78-10073

SPECTRAL MEASUREMENT OF WATERSHED COEFFICIENTS IN THE SOUTHERN GREAT PLAINS

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January 1978
Type III Final Report

Prepared for
Goddard Space Flight Center
Greenbelt, Maryland 20771

Contract No. NAS5-22534

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(E78-10073) SPECTRAL MEASUREMENT OF WATERSHED COEFFICIENTS IN THE SOUTHERN GREAT PLAINS Final Report (Texas A&M Univ.) 58 p HC A04/MF A01 CSCL 08H
N78-18482
Unclas
G3/43 00073

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Final Report RSC 3273

78-10073 III
CR-155718

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SPECTRAL MEASUREMENTS OF WATERSHED COEFFICIENTS IN THE SOUTHERN GREAT PLAINS

1.0 INTRODUCTION

The management of water resources systems has become a major concern with the development of an increasing population and the required agricultural systems to sustain that population. In order to manage water resources effectively, information is needed on each component of the hydrologic cycle and the interaction of some components.

One of the more difficult regions in the hydrologic cycle to model mathematically has been the interface between the atmosphere and the watershed surface. Numerous characteristics of the surface such as antecedent moisture, permeability, vegetation, and slope influence the amount of rainfall that ultimately becomes runoff. The combined effect of the surface characteristics are lumped together and are represented as a single coefficient in most simple empirical watershed runoff equations.

Selection of the appropriate coefficient to represent a particular watershed has conventionally been based on subjective selection of values from tables. Coefficients in such tables are related to a variety of surface cover and soil types and were derived from measurements on small relatively homogeneous watersheds. Selection of coefficients is tedious and difficult for non-homogeneous watersheds where a number of soil types and vegetation classes are found in one drainage area.

A system or technique that could provide a measurement of the interacting characteristics of the surface and near-surface condition would allow improvement in the estimates of runoff. A previous study (Blanchard, 1975) had been directed toward classification of the runoff potential of watershed surfaces by use of linear combinations of spectral data from the Multi-Spectral Scanner (MSS). Some encouraging results were obtained using data over twenty watersheds in a two-county area located in central Oklahoma. The study also provided some insight concerning limitations to the application of the technique. It was apparent that relatively dry and dormant conditions were necessary before differences related to runoff coefficients could be detected from average reflectance.

Soils in central Oklahoma are derived from outcrops of the permean red beds. As the geologic name of the parent material would indicate, these soils are various shades of red depending on the specific outcrop from which they originated. The limited area represented in the study did not include other colors of soil nor did it include watersheds with significant areas of timber cover.

2.0 OBJECTIVE AND APPROACH

2.1 Objective

The original objective of this study was to modify and test the concept of using linear equations of MSS data for the prediction of runoff coefficients for use with the commonly used Soil Conservation Service (SCS) watershed runoff equation.

The test was to include watersheds in central Texas and the more arid region represented by Arizona. Furthermore, the testing was to indicate limitations on the application of the technique that might be imposed by forested areas or areas having soils of different origin. A comparison was proposed to indicate whether or not the technique could be used to improve prediction of expected flood flows and thus improve the design criteria for flood detention structures.

2.2 Approach

The original concept of the study incorporated a proposal that sets of ten watersheds in each region would be used to develop a modified linear equation relating MSS spectral data to runoff coefficients. The linear equation was then to be tested on an independent set of ten watersheds in the same region.

To accomplish this task with a minimum of data and processing, several sequential steps were necessary. First, the selection of candidate watersheds within the two general regions would be made on a basis of adequate and reliable records with some limitation on size of drainage area Data from the selected watersheds would be collected and processed to produce a calculated coefficient that could be used in the SCS watershed runoff model.

Concurrently, the MSS scenes available from Landsat 1 and 2 were to be screened by comparing film transparencies with rainfall data collected at points within the Landsat scenes. Seventy mm film band 5 was to be used for selecting relatively cloud free scenes for each area of interest. Antecedent rainfall prior to the date of the MSS data collection would be checked and scenes with driest conditions would be given preference.

Digital data for each selected scene would be used to calculate the mean and variance in each of the four spectral regions for reflectance from each watershed drainage area. The calculated values would be combined in linear equations to estimate a dependent variable that would be related to the watershed runoff equation. It was intended that any linear equation that was reasonably well related to the runoff coefficients could then be tested on independent watersheds.

3.0 DATA SELECTION AND REDUCTION

3.1 Watershed Data Selection

A search was conducted to identify all watersheds in Texas where runoff had been measured on a relatively long-term basis. Watersheds considered were primarily those monitored by the United States Geological Survey (USGS) and the United States Department of Agriculture, Agricultural Research Service (ARS). These two agencies have different reasons for acquiring data on watersheds and thus measuring techniques and data collection are different in the two agencies.

Generally, the USGS is faced with collecting data for use by other agencies, consultants, and the general public in planning water resources development. The agency is faced with the task of characterizing flow at different points in streams scattered over a large area with a very limited number of experienced stream-gauging personnel. Since the demands on the agency far exceed funding and personnel available, most gauging stations are located at highway bridges and do not have weirs or uniform channel controls. The USGS must also rely on the collection of rainfall data by the National Weather Service (NWS) except on selected research watersheds operated in cooperation with some other agency.

These limitations result in emphasis being placed on larger streams and rivers and those smaller streams where some local need for data is urgent. Summaries of the data include a quality rating to provide the user with an estimate of the reliability.

The ARS, on the other hand, collects data for research purposes on smaller drainage areas than those gauged by USGS. Research watersheds operated by ARS are usually provided with some stable control, usually a calibrated weir, at the gauging station. The Agency interests are generally concerned with smaller volumes of water and therefore relatively precise measurements of rainfall and runoff are needed. The number of small watersheds monitored by ARS is limited by the extensive costs of long-term intense data networks; however, the data quality is excellent.

A set of eleven watersheds and sub-watersheds exists in Texas that were monitored by the USGS in a cooperative study with the SCS and the Texas Water Development Board. The length of record varies, however, there are generally twelve years of record on each watershed. Density of raingauge locations on these watersheds is much greater than the NWS network, and quality of the runoff data more nearly fits the need of research watersheds. Rainfall and runoff records were compiled by the USGS and published on an annual basis.

Watersheds in the Texas group, Figure 1, were selected on a basis of geographical location, size of watershed, quality of records, density of raingauges and the length of record.

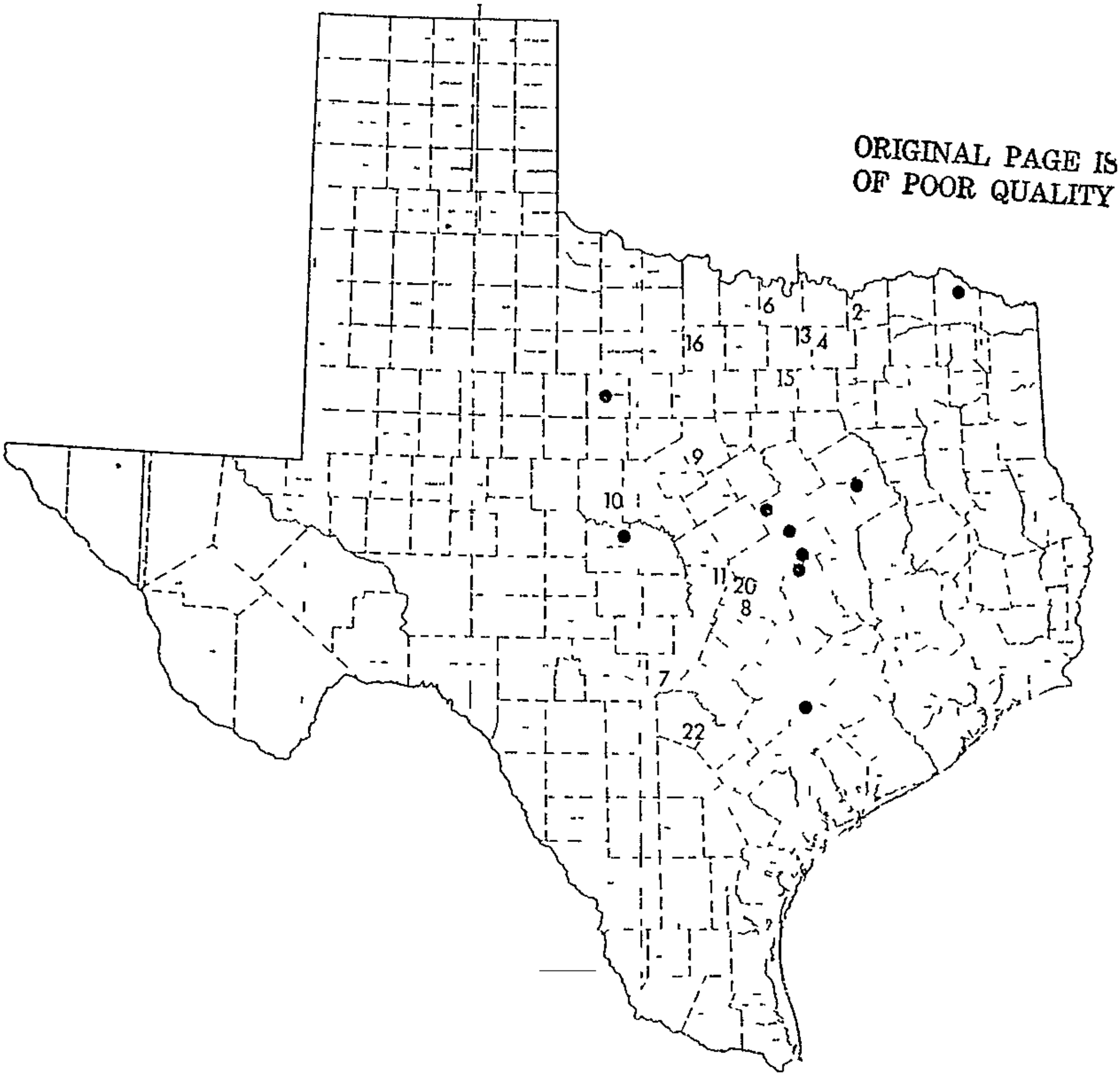


Figure 1. Texas test watershed locations. Watersheds represented by numbers were used in final data analysis.

The criteria were considered in the order listed. All Texas watersheds selected are listed in Table 1.

