3
50178	C4	250.3	221.3
50178	C5C6	250.0	221.4
50178	F1	252.1	227.7
50178	RG83	226.6	201.8
50178	RG88	229.9	
50178	R5	234.9	201.4
50178	R6	226.3	192.4
50178	R7	226.8	198.9
50178	R8	237.0	-
50178	TX 3	279.7	250.0
50178	TX 4	-	-
51278	C3	271.5	243.6
51278	C4	271.9	235.4
5127B	C5C6	262.2	230.5
51278	F1	250.7	214.8
51278	F2	250.6	221.4
51278	RG83	256.4	-
51278	RG88	248.7	-
51278	R5	248.5	212.2
51278	R6	245.6	210.6
51278	R7	257.4	-
5127B	R8	-	227.8
51278	TX 3	277.0	241.9
51278	TX 4	265.5	226.0
51278	TX 8	256.6	220.3
51278	TX 9	245.0	208.6
51278	TX10	259.8	236.2
51278	TX11	264.8	233.8
51278	TX12	255.8	220.8
51278	TX13	257.3	228.1
51278	TX15	260.8	227.0
53078	C3		-
53078	C4	-	-
53078	C5C6	229.2	189.7
53078	F1	231.0	202.2
5307?	F2	235.2	208.6
53078	RG83	236.4	
53078	RG88	223.3	-
53078	R5	222.1	192.0
53078	R6	224.1	-
53078	R7	226.0	198.2
53078	R8	233.5	205.4
53078	TX 3	289.5	258.4
53078	TX 4	283.3	252.6
53078	TX 8	292.1	265.1
53078	TX 9	288.0	255.2
53078	TX10	285.5	263.3
53078	TX11	294.4	265.6
53078	TX12	277.7	248.4
53078	TX13	278.0	247.7
53078	TX15	279.1	240.8

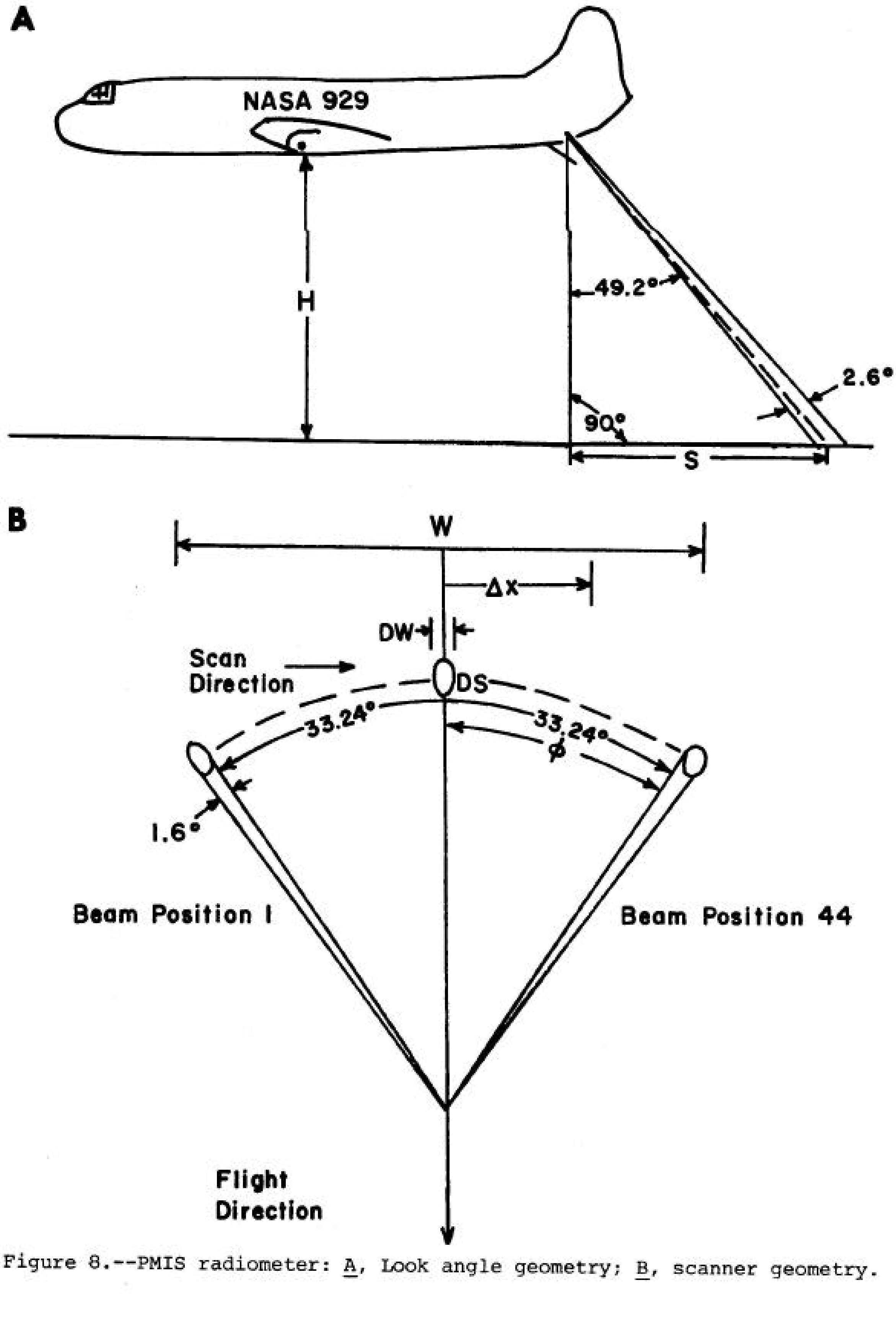


Figure 8.--PMIS radiometer: A, Look angle geometry; B, scanner geometry.

Table 25.--Geometric relationships and time corrections for PMIS data

Altitude	Geometric relationship [1/] S	W	DS	DW	Time corrections for ground speeds 224 kph	243 kph	261 kph	280 kph	299 kph
	M				Seconds				
245	283	322	27	16	4.58	4.23	3.93	3.67	3.44
275	318	362	31	19	5.16	4.76	4.42	4.13	3.87
305	354	402	34	21	5.73	5.29	4.91	4.58	4.30
335	389	443	37	23	6.30	5.82	5.40	5.04	4.73
365	425	513	41	25	6.88	6.35	5.89	5.50	5.16

[1/] S = 1.116 H, W = 1.319 H, DS = 0.111 H, DW = 0.068 H.

Geometric correction.--PMIS data can be used to generate an alphanumeric character map by assigning different characters to brightness temperature intervals. However, in order to use the data for locating fields or watersheds certain geometric distortions must be corrected. In the direction perpendicular to the flightline, one distortion is caused by the data recorded on a conical beam (fig. 9), as a line consisting of 44 elements that overlap. The true ground locations of a stationary aircraft scan are illustrated in figure 9 as the solid line. To determine how far any conical beam position center is displaced from the chord, the following equation is used:

$$DYS = S*\cos(33.24 - 1.51*BP) - S*\cos\Phi \qquad (3)$$

$$= 1.16*H \cos(33.24 - 1.51*BP) - 0.97*H$$

where BP is the beam position number and V is the ground speed in metrics per second.