In the more arid regions of the western states, runoff gauging stations are sparse. Since rainfall is infrequent and many times highly localized, significant stream flow usually occurs as flash floods. It is difficult to get gauging personnel to most measuring stations at the time high flows are occurring. Measuring flows during rapid stage changes is also extremely difficult. These conditions limit the volume of good records in Arizona.

The ARS and the USDA-Forest Service (FS) have built stable flumes and weirs in some smaller Arizona watersheds. Many of these devices have been modeled and calibrated, thus the records obtained under difficult circumstances are reliable. Watersheds monitored by these agencies are used primarily as a source of research data and are instrumented with moderate-to-dense raingauge networks. In addition, some smaller watersheds had been instrumented for research by the University of Arizona, Water Resources Research Center and by the USGS.

The majority of the watersheds selected, Figure 2, were those instrumented for research purposes. Generally, the watershed drainage area for the Arizona watersheds is smaller than those used in Texas and are more likely to

Table 1. Texas Watersheds

Watershed		Watershed Area (km)	Curve Number CN	Soil Map Symbols	Timber Cover (%)
1.	Little Pond Creek	57.50	75.9	14V	1.2
2.	Bois d'Arc Creek	186.48	74.3	14V	2.3
3.	North Elm Creek	125.88	70.4	14V	2.3
4.	Honey Creek	101.01	68.1	14V	2.1
5.	Lavaca River	279.72	63.4	15A 16V	3.6
6.	Elm Fork Trinity River	119.14	56.4	21A 52M	4.2
7.	Cibolo Creek	177.16	54.9	55M	34.7
8.	South Fork San Gabriel River	328.94	51.0	53M	22.6
9.	Green Creek	119.40	48.7	21A	1.0
10.	Mukewater Creek	181.30	48.7	41A 48M	0.7
11.	South Fork Rocky Creek	88.58	44.0	53M	7.1
12.	Pecan Bayou	259.00	75.1	15A 19A	18.8
13.	Little Elm Creek	195.55	72.8	15A 17M 14V	2.4
14.	Tehuacana Creek	367.79	68.9	15A 18A	17.3
15.	Big Bear Creek	76.67	63.4	22A	7.0
16.	North Creek	55.94	57.2	41A 42A	29.3
17.	Middle Bosque River	471.39	54.9	52M	5.8
18.	Cow Bayou	220.15	54.1	17M 14V	3.8
19.	North Fork Hubbord Creek	99.46	50.2	48M	0.4
20.	Berry Creek	211.87	48.7	53M	25.7
21.	Deep Creek	113.70	48.7	41A 48M	0.9
22.	Calaveras Creek	199.95	43.4	24A 14V	0.8

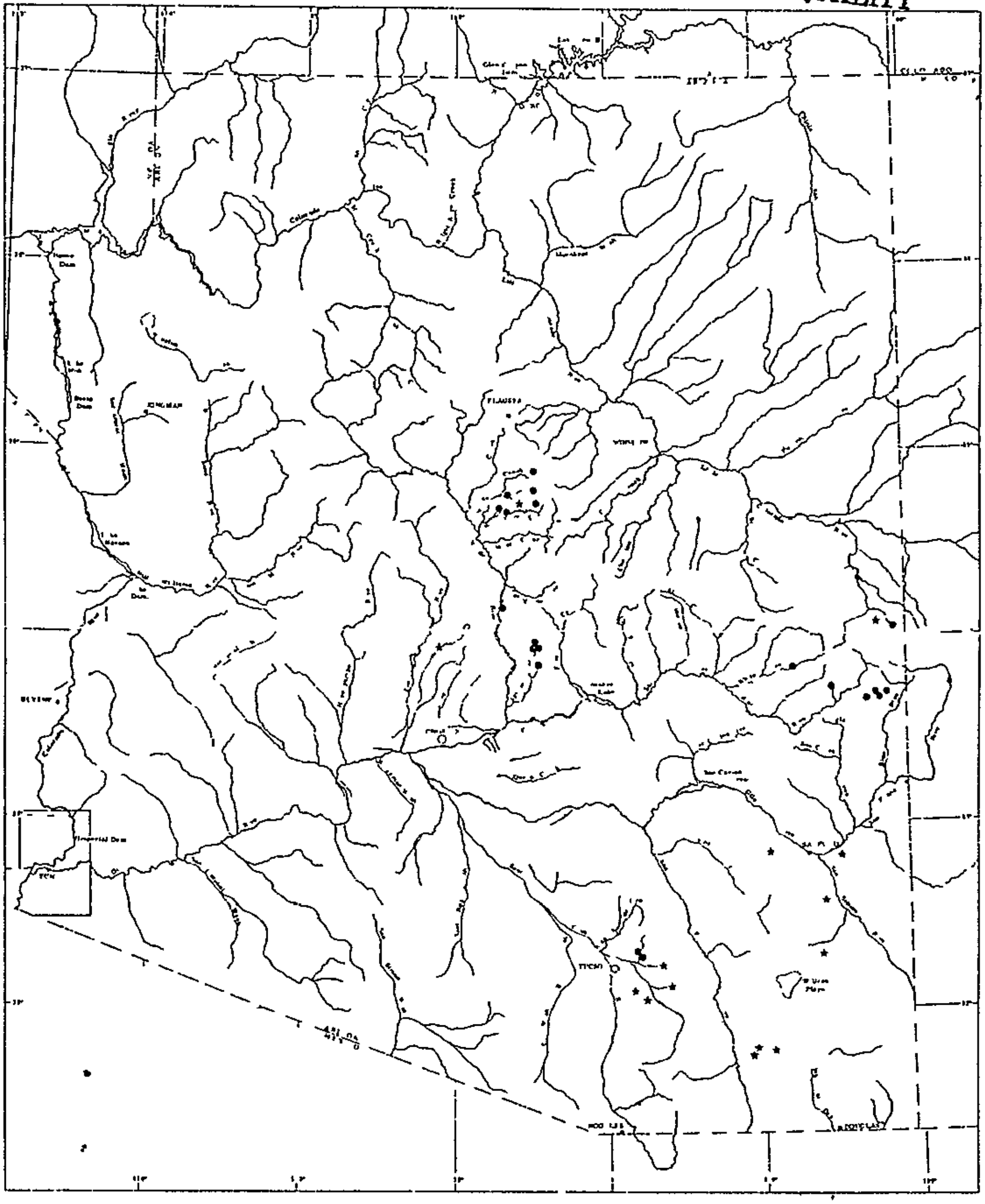


Figure 2. Test watershed locations in Arizona watersheds represented by stars were used in final data analysis

represent a single soil cover complex. A listing of the watersheds selected for the Arizona region appears in Table 2.

The search for data and examination of the quality of the data available indicated that selecting two sets of ten watersheds in each region would be difficult. There are not a sufficient number of watersheds with good quality data and without significant timber cover to provide two similar sets of watersheds in each region. Many partially forested watersheds were included in the original selection.

3.2 Watershed Data Reduction

The watershed boundaries were first outlined on topographic maps using 7.5 minute maps when available and 15 minute maps otherwise. Points were selected along the boundaries such that straight line segments between points would approximate the boundary. The points were numbered and the latitude and longitude for each was tabulated. Orthophoto quadrangle maps were available for many of the Arizona watersheds and these were used when available.

Rainfall and runoff data for periods of record ranging from 7 to 20 years in length were compiled. From these data, 15 to 20 of the most significant runoff-producing events were selected for each watershed. The storm data, rainfall amount and the associated storm runoff were tabulated for each event.

Table 2. Arizona and New Mexico Watersheds

Watershed		Watershed Area (km^2)	Curve Number CN	Soil Map Symbols	Timber Cover (%)
1.	Safford W-1	2.10	62.2	TS12	0.0
2.	Safford W-2	2.76	63.2	TS12	0.0
3.	Safford W-4	3.09	55.0	TS3 TS2	0.0
4.	Safford W-5	2.93	51.6	TS3 MH2	0.0
5.	Walnut Gulch W-3	8.98	56.6	TS4	0.0
6.	Walnut Gulch W-4	2.27	67.8	TS4	0.0
7.	Walnut Gulch W-11	8.24	65.8	TS4	0.0
8.	Atterbury W-2	11.90	46.5	TS14	0.0
9.	Atterbury W-3	1.22	49.7	TS14	0.0
10.	Tanque Verde Creek	111.40	76.9	TS6 MH2	18.2
11.	Rincon Creek	116.00	66.1	TS6 MH2	21.5
12.	Sabino Creek	91.90	81.2	TS6 MH2 FH5	31.0
13.	Bear Creek	42.22	77.6	TS6 MH2 FH5	27.5
14.	East Fork White River	100.49	63.0	FH2	70.7
15.	Pacheta Creek	38.33	47.2	FH2	85.3
16.	Nutrioso Creek	216.00	41.5	MS4 FH2	62 2
17.	East Fork Seven Springs	3.03	38.8	FH8	0.1
18.	East Fork Castle Creek	4.71	55.6	FH6	97.6
19.	North Fork Thomas Creek	1.89	41.8	FH2	86.8
20.	South Fork Thomas Creek	2.27	41.6	FH2	77.2
21.	East Fork Sycamore Creek	11.63	48.6	MH2	46.9
22.	West Fork Sycamore Creek W-1	11.86	47.8	MH2	52.1
23.	West Fork Sycamore Creek W-2	25.38	63.4	MH2	51.4
24.	Sycamore Creek	135.46	54.4	MH2	24.9
25.	New River	215.75	62.5	TS6	3.7

Table 2 (cont.)

Watershed		Watershed Area (km^2)	Curve Number CN	Soil Map Symbols	Timber Cover (%)
26.	Wet Bottom Creek	94.28	64.9	TS6	32.0
27.	Wet Beaver Creek	287.50	64.6	MS7 MS1 FH2	37.9
28.	Red Tank Draw	127.95	64.9	MS7 FH2	22.4
29.	Rattlesnake Canyon	63.72	71.8	MS7 FH2	39.4
30.	Beaver Creek W-4	1.40	65.7	MS7	0.3
31.	Beaver Creek W-8	7.29	62.9	FH2	84.6
32.	Beaver Creek W-13	3.68	59.2	FH2	77.2
33.	Beaver Creek W-18	0.98	74.8	FH2	55.6

A "Thiessen" weighted rainfall was calculated for watersheds having two or more rain gauges. Since the NWS raingauge locations are far apart in much of Arizona, the rainfall used on non-research watersheds in that region is an estimate based on the nearest gauge or the nearest 2 gauges. The rainfall estimates for USGS non-research watersheds in Texas usually contained information from two or three gauges within or near the watershed boundary.