A second correction must be applied since a scan takes 1 second during which time the aircraft is in motion. After 1 second the plane would be in a new beam position 44 with an equivalent swath shown as the dashed line in figure 9. This correction is computed straight from ground speed and beam position time. By using the following equation, the displacement is computed:

$$DYP = V*\ BP/44 \qquad (4)$$

The net displacement along the flightline at a beam position J on scan line I is computed as follows:

$$Y(I,J) = Y(I,l) - DYS(I,J) + DYP(I,J) \qquad (5)$$

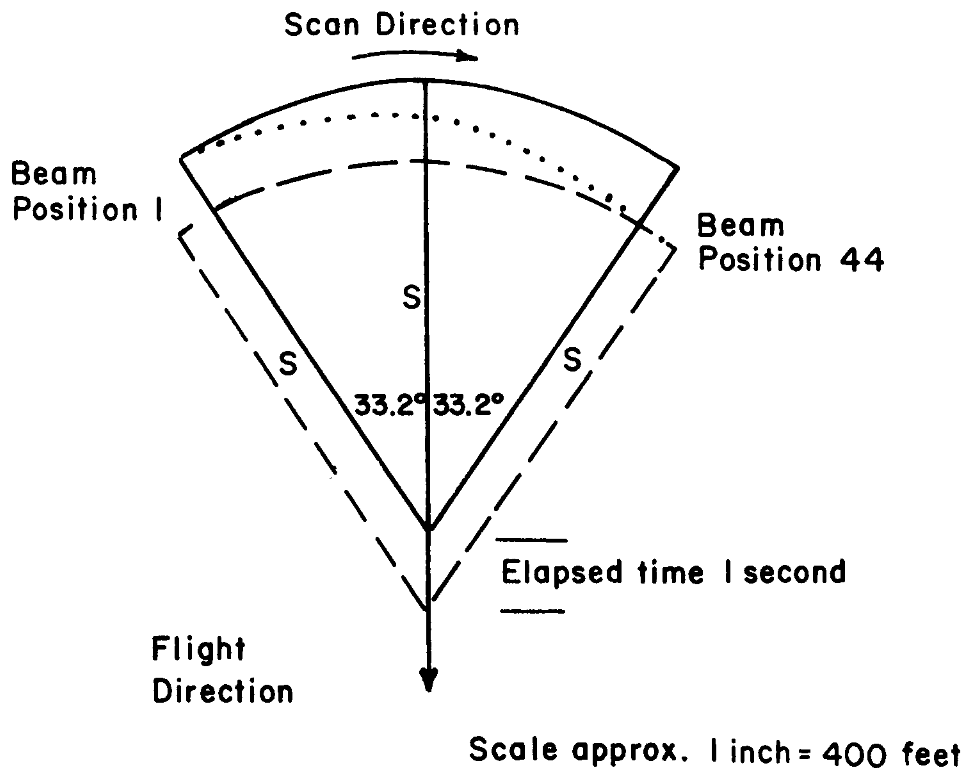


Figure 9.--PMIS radiometer beam position locations.

As an example, for beam position J = 44 at an altitude of H = 305 m and G = 224 kph.

$$Y(I,44) = Y(I,1) - 0 + 61 = Y(I,I) = 61 \qquad (6)$$

Adjustment for the overlap of beam positions across each scan line is also necessary to produce a useful character map. One adjustment is the determining of the center location of each beam position and using this for mapping. This can be done by dividing the swath width by the number of beam positions to determine the distance between centers, DX. One half of the beam positions fall on each side of the flightline. The procedure described above can be applied to each data point to determine its approximate X and Y coordinates. At each point one would have brightness temperature (BT(I,J), and location Y(I,J) and X (I,J)).

The data in this corrected form can be used to compute the average PMIS response for a field by determining the stop and start times as well as the left and right extreme points and averaging the values within the boundaries. However, in order to locate the boundaries a character map is required.

<u>Contour mapping</u>.--A printout can be generated from this raw-data set by using an intermediate contour mapping program. In these programs, a square grid point system of specified density is generated by resampling the original data.

These data can be printed by assigning characters to each grid point or a larger overlay grid can be used and all points within it averaged. This latter procedure is useful for scaling.

A program was written in FORTRAN to perform the geometric corrections on the raw PMIS data and to produce a new square grid of resampled data, which can be outputed as a contour map of brightness temperatures.

The geometric corrections previously described include one for the arc of the swath and two for plane movement which are based upon beam position, altitude, and ground speed.

The PMIS data are input as an I, J matrix where I is the scan line and J is the beam position. For each scanline the time is also input to identify the average altitude and ground speed. Ground speed and altitude are determined from the NERDAS printout.

Following the procedure previously described for computing ΔT, the photocenter times are corrected and the time, altitude, and ground speed for each are recorded as a matrix for input. This set of photo centers should cover the time period for the entire PMIS data set to be corrected.

Each PMIS scan line is assigned an altitude and ground speed by a linear interpolation between the values recorded at its two surrounding photo centers and the elapsed time since the first. PMIS observation time is TPM (I) and the surrounding photo center pair times are TPH (K) and TPH (K + I). Altitude pairs are ALT (K) and ALT (K + 1) and ground speed pairs are GDS (K) and GDS (K + 1). The calculations for scanline altitude and ground speed are:

$$H = ALT(K)+(ALT(K+1)-ALT(K))*(TPM(l)-TPH(K))/(TPH(K+1)-TPH(K)) \quad (7)$$

and

$$G = GDS(K)+(GDS(K+1)-GDS(K))*(TPM(I)-TPH(K))/(TPH(K+1)-TPH(K)) \quad (8)$$

These values are used in conjunction with equations 4, 5, and 6 to compute the location of each scan line beam position related to a 0,0 point.

Following the geometric correction, the new grid is generated and used to produce a contour map. Values from the new grid can be stored for field averaging once the boundaries are identified. The program is set up to process time sequential PMIS data sets. An example of the output is shown in figure 10.

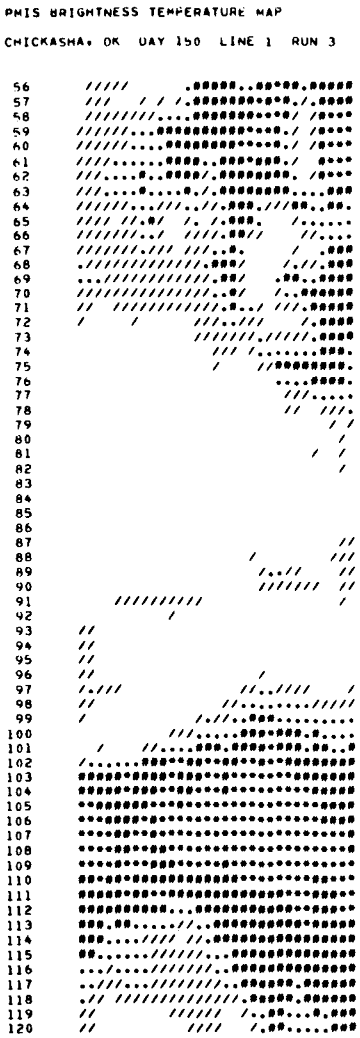
Site averaging.--The geometric correction and contour mapping program create a data file for each segment of the brightness temperatures and their locations corresponding to the contour maps. Site boundaries are then defined from the printouts and input to an averaging program which computes the mean and standard deviation for each site. Results obtained for each site are listed in table 26.

Scatterometers

The output of the scatterometer is recorded by a Mincom wideband recorder that has a bandwidth coverage from DC to 20 KHz. Data are recorded on a magnetic tape with 14 data channels and with a carrier modulating frequency of 108 KHz. The time of data taking is recorded through standard time code and NERDAS on two separated channels. In addition to the time information, NERDAS also records the aircraft navigation parameters, such as altitude, air speed, ground speed, roll pitch, and drift angles.

Due to the high cost of data processing only selected time frames were processed. Backscattering coefficients for the test sites are presented in table 27, 28 and 29 for the C, L, and P bands, respectively. Valves are tabulated for all available look angles.

Several system problems were encountered during the mission which greatly reduced the usable data from the scatterometers.



Brightness temperature interval	Symbol
-deg K-	
200 - 220	
220 - 240	/
240 - 260	.
260 - 280	*
280 - 300	#

Figure 10.--Example of PMIS radiometer alphanumeric map, Chickasha, Okla., flightline 1, May 30, 1978.

Table 26.--PMIS radiometer site averaged data

DATE	SITE	PMIS BRIGHTNESS TEMPERATURE			
		HORIZONTAL POLARIZATION		VERTICAL POLARIZATION	
		MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
		------------------DEG K-----------------			
50178	C3	262.0	6.0	270.2	5.6
50178	C4	265.5	6.6	274.9	10.9
50178	C5C6	287.6	3.1	284.1	6.6
50178	F1	285.1	2.4	284.2	3.0
50178	RG83	-	-	286.3	2.6
50178	RG88	-	-	-	-
50178	R5	276.4	7.0	277.2	5.6
50178	R6	267.3	5.4	281.1	5.4
50178	R7	254.0	6.3	275.1	4.7
50178	R8	260.5	8.4	277.2	4.0
50178	TX 3	-	-	-	-
50178	TX 4	-	-	-	-
51278	C3	273.9	5.6	284.5	3.1
51278	C4	268.3	5.3	285.2	7.8
51278	C5C6	286.6	3.4	288.9	3.6
51278	F1	288.3	3.0	288.1	3.2
51278	F2	289.3	2.2	289.1	2.5
51278	RG83	-	-	-	-
51278	RG88	-	-	-	-
51278	R5	289.7	2.6	289.5	2.7
51278	R6	288.1	2.2	289.5	2.6
51278	R7	-	-	-	-
51278	R8	-	-	-	-
51278	TX 3	-	-	-	-
51278	TX 4	-	-	-	-
51278	TX 8	-	-	-	-
51278	TX 9	-	-	-	-
51278	TX 10	-	-	-	-
51278	TX 11	-	-	-	-
51278	TX 12	-	-	-	-
51278	TX 13	-	-	-	-
51278	TX 15	-	-	-	-
53078	C3	205.5	21.4	256.2	14.9
53078	C4	205.9	20.1	243.9	16.1
53078	C5C6	272.6	15.6	279.3	21.0
53078	F1	-	-	-	-
53078	F2	-	-	-	-
53078	RG83	-	-	-	-
53078	RG88	-	-	-	-
53078	R5	270.9	5.9	-	-
53078	R6	271.0	5.2	-	-
53078	R7	264.4	7.3	282.3	4.9
53078	R8	266.6	7.7	285.4	3.7
53078	TX 3	-	-	-	-
53078	TX 4	-	-	-	-
53078	TX 8	-	-	-	-
53078	TX 9	-	-	-	-
53078	TX 10	-	-	-	-
53078	TX11	-	-	-	-
53078	TX12	-	-	-	-
53078	TX13	-	-	-	-
53078	TX 15	-	-	-	-

Table 27.--C band scatterometer data

DATE	SITE	BACKSCATTERING COEFFICIENT									
		DEGREE OF LOOK ANGLE									
		5	10	15	20	25	30	35	40	45	50
		DB									
50178	C3	-	-	-	-	-	-	-	-	-	-
50178	C4	-	-	-	-	-	-	-	-	-	-
50178	C5C6	-	-	-	-	-	-	-	-	-	-
50178	F1	-	-	-	-	-	-	-	-	-	-
50178	RG83	-	-	-	-	-	-	-	-	-	-
50178	RG88	-	-	-	-	-	-	-	-	-	-
50178	R5	-	-	-	-	-	-	-	-	-	-
50178	R6	-	-	-	-	-	-	-	-	-	-
50178	R7	-	-	-	-	-	-	-	-	-	-
50178	R8	-	-	-	-	-	-	-	-	-	-
50178	TX 3	-	-	-	-	-	-	-	-	-	-
50178	TX 4	-	-	-	-	-	-	-	-	-	-
51278	C3	0.7	-6.2	-8.3	-10.7	-12.1	-14.1	-14.7	-16.3	-17.9	-19.5
51278	C4	4.1	-5.5	-8.3	-9.8	-11.4	-12.1	-14.5	-16.1	-17.9	-19.1
51278	C5C6	3.0	-7.9	-10.3	-11.3	-12.2	-13.3	-13.8	-13.9	-15.6	-16.1
51278	F1	0.1	-6.4	-10.2	-13.0	-14.0	-15.4	-16.6	-18.1	-19.0	-20.1
51278	F2	-1.4	-8.6	-11.4	-12.7	-14.8	-16.5	-17.1	-17.7	-19.4	-19.8
51278	RG83	-	-	-	-	-	-	-	-	-	-
51278	RG88	-	-	-	-	-	-	-	-	-	-
51278	R5	0.9	-8.8	-13.4	-15.3	-16.3	-17.6	-17.4	-18.8	-19.0	-20.6
51278	R6	1.3	-6.4	-11.5	-14.0	-15.7	-17.9	-17.8	-18.8	-19.0	-20.2
51278	R7	2.0	-7.3	-9.9	-11.3	-13.6	-15.7	-16.6	-18.5	-19.1	-21.7
51278	R8	-0.1	-7.7	-11.1	-13.2	-14.7	-15.7	-15.5	-15.8	-18.1	-19.0
51278	TX 3	-	-	-	-	-	-	-	-	-	-
51278	TX 4	-	-	-	-	-	-	-	-	-	-
51278	TX 8	-	-	-	-	-	-	-	-	-	-
51278	TX 9	-	-	-	-	-	-	-	-	-	-
51278	TX 10	-	-	-	-	-	-	-	-	-	-
51278	TX 11	-	-	-	-	-	-	-	-	-	-
51278	TX 12	-	-	-	-	-	-	-	-	-	-
51278	TX 13	-	-	-	-	-	-	-	-	-	-
51278	TX 15	-	-	-	-	-	-	-	-	-	-
53078	C3	5.6	-5.8	-10.2	-14.3	-16.2	-19.0	-21.0	-22.5	-23.8	-26.0
53078	C4	5.6	-4.3	-8.8	-12.5	-15.3	-17.3	-19.5	-20.9	-23.2	-23.6
53078	C5C6	6.7	0.4	-2.9	-5.4	-7.1	-8.7	-10.7	-11.7	-11.7	-14.1
53078	F1	3.8	-2.7	-5.6	-8.1	-9.7	-12.1	-12.3	-13.9	-16.1	-17.6
53078	F2	4.8	-1.8	-5.0	-8.0	-10.1	-12.5	-14.2	-15.1	-17.2	-18.7
53078	RG83	-	-	-	-	-	-	-	-	-	-
53078	RG88	-	-	-	-	-	-	-	-	-	-
53078	R5	9.9	-0.5	-6.2	-9.5	-11.8	-13.8	-15.4	-15.5	-18.1	-18.8
53078	R6	8.0	-0.6	-5.5	-8.6	-10.9	-12.2	-14.1	-15.5	-17.5	-17.9
53078	R7	12.7	3.2	-2.7	-6.0	-8.8	-12.0	-13.9	-14.4	-15.5	-16.3
53078	R8	9.1	1.8	-3.7	-6.6	-8.8	-11.1	-12.2	-14.3	-15.0	-17.1
53078	TX 3	-	-	-	-	-	-	-	-	-	-
53078	TX 4	-	-	-	-	-	-	-	-	-	-
53078	TX 8	-	-	-	-	-	-	-	-	-	-
53078	TX 9	-	-	-	-	-	-	-	-	-	-
53078	TX 10	-	-	-	-	-	-	-	-	-	-
53078	TX11	-	-	-	-	-	-	-	-	-	-
53078	TX12	-	-	-	-	-	-	-	-	-	-
53078	TX13	-	-	-	-	-	-	-	-	-	-
53078	TX 15	-	-	-	-	-	-	-	-	-	-