Where snowfall was recorded in areas of Arizona, an attempt was made to avoid those periods when the delayed melting of snow could influence the flow.

The rainfall and runoff volumes representing each storm event were then used to calculate watershed runoff coefficients suitable for use with the SCS runoff volume equation (2). A modification of the conventional SCS runoff equations (Hawkins, 1973) was used in this study. Hawkins has proposed that the conventional equation (Equation 1) does not fully account for storm size.

$$Q = \frac{(P-.2S)^2}{P+.8S}$$

where

Q = storm runoff (cm/2.54)

P = storm rainfall (cm/2.54)

S = storage in the surface (cm/2.54)

$S = \frac{1000}{CN} - 10$

CN = Watershed runoff coefficient, a function of the soil cover complex and antecedent precipitation

When rainfall and runoff for a particular storm are known the conventional watershed coefficient (CN) can be calculated by the equation.

$$CN = 1000/10+5[(P+2Q)-(4Q^2-5PQ)^{\frac{1}{2}}] \tag{2}$$

Hawkins suggested a modification to equation 1 that would more adequately account for the storm size. He defined a coefficient k that accounts for a decline of the curve number with increasing storm size

$$k = \frac{CN-CN_o}{100-CN_o} \tag{3}$$

k = dimensionless coefficient

CN = coefficient for a specific storm

CN_o = coefficient when $Q = 0.0$

and $CN_o = 100/(1+P/2)$

a k value was calculated for each storm and then a weighted k_{avg} value for each watershed was calculated with the following equation:

$$k_{avg} = \frac{\Sigma P_i^2 k_i}{\Sigma P_i^2} \qquad i = 1,n$$

This weighting places slightly more emphasis on storms with large rainfall. The larger storms are more significant since the ultimate use of the resulting coefficient is for the design of flood control structures. CN representing Hawkins' modified coefficient for a specific design storm can be calculated by equation 5.

$$CN_p = 100 \frac{2+kP}{2+P} \qquad 5$$

Coefficients used in this study will be referred to as a "curve number" or CN values, however, these values were calculated by Hawkins' technique and should not be confused with the conventional curve number.

Curve numbers calculated for the Texas watersheds and Arizona watersheds for use in this study are listed in Tables 1 and 2, respectively. A 17.78 cm (7 in.) rainfall was used to calculate curve numbers for the Texas watersheds; whereas, a precipitation of 12.7 cm (5 in.) was used to determine the Arizona watershed curve numbers.

3.3 Landsat Data Selection

Certain criteria were established for selection of Landsat multispectral scanner (MSS) data. These were (a) Landsat coverage was during the dormant season, (b) the date of coverage was for a relatively dry period, and (c) no cloud cover was in the general area of the watershed. The dormant season was considered as anytime between October and March. The dry period or low moisture condition criterion was determined by calculating the antecedent precipitation index (API) by Linsley's (5) thirty-day decay method. To calculate API values for the Texas watersheds, regional groups of rain gauges representing north central and south central Texas were selected as potential dates of Landsat coverage. This API was assigned to the entire area covered by the Landsat images. The cloud cover criterion was further considered by viewing microfilm of Landsat imagery at the Remote Sensing Center's browsing library facility.

From the list of Landsat scenes that met these criteria, the ones with the lowest API that covered two or more watersheds were selected for use. Computer-compatible tapes (CCT) as well as the color transparency and the black and white transparencies of the four individual bands were ordered for the selected Landsat scenes.

Selection of Landsat data for the Arizona watersheds was somewhat different. Criteria for selecting the scenes was still the same. Seventy millimeter photographs of Landsat images (black and white transparency of band five) for cloud-free days during the dormant season were ordered that covered the general area of the selected watersheds. For each Landsat image, an API value was calculated from rainfall data acquired from gauges that surrounded the watersheds of interest. Landsat scenes with the lowest API were selected. Color as well as black and white transparencies and the CCT were ordered for these Landsat scenes.

3.4 Landsat Data Reduction

Procedures developed to reduce Landsat MSS digital data within the watershed drainage area from CCT were as follows The center point latitude and longitude of a block of data surrounding the watershed and the Landsat image center point latitude and longitude were input to an existing Remote Sensing Center (RSC) computer program referred to as MOVE. The block of data usually moved from the CCT encompassed a 12.5 km by 12.5 km square area; however, larger rectangular areas were sometimes necessary to encompass larger watersheds. The block of MSS data taken from the CCT was stored on a disk file to minimize future data handling.

Next a grey-scale map was generated of the Landsat digital data by another RSC computer program, MAP. Multispectral scanner bands five and seven were used to generate the grey-scale showing the most detail. Water bodies were mapped from band seven data. Band five data was used to identify differences in land surfaces. Information on the grey-scale maps was usually adequate to make identification of the principal drainage pattern, highways and contrasting areas having different vegetation.

After obtaining the grey-scale map of the area in and around the watershed, it was desirable to outline the watershed boundaries on it.

Since points around the watershed boundary were tabulated, a computer program was developed to convert latitude and longitude into records and pixels, respectively, in relation to the center point of the Landsat scene (degrees, minutes, and seconds). This technique worked reasonably well however, when the watershed area was distant from the center of the Landsat image the calculated records and pixels were sometimes in error. To correct for this, the latitude and longitude of several identifiable points were also input to the program. The difference between the identification points record and pixel and the calculated record and pixel for those points was applied as a correction factor to the calculated watershed boundary points in order to shift the boundary to its approximate location on the grey map. The corrected record and pixel values for the watershed boundary were then plotted and the watershed boundary drawn on the grey-scale map, thus providing a means of verifying the correct location of the boundary in the digital data file.

A program was developed that approximated an irregular area by a series of trapezoids. This program calculated the average value (in digital counts) for each MSS band. Pixels identified as water were deleted prior to averaging the counts. The program also zeroed all pixels in a rectangular file of data that fell outside the watershed boundary and stored this information on disk file for future reference. A grey-scale map of the resulting disk file provides a close approximation of a digital map of the watershed area.

Procedures used to obtain the spectral reflectance of the Arizona watersheds from Landsat MSS digital data were somewhat different from those used for the Texas watersheds. A block of data containing the watershed area was still moved from CCT and stored on disk file to reduce data handling. However, input controls to the computer program (MOVE) that transferred this block of data were estimated from a grid placed over a nine inch Landsat image A grey-scale map of the area was then obtained as before. To locate the watershed on the grey map, at least five identifiable points were selected (usually more) to correlate latitude and longitude to the corresponding record and pixel by a multiple linear regression computer program. Provided the correlation coefficients were of sufficient magnitude (on the order of 0.99), the watershed boundary points in latitude and longitude were converted into records and pixels. The estimated location of boundary points was verified on the grey-scale maps. Equations used to convert latitude and longitude to records and pixels, respectively, were of the form:

$$\text{Record} = A_1 \text{ X Latitude} + A_2 \text{ X Longitude} + A_0$$

$$\text{Pixel} = B_1 \text{ X Latitude} + B_2 \text{ X Longitude} + B_0$$

where A_1, A_2, A_0, B_1, B_2, and B_0 were coefficients determined by multiple linear regression. The watershed boundary points were then plotted and the boundary outlined on the grey map. Average spectral reflectance (in counts) for the four MSS bands less the influence of water surfaces were also computed from the digital data within the watershed boundary for these data sets.

Additional ground truth data seemed advisable after a preliminary examination of calculated CN values and Landsat data. Additional information gathered for each watershed included soil types within the drainage area, API for date of Landsat coverage for the watershed, and an improved estimate of timber cover on the watershed.

A first-degree approximation of the different soils in the Texas and Arizona watersheds was obtained from the General Soil Map of Texas and the Arizona General Soil Map. Tables 1 and 2 give the soil map symbol designated for the various soil associations found in the Texas and Arizona watersheds, respectively. These soil map symbols are defined in Appendix A for both the Texas watersheds and the Arizona watersheds. Soil series names that make up the soil association are described by color and texture obtained from soil survey manuals. A short narrative of the soil association is also given.

The last column in Tables 3 and 4 lists the actual API (30-day) value for the watershed on the date of Landsat coverage. Landsat scenes listed in this table were ordered on the basis of low regional API values with the assumption that the antecedent moisture conditions were not significantly different throughout the area of coverage. However, as shown by Table 3, API values for the Texas watersheds were very high for a number of watersheds. Antecedent precipitation index values determined for the Arizona watersheds are not as reliable as those calculated for Texas because rain gauge density is low.

Timber cover was determined as a percentage of total watershed area. Initially, percent of drainage area in timber was estimated from USGS topographic maps by measuring the green shaded area inside the watershed boundary for the Texas watersheds. Since the green shaded areas on topographic maps of the Arizona watersheds did not seem to represent the actual timber areas, timber cover was estimated from orthophotoquads of the watershed area It was sometimes impossible to distinguish between timber and brush by this method which grossly overestimated the timber cover percentage on some watersheds. Therefore, it was felt necessary to devise a classification scheme to detect timber from Landsat data. Since the Landsat data used in this study were collected

Table 3. Texas Watersheds

Watershed	Landsat Scene Date	Landsat Scene I.D.	API (cm)
Deep Cr.	10-07-72	1076-16414	1.14
Green Cr.	10-07-72	1076-16414	0.56
Mukewater Cr.	10-07-72	1076-16414	0.71
North Cr.	10-07-72	1076-16411	0.30
N. Fk. Hubbard Cr.	10-07-72	1076-16411	1.32
Cow Bayou	11-11-72	1111-16363	4.60
Middle Bosque R.	11-11-72	1111-16363	2.90
Little Pond Cr.	11-28-72	1128-16305	2.69
North Elm Cr.	11-28-72	1128-16305	2.34
Tehuacana Cr.	11-28-72	1128-16305	2.59
Lavaca R.	12-16-72	1146-16311	1.55
Berry Cr.	12-12-73	1507-16340	0.53
Cibolo Cr.	12-12-73	1507-16340	0.13
S. Fk. San Gabriel R.	12-12-73	1507-16340	0.43
S. Fk. Rocky Cr.	12-12-73	1507-16340	0.23
Calaveras Cr.	02-22-74	1579-16323	0.18
Bois d'Arc Cr.	03-29-74	1614-16245	0.76
Honey Cr.	03-29-74	1614-16245	0.76
Little Elm Cr.	03-29-74	1614-16245	0.94
Pecan Bayou	03-29-74	1614-16245	1.55
Big Bear Cr.	10-09-75	5173-16065	0.15
Elm Fk. Trinity R.	10-09-75	5173-16065	0.33