Table 28.--L band scatterometer data

DATE	SITE	BACKSCATTERING COEFFICIENT									
		DEGREE OF LOOK ANGLE									
		5	10	15	20	25	30	35	40	45	50
		DB									
50178	C3	-5.4	-7.9	-8.5	-10.4	-13.6	-14.4	-15.7	-18.3	-20.3	-21.5
50178	C4	-2.9	-8.3	-6.8	-10.3	-11.6	-14.3	-14.2	-14.7	-17.2	-21.1
50178	C5C6	-7.4	-10.9	-13.3	-14.4	-14.2	-17.2	-18.7	-20.5	-21.3	-23.9
50178	F1	-0.4	-4.8	-7.5	-10.6	-14.9	-17.2	-18.8	-19.8	-22.3	-23.4
50178	RG83	-	-	-	-	-	-	-	-	-	-
50178	RG88	-	-	-	-	-	-	-	-	-	-
50178	R5	-1.2	-8.9	-13.2	-16.2	-18.5	-19.7	-20.7	-22.5	-24.4	-26.8
50178	R6	22.6	-5.2	-11.2	-15.2	-17.7	-19.4	-20.5	-22.5	-22.1	-23.5
50178	R7	67.8	-2.4	-7.0	-10.8	-14.0	-15.7	-17.9	-19.7	-22.9	-22.9
50178	R8	2.5	-5.1	-7.1	-10.5	-12.8	-14.0	-16.1	-15.3	-17.9	-20.1
50178	TX 3	-	-	-	-	-	-	-	-	-	-
50178	TX 4	-	-	-	-	-	-	-	-	-	-
51278	C3	-0.4	-3.0	-6.4	-10.7	-13.9	-16.6	-17.9	-20.8	-20.5	-23.4
51278	C4	0.3	-5.1	-9.4	-11.7	-14.5	-17.2	-18.4	-22.2	-21.6	-22.7
51278	C5C6	-2.4	-8.1	-11.0	-14.1	-16.7	-19.8	-21.1	-24.0	-24.6	-24.9
51278	F1	-1.6	-6.4	-9.9	-12.3	-15.1	-18.6	-19.6	-21.1	-23.1	-23.7
51278	F2	-0.9	-7.6	-7.9	-12.5	-16.4	-18.5	-21.0	-23.1	-24.8	-25.0
51278	RG83	-	-	-	-	-	-	-	-	-	-
51278	RG88	-	-	-	-	-	-	-	-	-	-
51278	R5	2.5	-4.3	-12.7	-16.0	-18.9	-21.2	-22.5	-25.4	-26.3	-26.9
51278	R6	4.0	-1.9	-7.7	-12.7	-17.7	-20.2	-22.7	-25.4	-26.2	-27.9
51278	R7	-3.6	-9.7	-11.6	-14.7	-17.7	-17.6	-21.1	-23.6	-24.7	-23.1
51278	R8	-3.4	-8.4	-11.6	-14.3	-17.3	-18.3	-19.4	-20.4	-21.7	-21.0
51278	TX 3	-	-	-	-	-	-	-	-	-	-
51278	TX 4	-	-	-	-	-	-	-	-	-	-
51278	TX 8	-	-	-	-	-	-	-	-	-	-
51278	TX 9	-	-	-	-	-	-	-	-	-	-
51278	TX 10	-	-	-	-	-	-	-	-	-	-
51278	TX 11	-	-	-	-	-	-	-	-	-	-
51278	TX 12	-	-	-	-	-	-	-	-	-	-
51278	TX 13	-	-	-	-	-	-	-	-	-	-
51278	TX 15	-	-	-	-	-	-	-	-	-	-
53078	C3	-6.0	-13.8	-16.3	-19.8	-22.8	-24.7	-26.5	-28.0	-28.6	-28.9
53078	C4	-3.2	-10.5	-14.1	-18.3	-21.9	-22.0	-25.8	-28.5	-29.2	-30.5
53078	C5C6	-4.2	-11.1	-13.6	-15.5	-16.3	-17.8	-21.0	-22.7	-24.4	-26.0
53078	F1	3.1	-0.6	-4.0	-6.2	-10.1	-12.7	-16.9	-17.5	-19.5	-22.5
53078	F2	2.4	-1.3	-5.5	-7.4	-10.8	-13.2	-17.5	-20.1	-21.5	-23.5
53078	RG83	-	-	-	-	-	-	-	-	-	-
53078	RG88	-	-	-	-	-	-	-	-	-	-
53078	R5	4.0	-4.7	-9.7	-15.3	-17.8	-20.2	-22.0	-24.3	-25.4	-25.8
53078	R6	3.7	-6.0	-11.2	-14.7	-17.8	-19.1	-21.6	-22.4	-23.9	-23.8
53078	R7	32.4	-0.8	-6.8	-11.1	-13.2	-16.2	-17.8	-18.8	-20.8	-21.1
53078	R8	6.5	-1.4	-6.0	-10.4	-13.2	-15.3	-16.4	-17.6	-18.7	-19.2
53078	TX 3	-	-	-	-	-	-	-	-	-	-
53078	TX 4	-	-	-	-	-	-	-	-	-	-
53078	TX 8	-	-	-	-	-	-	-	-	-	-
53078	TX 9	-	-	-	-	-	-	-	-	-	-
53078	TX 10	-	-	-	-	-	-	-	-	-	-
53078	TX11	-	-	-	-	-	-	-	-	-	-
53078	TX12	-	-	-	-	-	-	-	-	-	-
53078	TX13	-	-	-	-	-	-	-	-	-	-
53078	TX 15	-	-	-	-	-	-	-	-	-	-

Table 29. -- P band scatterometer data

		BACKSCATTERING COEFFICIENT									
		DEGREE OF LOOK ANGLE									
DATE	SITE	5	10	15	20	25	30	35	40	45	50
		DB									
50178	C3	-27.2	-35.7	-42.1	-42.0	-44.6	-43.1	-46.7	-43.5	-45.2	-42.8
50178	C4	-24.7	-32.0	-38.1	-39.2	-40.5	-39.7	-43.9	-38.7	-37.1	-45.0
50178	C5C6	-16.8	-35.1	-40.4	-42.0	-45.7	-40.6	-44.6	-44.1	-42.4	-42.0
50178	F1	-11.0	-30.7	-34.7	-40.6	-42.2	-43.5	-44.3	-42.1	-40.6	-38.8
50178	RG83	-	-	-	-	-	-	-	-	-	-
50178	RG88	-	-	-	-	-	-	-	-	-	-
50178	R5	-31.3	-42.9	-47.4	-46.9	-49.8	-48.8	-47.0	-43.4	-44.5	-37.8
50178	R6	-26.3	-35.6	-45.8	-48.6	-51.4	-50.6	-47.8	-51.8	-44.0	-44.2
50178	R7	-23.6	-31.7	-43.9	-45.3	-45.0	-43.1	-43.7	-40.9	-41.6	-39.5
50178	R8	-25.5	-33.9	-36.4	-34.7	-33.7	-33.3	-34.5	-35.6	-32.9	-32.5
50178	TX 3	-	-	-	-	-	-	-	-	-	-
50178	TX 4	-	-	-	-	-	-	-	-	-	-
51278	C3	-23.2	-33.0	-43.9	-45.3	-43.9	-41.9	-42.5	-41.1	-41.1	-39.1
51278	C4	-24.5	-34.7	-44.1	-47.2	-48.1	-43.3	-46.2	-42.7	-41.3	-37.7
51278	C5C6	-22.9	-38.6	-46.6	-49.2	-48.2	-49.4	-50.9	-50.8	-50.5	-47.8
51278	F1	-30.3	-42.5	-42.2	-47.3	-47.6	-48.8	-50.7	-47.8	-47.5	-48.1
51278	F2	-22.3	-37.6	-46.7	-47.1	-46.0	-46.9	-46.5	-43.2	-39.1	-37.4
51278	RG83	-	-	-	-	-	-	-	-	-	-
51278	RG88	-	-	-	-	-	-	-	-	-	-
51278	R5	-20.8	-34.4	-41.5	-45.1	-46.4	-45.8	-47.7	-47.1	-44.1	-45.6
51278	R6	-26.6	-37.7	-49.8	-47.5	-50.7	-49.0	-51.3	-50.1	-49.8	-46.2
51278	R7	-	-	-	-	-	-	-	-	-	-
51278	R8	-21.6	-30.5	-34.6	-35.1	-35.9	-35.9	-35.7	-34.2	-33.2	-34.3
51278	TX 3	-	-	-	-	-	-	-	-	-	-
51278	TX 4	-	-	-	-	-	-	-	-	-	-
51278	TX 8	-	-	-	-	-	-	-	-	-	-
51278	TX 9	-	-	-	-	-	-	-	-	-	-
51278	TX 10	-	-	-	-	-	-	-	-	-	-
51278	TX 11	-	-	-	-	-	-	-	-	-	-
51278	TX 12	-	-	-	-	-	-	-	-	-	-
51278	TX 13	-	-	-	-	-	-	-	-	-	-
51278	TX 15	-	-	-	-	-	-	-	-	-	-
53078	C3	-24.8	-31.7	-37.7	-38.4	-39.2	-39.6	-39.4	-37.8	-38.5	-35.1
53078	C4	-23.4	-29.9	-38.2	-38.9	-46.5	-40.9	-41.6	-43.7	-40.3	-40.9
53078	C5C6	-14.1	-31.6	-41.2	-44.3	-44.4	-40.3	-42.9	-46.4	43.9	-39.0
53078	F1	-11.5	-28.5	-34.9	-40.7	-43.3	-43.6	-44.7	-43.2	-43.0	-42.1
53078	F2	-12.6	-30.6	-33.4	-34.9	-36.7	-38.5	-40.2	-41.0	41.3	-40.0
53078	RG83	-	-	-	-	-	-	-	-	-	-
53078	RG88	-	-	-	-	-	-	-	-	-	-
53078	R5	-28.2	-41.7	-44.5	-48.0	-48.8	-44.6	-46.5	-44.9	-43.4	-45.7
53078	R6	-28.9	-37.5	-45.1	-50.0	-48.1	-46.7	-50.1	-45.9	-41.1	-42.7
53078	R7	-26.9	-34.5	-37.6	-41.0	-40.2	-39.1	-42.6	-40.7	-38.9	-36.4
53078	R8	-27.6	-31.1	-39.7	-42.0	-40.4	-38.3	-40.2	-38.1	-36.5	-33.9
53078	TX 3	-	-	-	-	-	-	-	-	-	-
53078	TX 4	-	-	-	-	-	-	-	-	-	-
53078	TX 8	-	-	-	-	-	-	-	-	-	-
53078	TX 9	-	-	-	-	-	-	-	-	-	-
53078	TX 10	-	-	-	-	-	-	-	-	-	-
53078	TX11	-	-	-	-	-	-	-	-	-	-
53078	TX12	-	-	-	-	-	-	-	-	-	-
53078	TX13	-	-	-	-	-	-	-	-	-	-
53078	TX 15	-	-	-	-	-	-	-	-	-	-

SUMMARY

Experiments were designed and conducted to develop a data set for the analysis of relationships between remote sensing data and hydrologic variables and parameters. This particular series of experiments conducted in Chickasha, Okla., and Riesel, Tex., was successful. However, additional experiments are needed to cover a wider range of soil moisture conditions within semiarid areas. The conditions encountered here were relatively wet and a few sets of dryer condition observations are needed. In addition, experiments should be conducted within more humid climatic areas and areas with sandy soils. These results of aircraft remote sensing of soil moisture and hydrologic parameters are being published to aid researchers working in related areas.

APPENDIX

CHICKASHA, OKLA., SOILS MAPS, SAMPLING SITES AND TOPOGRAPHY

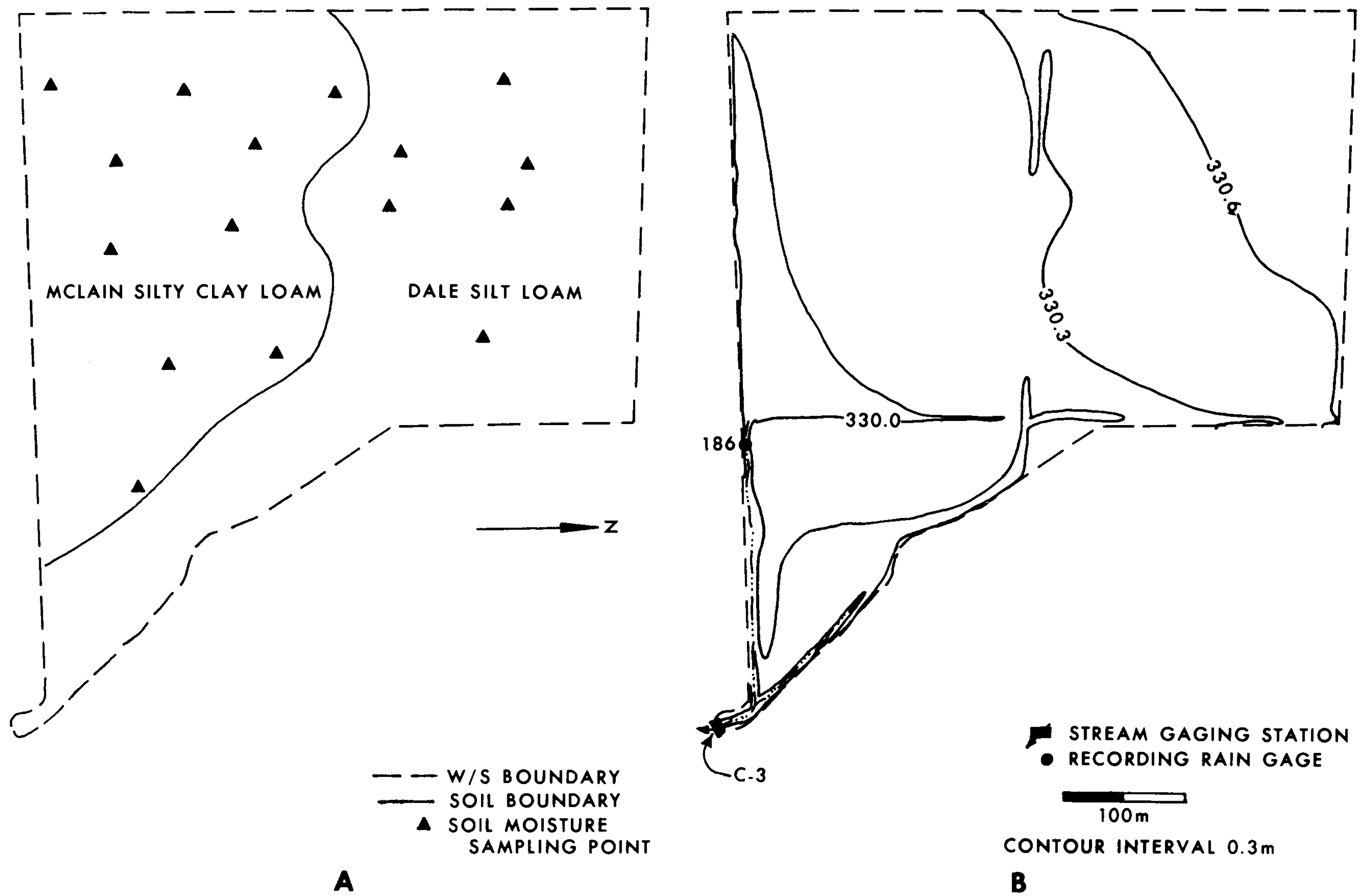


Figure 11.-- Watershed C3, Chickasha, Okla.: A, Soils and sampling locations; B, topography.