Table 4. Arizona and New Mexico Watersheds

Watershed	Landsat Scene Date	Landsat Scene I.D.	API (cm)
Albuquerque W-1	10-25-75	2276-17022	0.00
Albuquerque W-2	10-25-75	2276-17022	0.00
Albuquerque W-3	10-25-75	2276-17022	0.00
Safford W-1	10-09-75	2260-17142	0.13
Safford W-2	10-09-75	2260-17142	0.13
Safford W-4	10-09-75	2260-17142	0.13
Safford W-5	10-09-75	2260-17142	0.13
Walnut Gulch W-3	11-14-75	2296-17143	0.03
Walnut Gulch W-4	11-14-75	2296-17143	0.03
Walnut Gulch W-11	11-14-75	2296-17143	0.03
Atterbury W-2	11-14-75	2296-17143	0.03
Atterbury W-3	11-14-75	2296-17143	0.03
Tanque Verde Cr.	11-14-75	2296-17143	0.03
Rincon Cr.	11-14-75	2296-17143	0.03
Sabino Cr.	11-14-75	2296-17143	0.03
Bear Cr.	11-14-75	2296-17143	0.03
E. Fk. White R.	10-09-75	2260-17140	0.38
Pacheta Cr.	10-09-75	2260-17140	0.38
Nutrioso Cr.	10-09-75	2260-17140	0.38
E. Fk. Seven Springs	10-09-75	2260-17140	0.38
E. Fk. Castle Cr.	10-09-75	2260-17140	0.38
N. Fk. Thomas Cr.	10-09-75	2260-17140	0.38
S. Fk. Thomas Cr.	10-09-75	2260-17140	0.38
W. Fk. Willow Cr.	10-09-75	2260-17140	0.38

Table 4 (cont.)

Watershed	Landsat Scene Date	Landsat Scene I.D.	API (cm)
E. Fk. Sycamore Cr.	10-10-75	2261-17194	0.13
W. Fk. Sycamore Cr W-1	10-10-75	2261-17194	0.13
W. Fk. Sycamore Cr. W-2	10-10-75	2261-17194	0.13
Sycamore Cr.	10-10-75	2261-17194	0 13
New R.	10-10-75	2261-17194	0.13
Wet Bottom Cr.	10-10-75	2261-17194	0.13
Wet Beaver Cr.	10-10-75	2261-17194	0.13
Red Tank Draw	10-10-75	2261-17194	0.13
Rattlesnake Canyon	10-10-75	2261 17194	0.13
Beaver Cr. W-4	10-10-75	2261-17194	0.13
Beaver Cr. W-8	10-10-75	2261-17194	0.13
Beaver Cr. W-13	10-10-75	2261-17194	0.13
Beaver Cr. W-18	10-10-75	2261-17194	0.13

during the dormant season, a good estimate of timber on the watersheds was possible since brush species appear different than timber when vegetation was relatively dormant. It is apparent that grass and other low vegetation grows under brush cover and cannot be detected in the growing season. During the dormant season, the presence of dead grass apparently aids in the separation of brush and timber.

To determine the spectral signature of the different species of trees in the watersheds, eight representative watersheds were selected for study, four in Texas and four in Arizona. The digital data within the previously defined watershed boundary were displayed on a dynamic color display (DCD). Selected levels of band five MSS data were found to represent the timbered areas best. After being assured that the timbered areas displayed on the screen were similar to the timbered areas denoted by USGS topographic maps, small areas representing timber were outlined with a cursor. The mean value of the digital data in the outlined area was calculated for the four MSS bands by the computer. Open areas adjoining timbered areas were also outlined and the mean value computed for the four data bands.

A cursory examination of the data from these eight watersheds indicated that digital data in MSS bands five and seven showed the most promise of detecting timbered areas. A range of values representing timber were calculated by using one standard deviation on either side of the mean for band five and band seven. These intervals were graphed as shown in Figure 3. The algorithm devised to detect timber merely determines if the values of band 5 and 7 place the data point in a region near the training set. The algorithm was implemented in a computer program and timber cover calculated for all Texas and Arizona watersheds known to have timber within their drainage area. Tables 1 and 2 list timber cover percentages for the various watersheds in Texas and Arizona, respectively.

4.0 ANALYSIS AND DISCUSSION

Average curve numbers and the mean value of the digital data from Landsat MSS bands four, five, six, and seven were tabulated for all watersheds used in this study. These data are presented in Tables 5 and 6 for the Texas watersheds and the Arizona watersheds, respectively. Curve number versus the individual band data as well as combinations of the MSS bands were plotted for both the Texas watersheds and the Arizona watersheds. No definite correlation between calculated curve number and spectral reflectance from the watersheds was obvious when all watersheds in each region were considered. Plots of the Texas watershed data exhibited more scatter than plots of the Arizona watershed data. The Arizona watershed data showed some promise of a linear relationship between curve numbers and Landsat data for the watersheds with no timber cover.

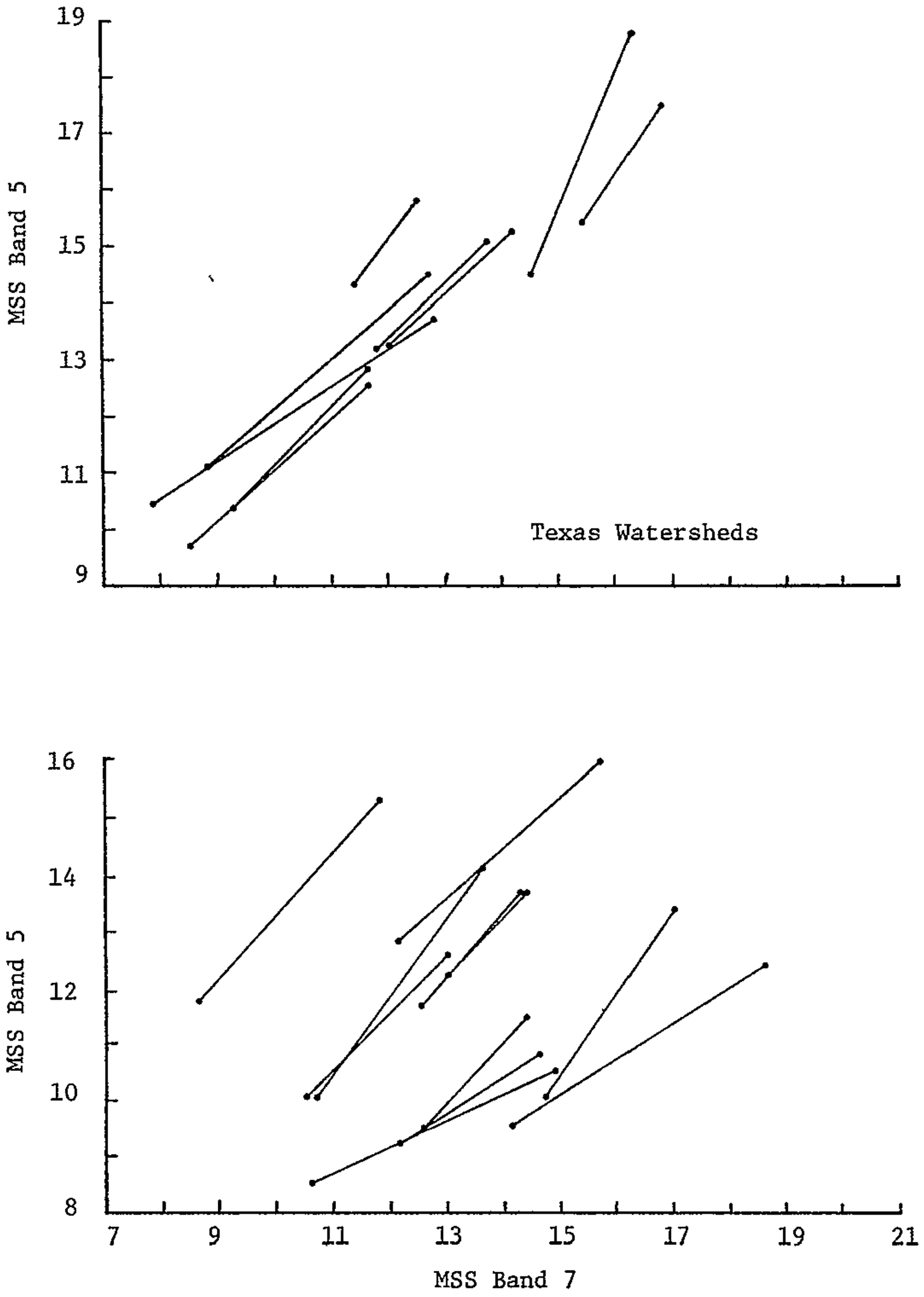


Figure 3. Basis for timber classification scheme during dormant season. Lines denote one standard deviation on either side of the mean value.

Table 5. Curve numbers and Landsat MSS digital data means for the selected Texas watersheds. Influence from ponded water on spectral reflectance from the watershed was deleted.

Watershed	Curve Number	MSS Band Averages			
		4	5	6	7
Little Pond Creek	75.7	27.16	22.34	22.49	10.23
Bois d'Arc Creek	74.3	30.64	26.78	37.33	19.46
North Elm Creek	70.4	23.86	20.25	21.25	10.74
Honey Creek	68.1	30.89	27.45	35.84	18.22
Lavaca River	63.4	22.37	19.79	23.47	13.50
Elm Fork Trinity River	56.4	26.75	24.25	31.50	14.65
Cibolo Creek	54.9	20.44	17.89	23.49	13.14
South Fork San Gabriel River	51.0	20.69	18.64	23.30	12.84
Green Creek	48.7	31.64	29 45	38.80	19.64
Mukewater Creek	48.7	32.39	31.41	36.72	17.76
South Fork Rocky Creek	44.0	21.50	20.11	23.82	12.89
Pecan Bayou	75.1	26.68	22.32	35.51	19.46
Little Elm Creek	72.8	31.90	28.41	39.69	20.35
Tehuacana Creek	68.9	22.40	19.53	25.60	13.64
Big Bear Creek	63.4	28.02	25.71	34.39	16.08
North Creek	57.2	29.41	25 86	32.78	16.29
Middle Bosque River	54.9	25.36	21.57	24.73	11.86
Cow Bayou	54.1	26.27	22.35	26.37	12.69
North Fork Hubbard Creek	50.2	31.05	26.53	36.40	18.29
Berry Creek	48 7	20.52	18.52	23.67	13.05
Deep Creek	48.7	31.14	27.48	35.99	17.98
Calaveras Creek	43 4	26.86	26.00	31.31	16.77

Table 6. Curve numbers and Landsat MSS digital data means for selected Arizona watersheds. Influence from ponded water on spectral reflectance from the watershed was deleted.