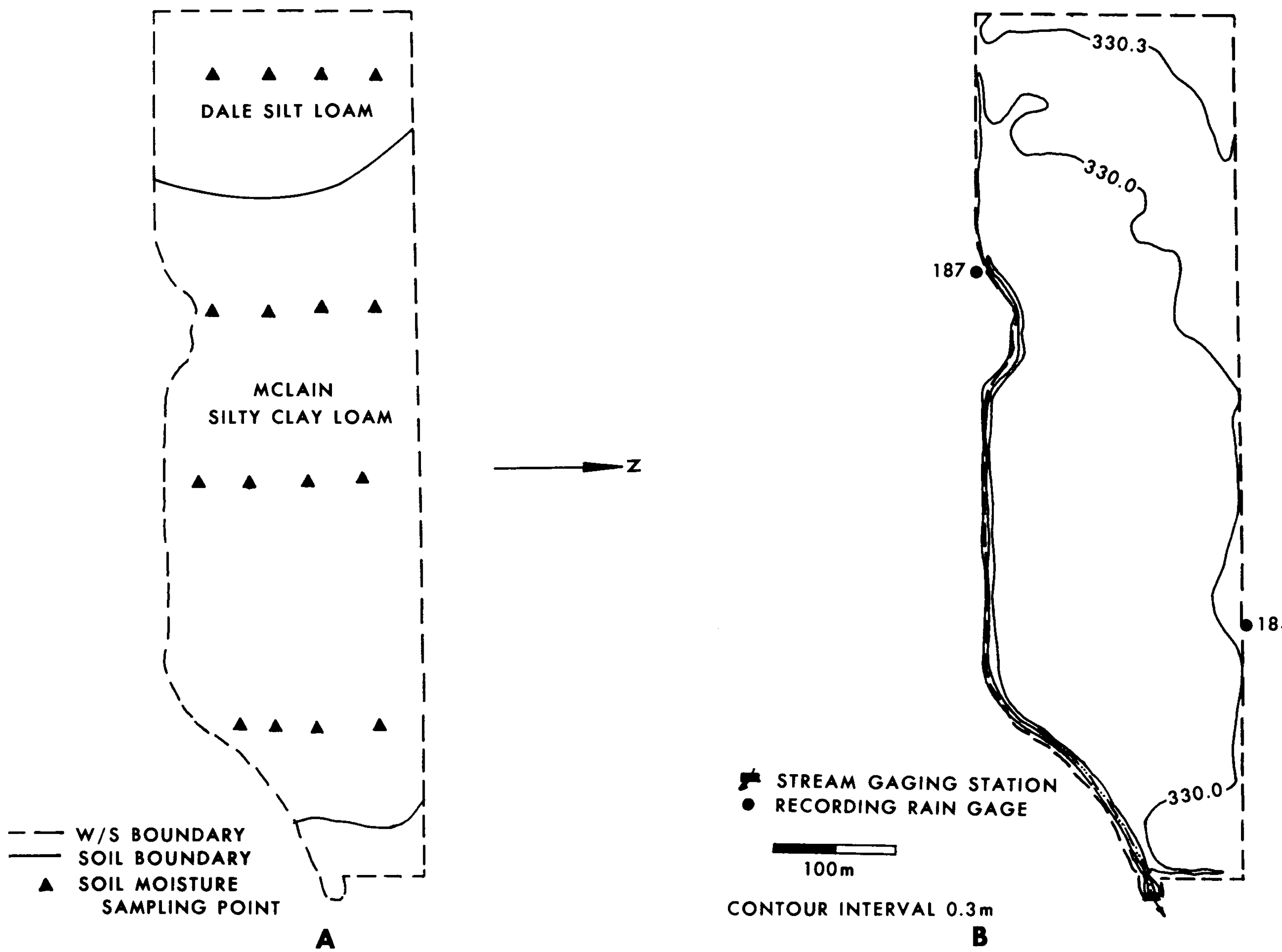


Figure 12.--Watershed C4, Chickasha, Okla.: A, Soils and sampling locations; B, topography.

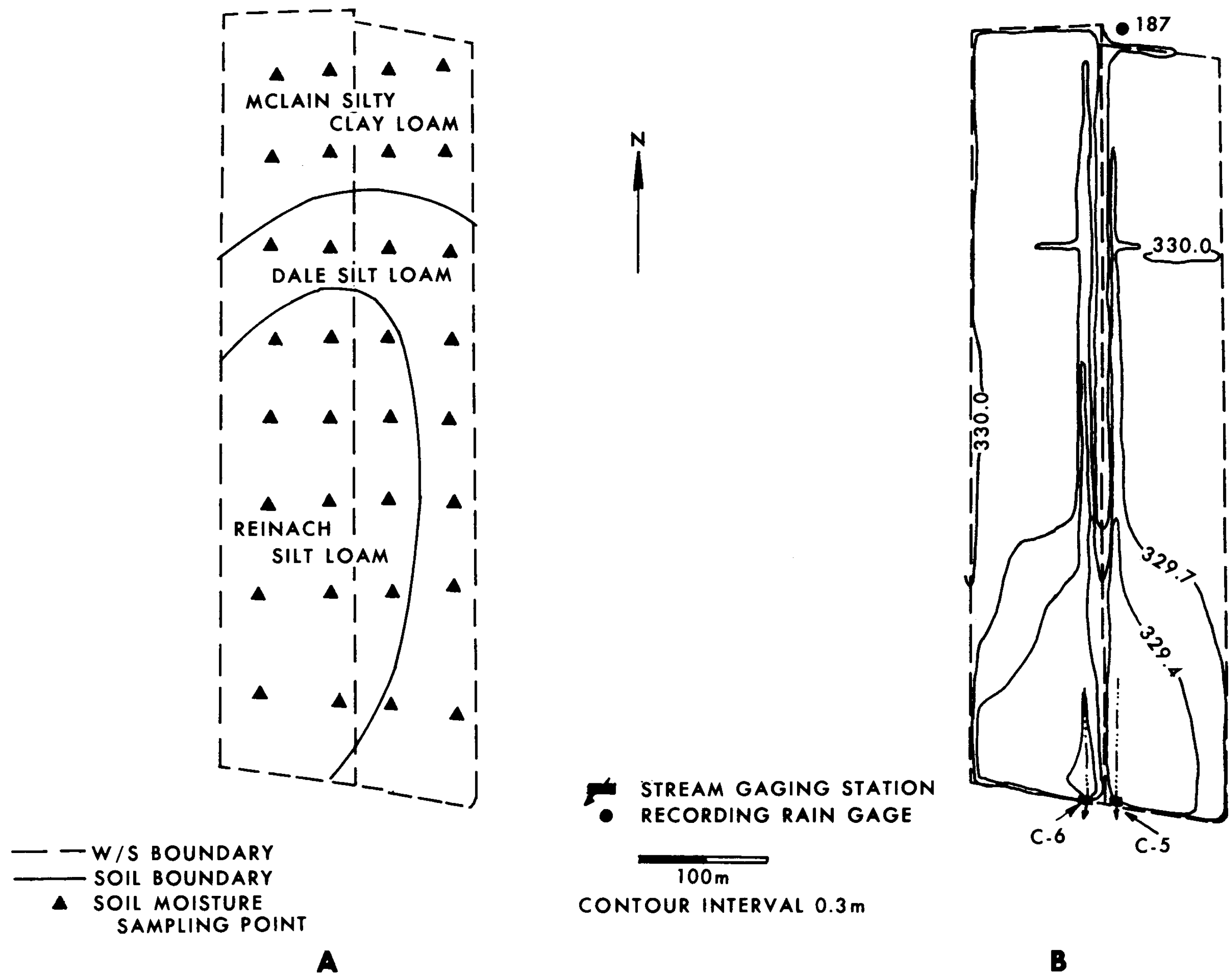


Figure 13.--Watersheds C5 and C6, Chickasha, Okla.: A, Soils and sampling locations; B, topography.