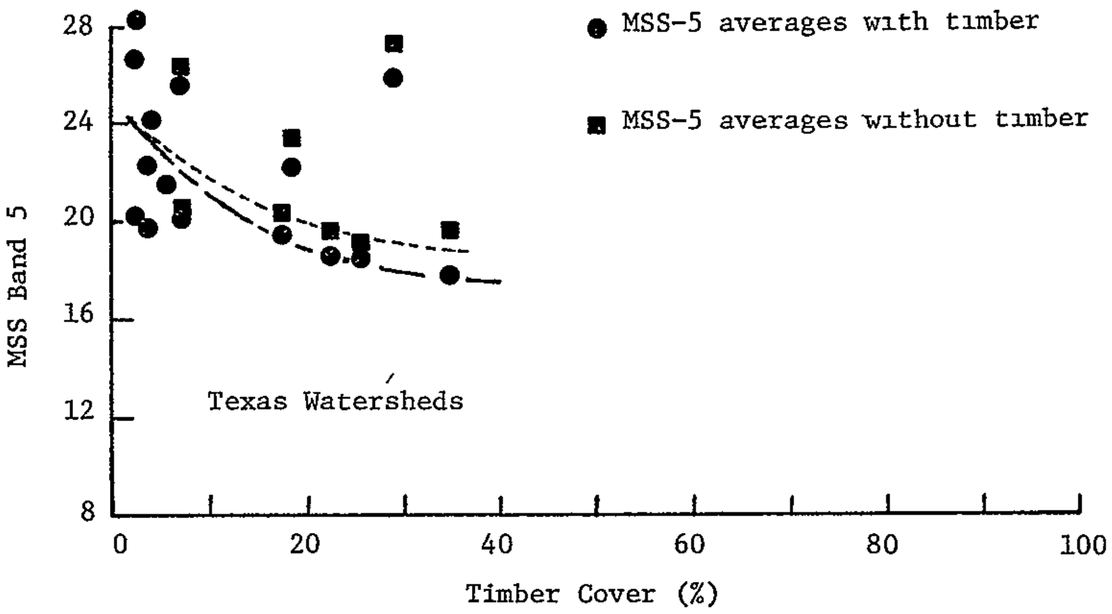
Watershed	Curve Number	MSS Band Averages 4	5	6	7
Safford W-1	62.2	24.68	37.62	42.72	16.52
Safford W-2	63.2	29.54	47.53	53.79	22.01
Safford W-4	55.0	32.87	55.26	62.73	25.24
Safford W-5	51.6	25.37	37.67	47.40	19.83
Walnut Gulch W-3	56.6	22.10	33.74	38.39	16.18
Walnut Gulch W-4	67.8	20.71	30.76	34.87	14.56
Walnut Gulch W-11	65.8	21.64	32.49	37.44	15.86
Atterbury W-2	46.5	26.89	41.26	46.98	19.86
Atterbury W-3	49.7	27.45	42.57	48.57	20.54
Tanque Verde Creek	76.9	17.87	24.88	31.65	14.14
Rincon Creek	66.1	16.69	22.92	30.91	14.17
Sabino Creek	81.2	14.86	19.52	30.67	15.19
Bear Creek	77.6	15.52	20.71	31.32	15.28
East Fork White River	63.0	9.49	10.57	25.40	13.34
Pacheta Creek	47.2	10.45	12.94	27.54	14.32
Nutrioso Creek	41.5	11.86	15.19	27.73	13.72
East Fork Seven Springs	38.8	15.43	22.61	34.69	16.88
East Fork Castle Creek	55.6	9.66	10.97	22.83	11.46
North Fork Thomas Creek	41.8	9.22	10.14	25.11	13.15
South Fork Thomas Creek	41.6	8.59	9.13	22.30	11.59
West Fork Willow Creek	44.6	9.06	10.17	24.44	12.95
East Fork Sycamore Creek	48.6	14.34	17.01	33.47	16.74
West Fork Sycamore Creek W-1	47.8	13.78	16.64	32.62	16.37
West Fork Sycamore Creek W-2	63.4	14.02	16.89	32.78	16.32
Sycamore Creek	54.4	16.62	21.28	33.35	15.38

Table 6 (cont.)

Watershed	Curve Number	MSS Band Averages			
		4	5	6	7
New River	62.5	21.36	29.88	36.68	15.31
Wet Bottom Creek	64.9	15.11	19.89	31.03	14.26
Wet Beaver Creek	64.6	14.54	19.69	30.21	14.02
Red Tank Draw	64.9	15.90	21.96	31.05	13.97
Rattlesnake Canyon	71.8	13.96	18.49	29.18	13.50
Beaver Creek W-4	65.7	16.89	25.24	33.11	14.69
Beaver Creek W-8	62.9	11.63	14.30	28.19	14.01
Beaver Creek W-13	59.2	12.49	15.28	29.41	14.37
Beaver Creek W-18	74.8	13.33	17.63	29.92	14.15

The data scatter for watersheds with timbered cover may be due to a number of factors. The watershed surface may be wet even though the regional antecedent index was low. Secondly, at the low latitudes where these watersheds were located there may have been green vegetation even though the season was considered dormant. Most important, spectral reflectance from timbered areas is dependent on the tree species and the stage of growth. Soil color is not detectable under timber and little or no grass is present in the forested areas. Some differences in the spectral response from the Arizona watersheds were likely due to shadows and rough terrain. Not actually seeing the soil surface due to various amounts of timber cover on the watersheds was considered to be the most serious problem.

Many of the Arizona watersheds have considerable amounts of timber on them and a few of the Texas watersheds have some timber. Heavily timbered areas were found to absorb light and, thus, reduce the average reflectance. It was decided therefore to delete the effects of timber from Landsat digital data. The effect of timber on reflectance as represented by the digital data is shown by Figure 4. The mean of MSS band five digital data with timber effects included was plotted versus percent timber cover for the watershed. As timber cover increased, MSS band five values decreased. An



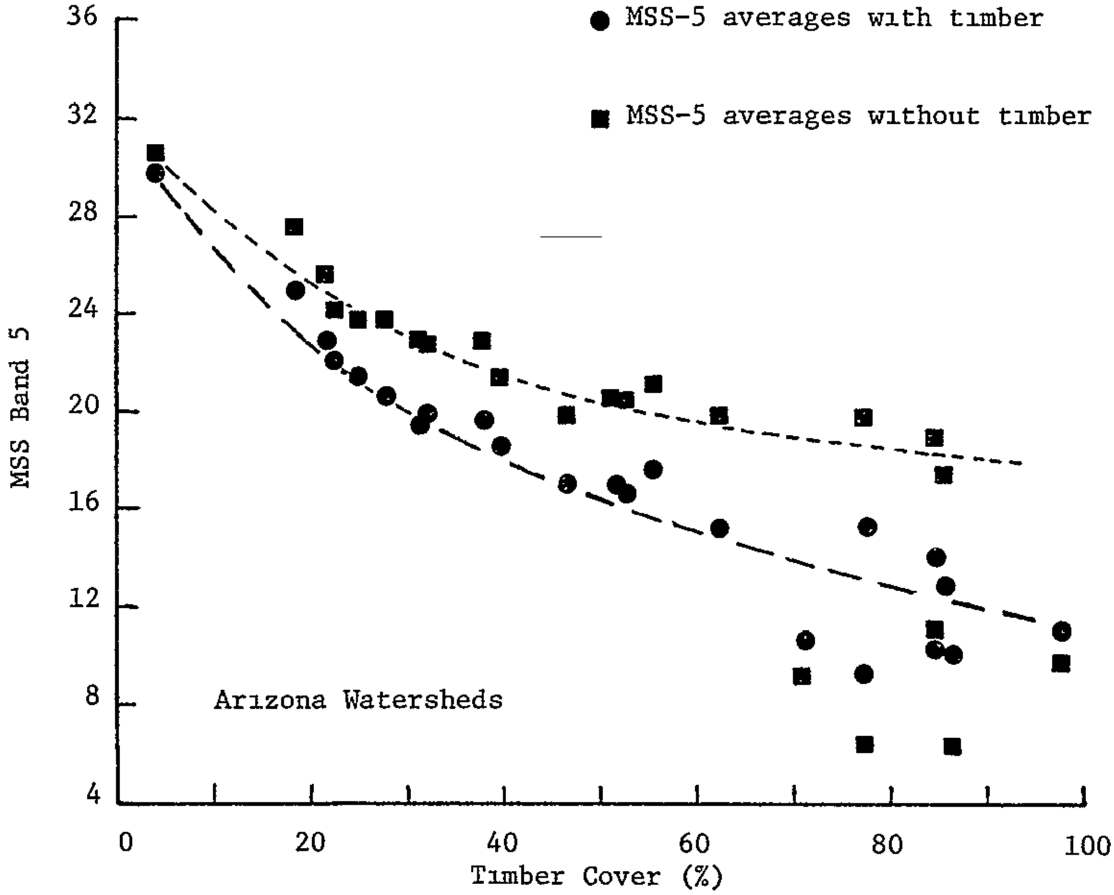


Figure 4. Timber influences on Landsat MSS band 5 digital data.

algorithm was developed to detect pixels representing timbered areas and was then used to delete those pixels from each data set. Consequently, a mean digital value for the four MSS bands without the influence of water and timber was determined for all the watersheds. These data are presented in Tables 7 and 8 for the Texas watersheds and the Arizona watersheds, respectively. Also tabulated for each watershed is the mean of MSS-5 minus the mean of MSS-4 and the curve number. Multispectral scanner band five digital means with timber deleted versus percent timber cover (Figure 4) were plotted to show the effect timber has on spectral reflectance from a timbered watershed. Generally, as timber cover increased, the difference between MSS-5 means with timber included (dots) and MSS-5 means without timber influences (squares) increased which indicates heavily timbered areas absorb much of the energy in this band. It is also evident that much of the influence of timber in the Arizona watersheds was not removed by the algorithm used.

Data plots of calculated curve number versus digital averages of the four bands with timber deleted still produced considerable data scatter. The two combinations of MSS data $\mu_5-\mu_4$ and $\mu_5+\mu_6-(\mu_4+2\mu_7)$, that correlated with CN for the Oklahoma watershed study (Blanchard, 1975) were also plotted versus calculated curve numbers. Plots of MSS-5 minus MSS-4 had less data scatter than the other band combination and

Table 7. Landsat MSS digital data means for individual bands, difference between two bands, and curve numbers for the Texas test watersheds. Influence from ponded water and timber on spectral reflectance from the watershed were deleted.

Watershed	MSS Band Averages 4	5	6	7	5-4	Curve Numbers
Little Pond Creek	27.16	22.34	22.49	10.23	-4.82	75.9
*Bois d'Arc Creek	30.64	26.78	37.33	19.46	-3.86	74.3
North Elm Creek	23.92	20.36	21.19	10.68	-3.56	70.4
*Honey Creek	30.89	27.45	35.84	18.22	-3.44	68.1
Lavaca River	22.37	19.79	23.47	13.50	-2.58	63.4
*Elm Fork Trinity River	26.96	24.62	31.66	14.67	-2.34	56.4
*Cibolo Creek	21.45	19.74	24.58	13.53	-1.71	54.9
*South Fork San Gabriel River	21.23	19.69	23.62	12.84	-1.54	51.0
*Green Creek	31.71	29.58	38.90	19.68	-2.13	48.7
*Mukewater Creek	32.45	31.51	36.77	17.78	-0.94	48.7
*South Fork Rocky Creek	21.70	20.49	23.99	12.93	-1.21	44.0
Pecan Bayou	27.52	23.52	37.03	20.26	-4.00	75.1
*Little Elm Creek	31.90	28.41	39.69	20.35	-3.49	72.8
Tehuacana Creek	22.86	20.36	26.11	13.81	-2.50	68.9
*Big Bear Creek	28.40	26.39	34.73	16.15	-2.01	63.4
*North Creek	30.39	27.45	33.76	16.61	-2.94	57.2
Middle Bosque River	25.62	22.00	24.86	11.87	-3.62	54.9
Cow Bayou	26.27	22.35	26.37	12.69	-3.92	54.1

Table 7 (cont.)

Watershed	MSS Band Averages					Curve Numbers
	4	5	6	7	5-4	
North Fork Hubbard Creek	31.07	26.57	36.43	18.31	-4.50	50.2
*Berry Creek	21.02	19.22	23.85	12.96	-1.80	48.7
Deep Creek	31.20	27.58	36.05	18.00	-3.62	48.7
*Calaveras Creek	26.92	26.12	31.46	16.86	-0.80	43.4

Table 8. Landsat MSS digital data means for the individual bands, difference between two bands and Hawkins CN for the Arizona test watersheds. Influences from ponded water and timber on spectral reflectance from the watershed were deleted.

Watershed	MSS Band Averages					Curve Numbers
	4	5	6	7	5-4	
*Safford W-1	24.68	37.62	42.72	16.52	12.94	62.2
*Safford W-2	29.54	47.53	53.79	22.01	17.99	63.2
*Safford W-4	32.87	55.26	62.73	25.24	22.39	55.0
*Safford W-5	25.37	37.67	47.40	19.83	12.30	51.6
*Walnut Gulch W-3	22.10	33.74	38.39	16.18	11.64	56.6
*Walnut Gulch W-4	20.71	30.76	34.87	14.56	10.05	67.8
*Walnut Gulch W-11	21.64	32.49	37.44	15.86	10.85	65.8
*Atterbury W-2	26.89	41.26	46.98	19.86	14.37	46.5
*Atterbury W-3	27.45	42.57	48.57	20.54	15.12	49.7
*Tanque Verde Creek	19.41	27.57	33.94	14.97	8.16	76.9
*Rincon Creek	18.27	25.61	32.66	14.61	7.34	66.1
Sabino Creek	16.99	22.98	33.02	15.90	5.99	81.2
Bear Creek	17.41	23.85	33.38	15.90	6.44	77.6
East Fork White River	8.57	9.18	21.86	11.43	0.61	63.0
Pacheta Creek	12.48	17.46	33.54	17.91	4.98	47.2
Nutrioso Creek	14.34	19.83	31.17	14.95	5.49	41.5
*East Fork Seven Springs	15.44	22.62	34.71	16.89	7.18	38.8
East Fork Castle Creek	9.64	9.82	20.05	9.77	0.18	55.6

Table 8 (cont.)

Watershed	MSS Band Averages 4	5	6	7	5-4	Curve Numbers
North Fork Thomas Creek	7.58	6.38	14.91	7.51	-1.20	41.8
South Fork Thomas Creek	7.28	6.49	15.64	7.99	-0.79	41.6
West Fork Willow Creek	9.77	11.23	23.16	12.06	1.46	44.6
East Fork Sycamore Creek	15.98	19.92	37.38	18.75	3.94	48.6
West Fork Sycamore Creek W-1	15.91	20.64	37.56	18.81	4.73	47.8
West Fork Sycamore Creek W-2	16.04	20.59	37.40	18.58	4.55	63.4
Sycamore Creek	17.98	23.76	35.34	16.08	5.78	54.4
*New River	21.68	30.46	37.17	15.48	8.78	62.5
Wet Bottom Creek	16.55	22.79	34.02	15.46	6.24	64.9
Wet Beaver Creek	16.19	23.01	31.53	14.13	6.82	64.6
Red Tank Draw	17.03	24.19	31.94	14.08	7.16	64.9
Rattlesnake Canyon	15.41	21.48	30.31	13.61	6.07	71.8
*Beaver Creek W-4	16.91	25.28	33.13	14.70	8.37	65.7
Beaver Creek W-8	13.29	18.91	29.64	14.50	5.62	62.9
Beaver Creek W-13	15.46	21.75	32.48	15.17	6.29	59.2
Beaver Creek W-18	14.72	21.21	31.76	14.61	6.49	74.8

and are shown in the top graph of Figure 5 for the Texas watersheds and in Figure 6 for the Arizona watersheds. A correlation between Landsat data and CN was not obvious, especially for the Arizona watersheds. Since API values were high for several Texas watersheds, those with an API greater than one cm were deleted. This decision was based on the conclusion in the Oklahoma watershed study that MSS digital data can be related to watershed runoff coefficients only when dry surface conditions exist. Deleting the watersheds with high API values resulted in a fairly good correlation (R^2=0.81) between Landsat digital data and calculated curve number (bottom graph of Figure 5). Landsat data plotted was the mean of MSS-5 minus the mean of MSS-4 for the watershed with timber influences deleted from the digital data averages. Texas watersheds used in Figure 5 are identified with an asterisk and their locations are numbered in Figure 1.

Data scatter for the plot of Landsat MSS-5 minus MSS-4 versus CN (Figure 6) for the Arizona watersheds could not be attributed to wet surfaces since the API values were low. The timber situation was again considered. A close examination of MSS-5 digital data versus timber cover for the Arizona watersheds was undertaken. A difference of approximately five counts for MSS-5 data existed between a watershed

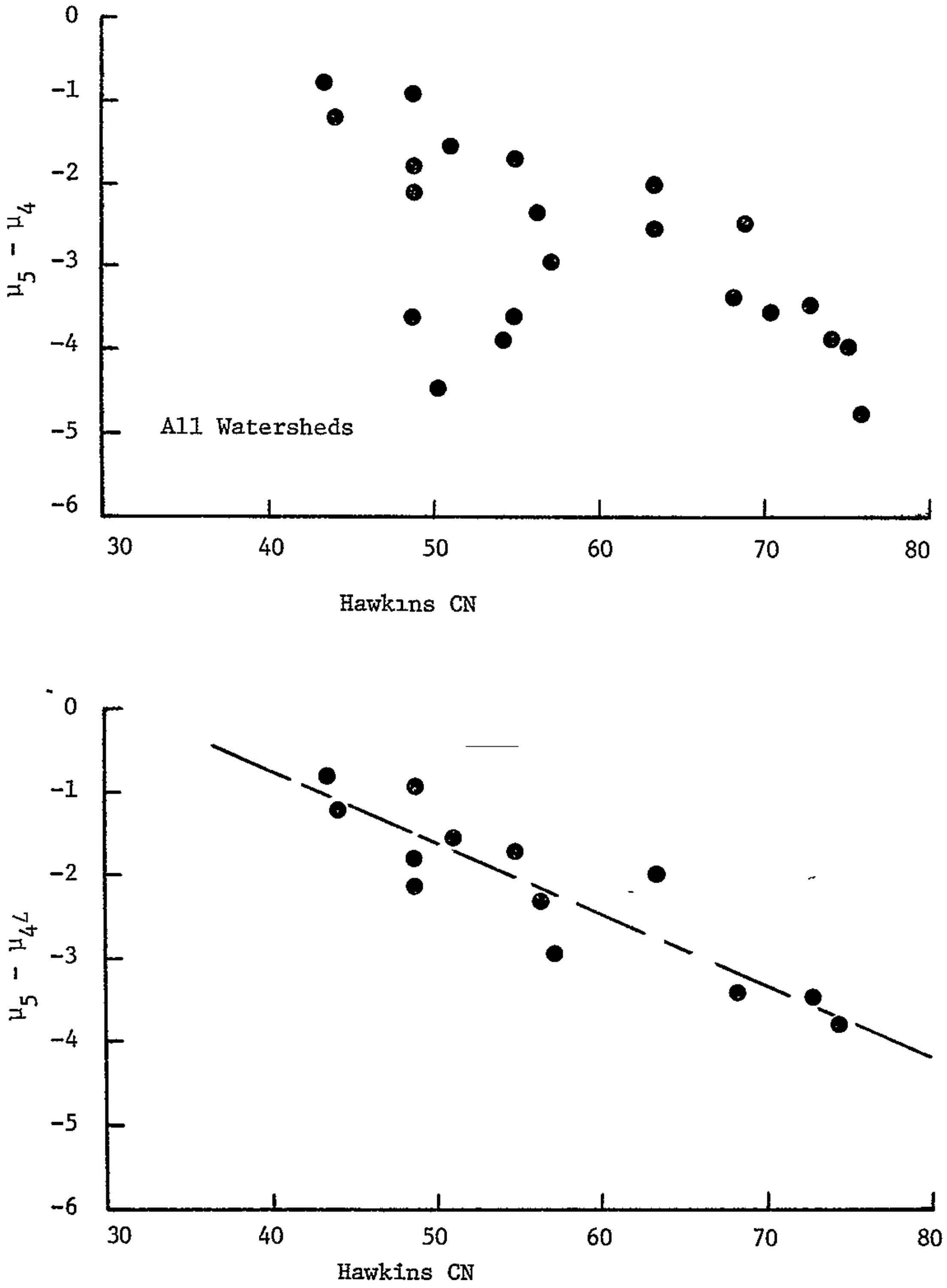


Figure 5. Landsat MSS digital data for band 5 mean minus band 4 mean versus calculated curve number for Texas test watersheds. Ponded water and timber effects deleted from Landsat data.