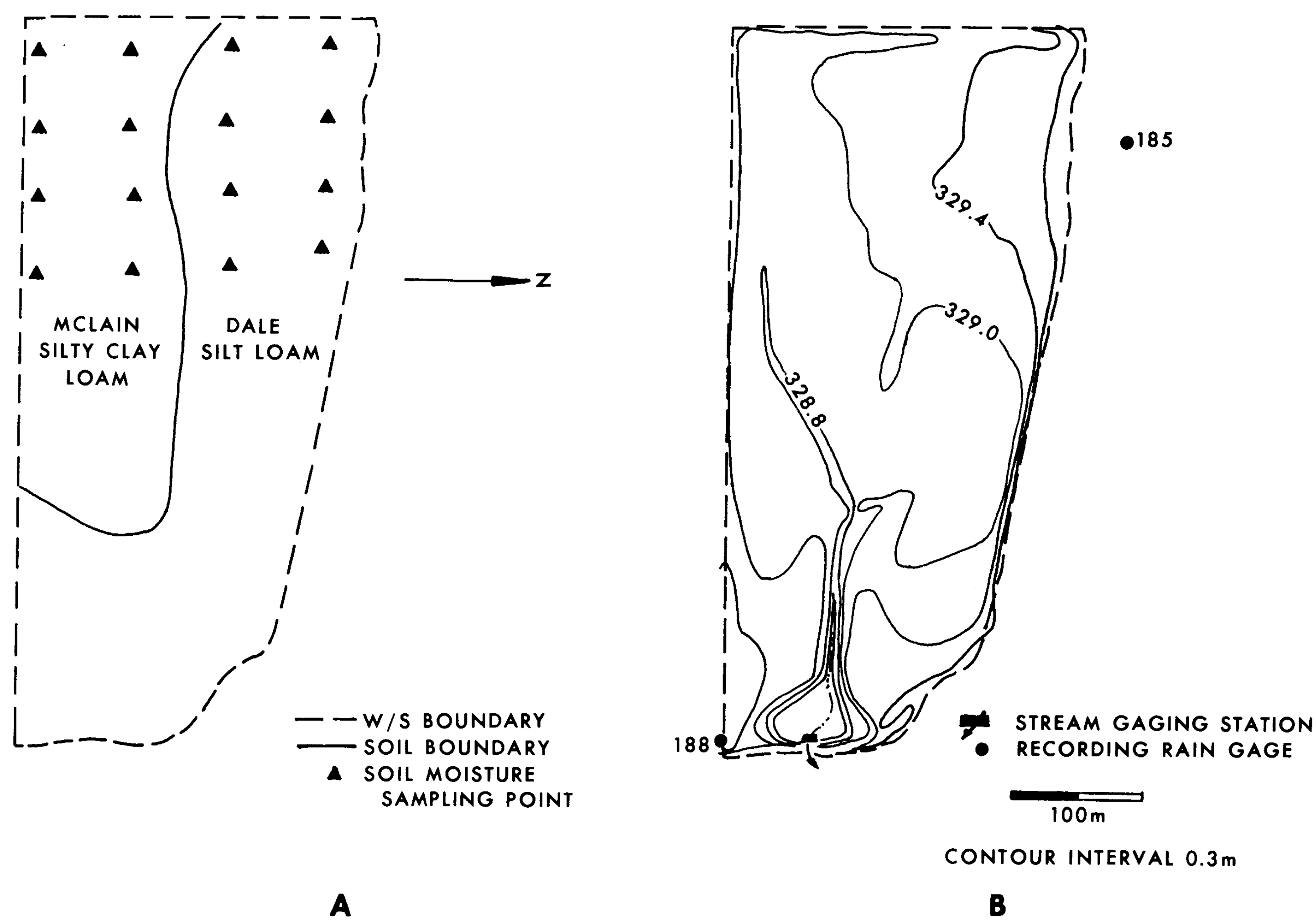


Figure 14.--Watershed C8, Chickasha, Okla.: A, Soils and sampling locations; B, topography.

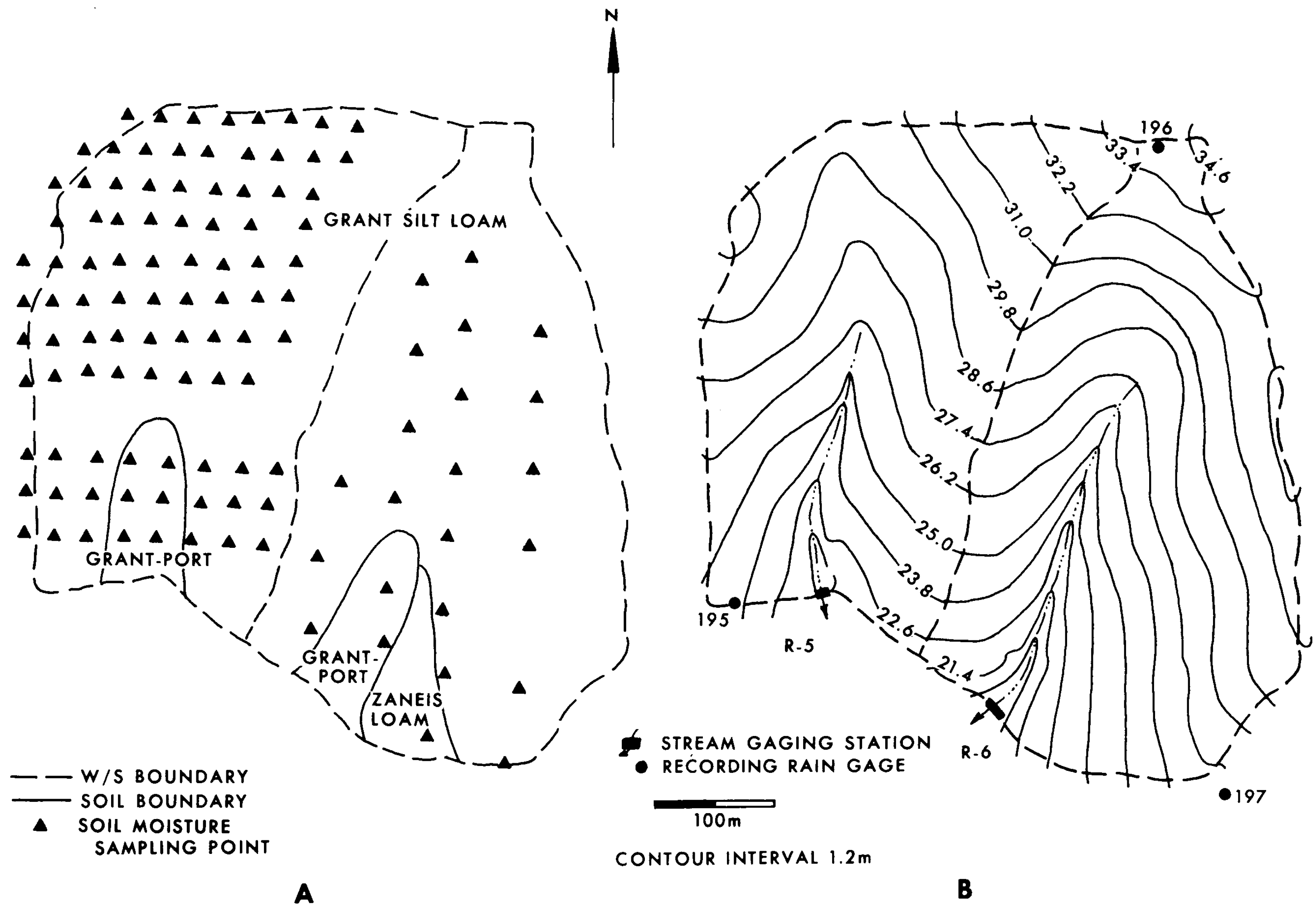


Figure 15.--Watersheds R5 and R6, Chickasha, Okla.: A, Soils and sampling locations; B, topography.

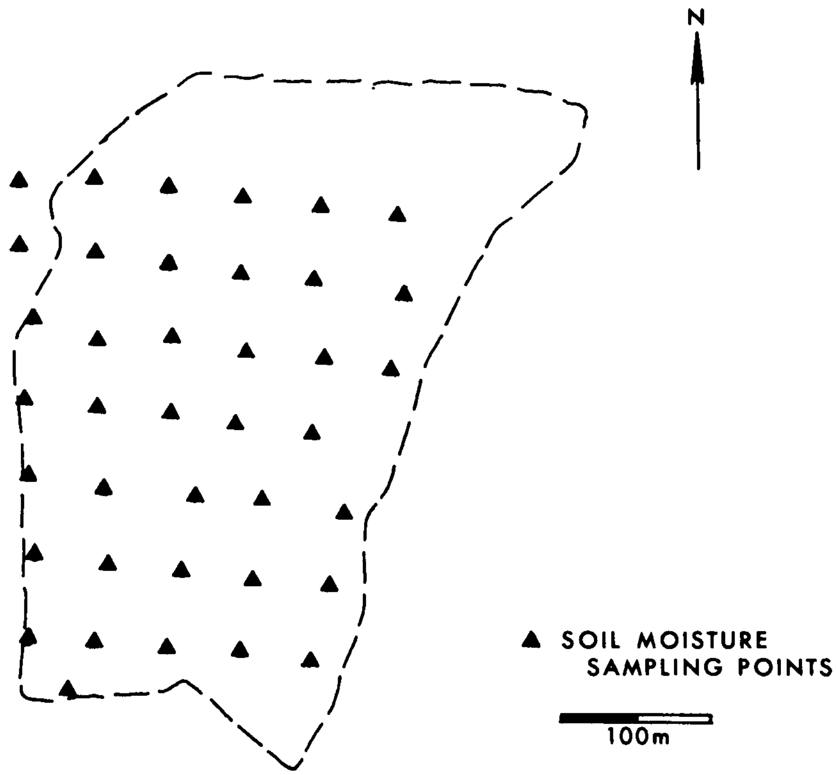


Figure 16.--Watershed R5, Chickasha, Okla., sampling locations on May 12 and 30, 1978.