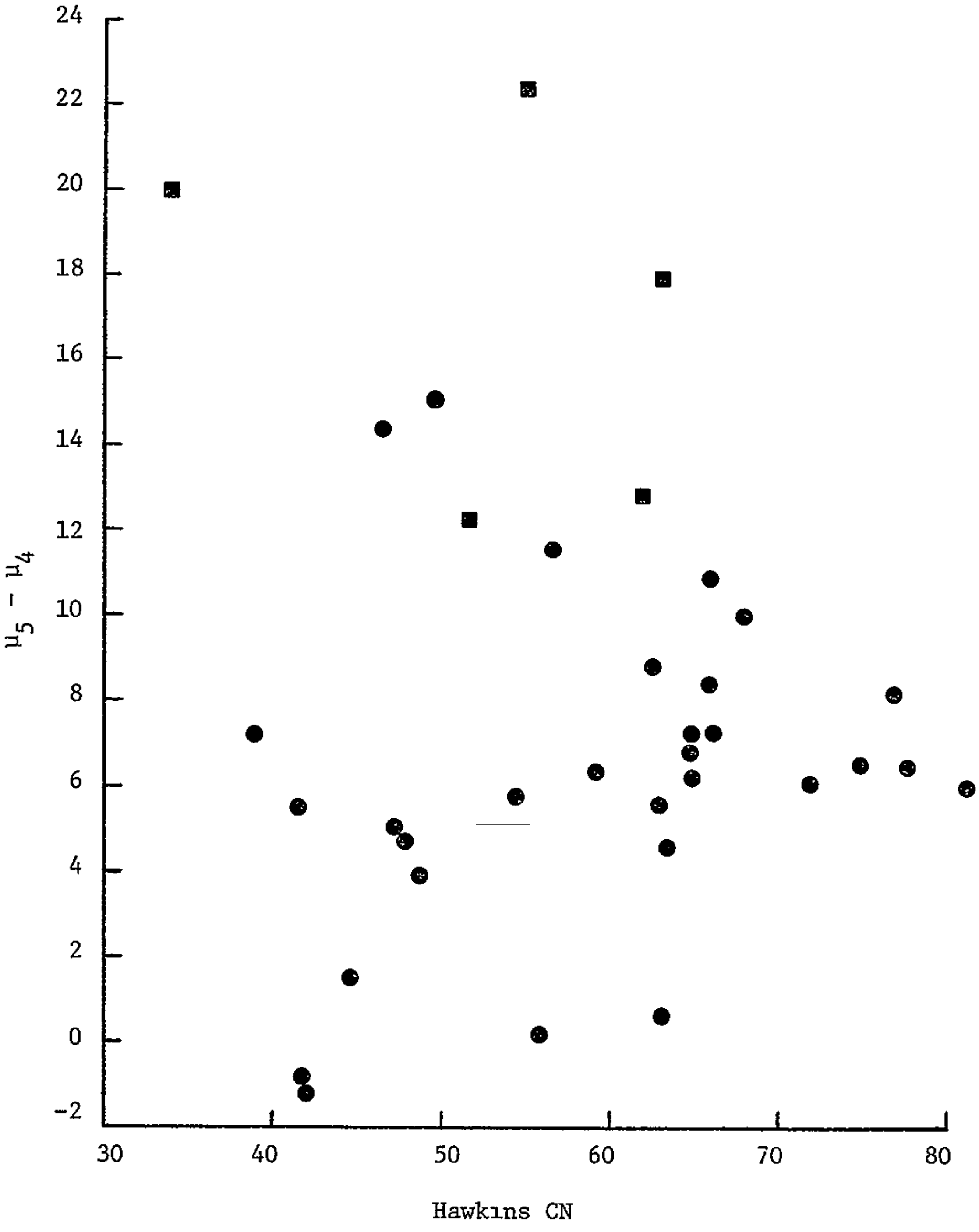


Figure 6. Landsat MSS digital data for band 5 mean minus band 4 mean versus calculated curve number for all the Arizona test watersheds. Ponded water and timber effects deleted from Landsat data.

with less than 5 percent timber cover and a watershed with 35 percent timber cover. This was for the timber-deleted averages. Upon examining MSS-5 data from Arizona watersheds represented in Figure 4, it was evident that a watershed with more than 21 percent timber cover exceeded the five count difference. Therefore, any watershed with more than 21 percent timber cover was deleted and the data points replotted. Figure 7 shows Landsat MSS-5 minus MSS-4 mean digital data versus calculated curve number plotted for watersheds with 21 percent timber cover or less.

Figure 7 indicates that some influence remained in the spectral data that was due to effects of timber cover or possibly heavier brush cover. The figure also implies that for watersheds that have no timber there is a possible relation between spectral response and curve numbers. The scarcity of watersheds without timber of brush and with adequate records to calibrate the system would, however, limit application in the arid regions.

Watersheds used in Figure 7 are identified with an asterisk in Table 6 and their locations are starred in Figure 2. A linear regression of the Arizona data was not done because a lack of a clear understanding of remaining influences of timber and brush cover. There are three outlying points in Figure 7. The point in the lower left corner is

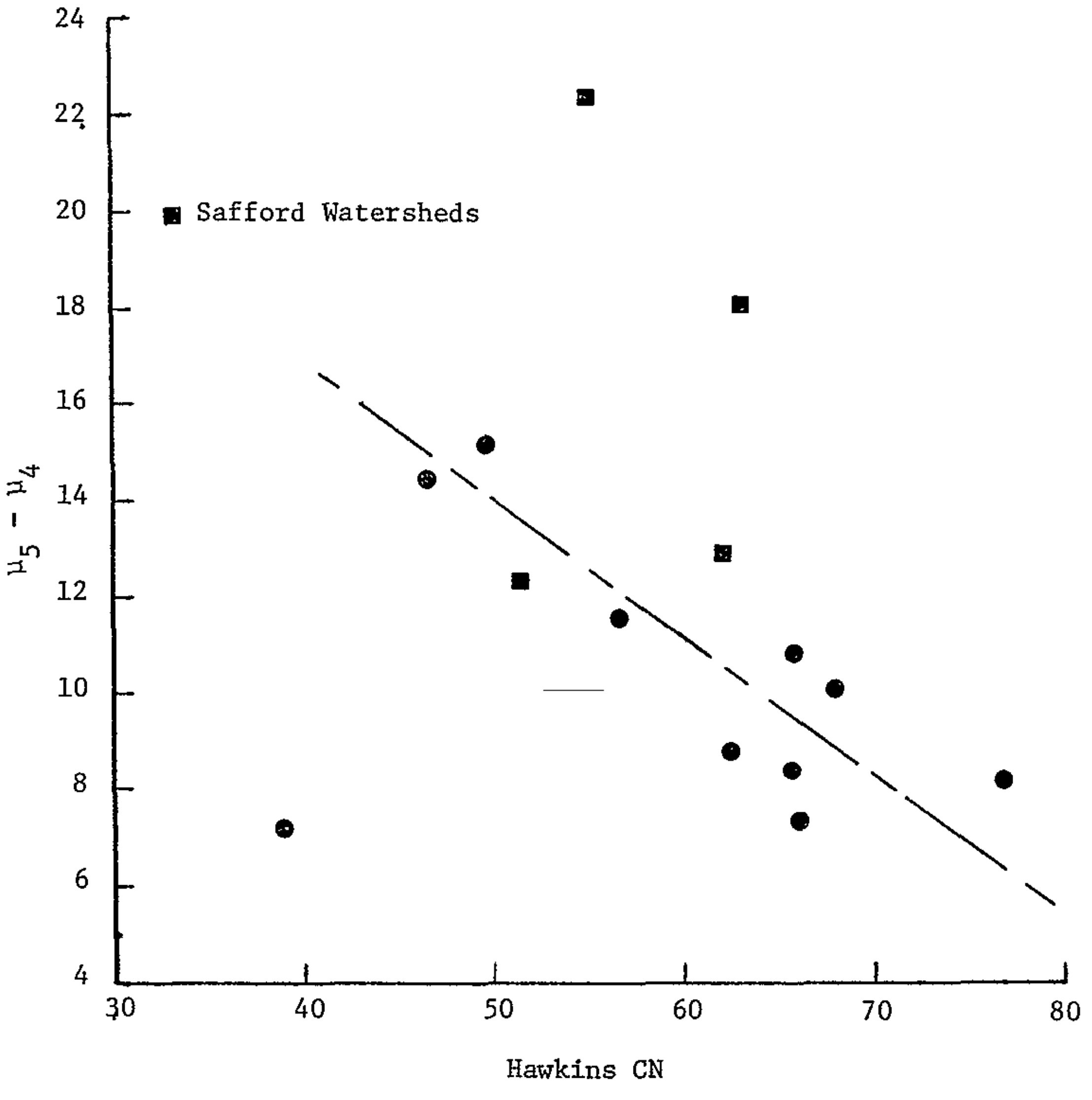


Figure 7. Landsat MSS digital data for band 5 mean minus band 4 mean versus calculated curve number for the Arizona test watersheds with 21% timber cover or less. Ponded water and timber effects deleted from Landsat data.

East Fork Seven Springs watershed. It is a high elevation grassland watershed which accumulates snow and builds a good snow pack. Thus, snow melt is a likely major contribution to streamflow. Only storm events during the summer and early fall were selected to calculate curve numbers. Very small amounts of runoff resulted from these storms making the curve number suspect. The soils on this watershed are dark brown to very dark grayish-brown which may explain why Landsat digital data is low. The other two outlying points are two of the four Safford experimental watersheds (square symbols). The uppermost point is watershed W-4; the other one is watershed W-2. Soils descriptions for these two watersheds indicate color of the soil may tend to be more reddish-brown thus a greater difference would be expected between bands five and four.

The trend in both Figures 5 and 7 is in the same direction. An increase in the difference between band 5 and 4 reduces the curve number. This trend is opposite the trend found in central Oklahoma in the previous study. Soils in the watershed areas used in the previous study were various shades of red and reddish-brown. The soils in the Texas watersheds range from gray to black and the Arizona soils are generally classed as brown. In the red soils of central Oklahoma the deep red color occurs in the more impermeable soils while lighter colored soils are highly permeable. The dark gray soils in Texas are impermeable and the light gray soils are more permeable. One would expect low reflectance in all Landsat bands from Houston black clay and a small difference between bands five and four, however, the red clay of Oklahome should produce a marked difference between bands five and four. The more permeable soils in both locations should produce similar Landsat data. The trend when relating the difference versus curve numbers over bare soils in these two regions should be different. This would indicate a strong dependence on the color of the soils in a region and would restrict application of the techniques to soils of the same basic color as the soils of the calibration watersheds.

5.0 CONCLUSIONS

It is readily apparent in this study that the spectral calibration of runoff curve numbers cannot be achieved on watersheds where significant areas of timber are within the drainage area.

The absorption of light by wet soil conditions restricts differentiation of watersheds with regard to watershed runoff curve numbers.

It appears that the predominant factor influencing the classification of watershed runoff curve numbers is the difference in soil color and its associated reflectance when dry.

In regions where vegetation grows throughout the year, where wet surface conditions prevail or where watersheds are timbered, there is little hope of classifying runoff potential with visible light alone.

ACKNOWLEDGEMENTS

The author wishes to express appreciation to Dr. K.G. Renard at the Southwest Research Center in Tucson, Arizona, for providing rainfall and runoff data from the Walnut Gulch and Safford experimental watersheds used in this study. Assistance from his staff in compiling the data was greatly appreciated.

Sincere thanks is expressed to Mr. Sol D. Resnick, Director of Water Resources Research at the University of Arizona, for providing rainfall and runoff data summaries. for the Atterbury experimental watersheds.

The author also appreciates data provided by staff at the Rocky Mountain Forest and Range Experiment Station. In particular, appreciation is expressed to Dr. J.R. Thompson at Tempe, Arizona, for providing streamflow and precipitation summaries for the following watersheds used in this study: East Fork Seven Spring, West Fork Willow Creek, North Fork and South Fork Thomas Creek, and East Fork Castle Creek as well as others not used in the study. Data from Beaver Creek watersheds four, eight, thirteen, and eighteen supplied by Dr. D. Ross Carder at Flagstaff, Arizona, were greatly appreciated.

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APPENDIX A

15A Wilson - dark grayish-brown clay loam
Crockett - dark grayish-brown loam
Burleson - dark gray clay

Slightly acid soils with loamy surface layers and cracking clayey subsoils, and noncalcareous cracking clayey soils.

16V Burleson - dark gray clay
Heiden - dark grayish-brown clay
Crockett - dark grayish-brown loam

Noncalcareous and calcareous cracking clayey soils; and slightly acid soils with loamy surface layers and cracking clayey subsoils.

18A Lufkin - light brownish-gray fine sandy loam
Axtell - grayish-brown fine sandy loam
Tabor - grayish-brown fine sandy loam

Soils with loamy surface layers and mottled gray and red or yellow cracking clayey subsoils.

19A Wrightville - dark grayish-brown very fine sandy loam
Susquehanna - gray fine sandy loam
Muskogee - pale brown silt loam

Soils with loamy surface layers and mottled gray and red or yellow cracking clayey subsoils.

21A Windthorst - light brownish-gray fine sandy loam
Nimrod - grayish-brown fine sand
Duffau - dark grayish-brown fine sandy loam

Soils with loamy or sandy surface layers and red or mottled clayey or loamy subsoils.

22A Windthorst - light brownish-gray fine sandy loam
Galey - brown loamy fine sand
Konawa - light brown fine sandy loam

Soils with loamy or sandy surface layers and red or mottled clayey or loamy subsoils.

24A Miguel - brown fine sandy loam
San Antonio - dark brown clay loam

Light colored soils with loamy surface layers and clayey subsoils.

41A Truce - brown fine sandy loam
Owens - light olive-brown clay
Waurika - grayish-brown fine sandy loam

Moderately deep to deep soils with loamy surface layers and clayey subsoils, and shallow clayey soils.

42A Bonti - brown fine sandy loam
Truce - brown fine sandy loam
Vashti - grayish-brown loamy fine sand

Moderately deep to deep soils with loamy surface layers and clayey subsoils, and shallow clayey soils.

14V Houston Black - very dark gray clay
Heiden - dark grayish-brown clay
Austin - dark grayish-brown silty clay

Dark calcareous mostly cracking clayey soils

17M Austin - dark grayish-brown silty clay
Stephen - dark grayish-brown silty clay
Eddy - light brownish-gray gravelly clay loam

Deep to shallow calcareous clayey soils over chalk.

48M Tarrant - dark grayish-brown silty clay
Kavett - dark grayish-brown silty clay
Rowena - dark grayish-brown clay loam

Mostly shallow and moderately deep soils over limy earths, red beds, or limestone; some deep soils with loamy surface layers and clayey subsoils.

52M Denton - dark grayish-brown silty clay
Purves - dark brown silty clay
Brackett - light brownish-gray loam

Moderately deep cracking clayey soils, shallow clayey and loamy soils, some stony or gravelly.

53M Tarrant - dark grayish-brown silty clay
Brackett - light brownish-gray loam
Denton - dark grayish-brown silty clay

Moderately deep cracking clayey soils, shallow clayey and loamy soils, some stony or gravelly.

55M Tarrant - dark grayish-brown silty clay
Brackett - light brownish-gray loam
Speck - very dark grayish-brown gravelly clay loam

Shallow stony to gravelly clayey soils, shallow loamy soils, and deep cracking clayey soils.

TS2 Pima - brown loam
Guest - brown clay loam

Deep, moderately coarse to moderately fine-textured, nearly level to gently sloping soils on floodplains and alluvial fans.

TS3 Tubac - yellowish-red sandy loam
Sonoita - brown sandy loam
Grabe - brown loam

Deep, moderately coarse to fine-textured, nearly level to strongly sloping soils of the uplands and drainageways.

TS4 White House - brown gravelly sandy loam
Bernardino - reddish-brown gravelly sandy loam
Hathaway - dark grayish brown gravelly loam

Deep, fine-textured and gravelly, moderately coarse to moderately fine-textured, nearly level to moderately steep soils on alluvial fan surfaces and steep side slopes.

TS6 Rockland - consists of 50-90% rock outcrops
Lehmans - brown gravelly clay loam
House Mountain - brown very gravelly loam
Cellar - pale brown very strong sandy loam

Shallow, cobbly, and gravelly, strongly sloping to very steep soils and rock outcrop on hills and mountains.

TS12 Continental - reddish-brown gravelly sandy loam
Latene - pinkish-gray gravelly sandy loam
Pinaleno - brown gravelly loam

Deep, gravelly, medium to fine-textured, nearly level to steep soils on dissected alluvial fan surfaces.

TS14 Nickel - grayish-brown granular gravelly loam
Latene - pinkish-gray gravelly sandy loam
Cave - pinkish-gray gravelly loam

Deep and shallow, limy and gravelly, medium and moderately coarse-textured, nearly level to very steep soils on dissected alluvial fan surfaces.

MH2 Barkerville - dark grayish-brown cobbly sandy loam
Moano - brown gravelly loam

Shallow, gravelly and cobbly, moderately coarse to moderately fine-textured, gently sloping to very steep soils with rock outcrop on hills and mountains.

FH2 Siesta - dark reddish-brown stony silt loam
Sponseller - dark reddish-brown stony silt loam
Brolliar - dark brown very stony loam

Moderately deep and deep, medium and moderately fine-textured, moderately sloping to very steep mountain soils.

FH5 Mirabal - grayish-brown gravelly sandy loam
Baldy - brown gravelly sandy loam
Rockland - consists of 50-90% rock outcrops

Shallow to deep, gravelly and cobbly, moderately coarse-textured, hilly to very steep mountain soils and rock outcrop

FH6 Eutroboralfs - brown very cobbly sandy loam
Mirabal - grayish-brown gravelly sandy loam

Shallow to deep, cobbly, moderately coarse and gravelly fine-textured, gently sloping to very steep mountain soils.

FH8 Gordo - dark brown silt loam
Tatiyee - very dark grayish-brown gravelly loam

Deep and moderately deep, gravelly, medium to fine-textured, nearly level to rolling soils of the mountain meadows.

MS1 Tortugas - dark grayish-brown very stony loam
Purner - reddish-brown gravelly loam
Jacks - reddish-brown light fine sandy loam

Shallow to moderately deep, gravelly and cobbly, medium and fine-textured, undulating to steep soils on hills and mountains.

MS4 Rudd - grayish-brown gravelly loam
Bandera - brown gravelly loam
Cabezon - brown very stony loam

Shallow, gravelly, cobbly and stony, medium and fine-textured, undulating soils on plains and mesa tops and gently rolling to steep soils on cinder cones.

MS7 Cabezon - brown very stony loam
Thunderbird - dark brown cobbly clay
Springerville - brown cobbly clay

Shallow to deep, gravelly, cobbly and stony, fine-textured, nearly level to very steep soils on basaltic plains, mesas, and hills.

The REMOTE SENSING CENTER was established by authority of the Board of Directors of the Texas A&M University System on February 27, 1968 The CENTER is a consortium of four colleges of the University, Agriculture, Engineering, Geosciences, and Science. This unique organization concentrates on the development and utilization of remote sensing techniques and technology for a broad range of applications to the betterment of mankind.