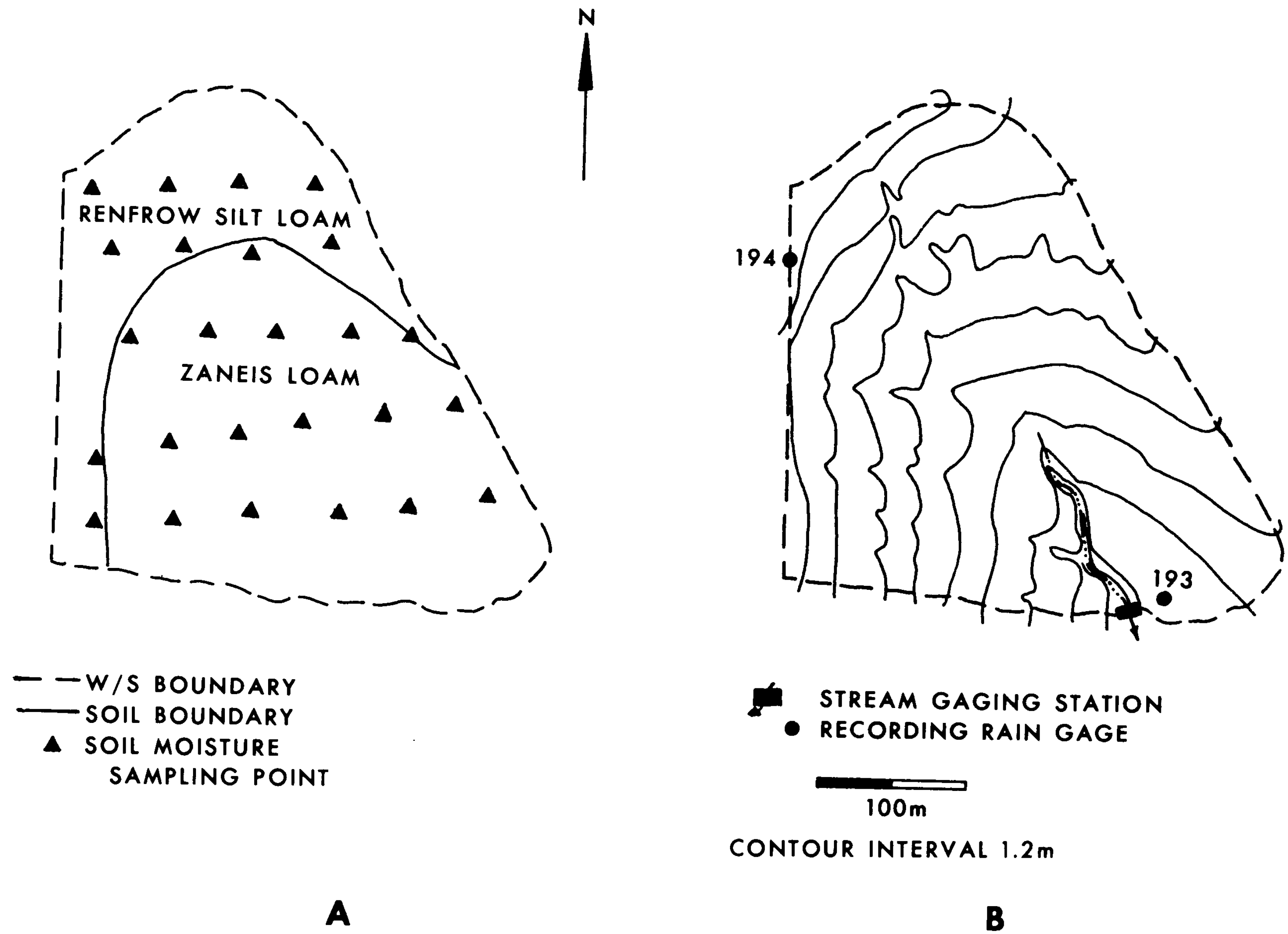


Figure 17.--Watershed R7, Chickasha, Okla.: A, Soils and sampling locations; B, topography.

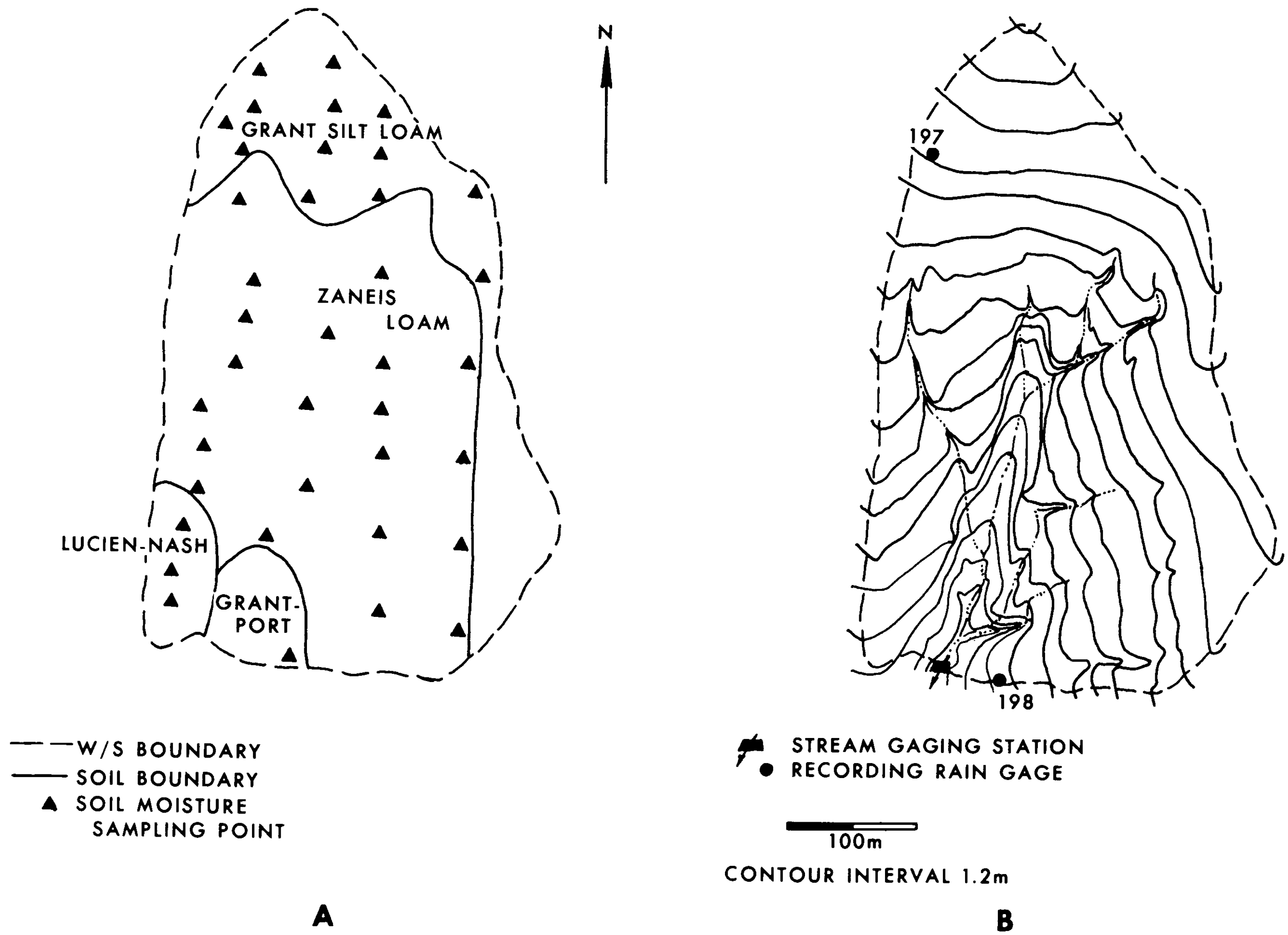


Figure 18.--Watershed R8, Chickasha, Okla.: A, Soils and sampling locations; B, topography.