Final Report RSC 3018-6

APPLIED REGIONAL MONITORING OF THE VERNAL ADVANCEMENT AND RETROGRADATION (GREEN WAVE EFFECT) OF NATURAL VEGETATION IN THE GREAT PLAINS CORRIDOR

Principal Investigator
John W. Rouse, Jr.
Remote Sensing Center
College Station, Texas 77843

Author
D. W. Deering

Contributing Authors
R. H. Haas, R. I. Welch, J. C. Harlan, P. R. Whitney

January 1977
Type III Report for Period
February 1975-December 1976

In cooperation with the
Texas Agricultural Experiment Station
Texas A&M University
College Station, Texas 77843

Prepared for
Goddard Space Flight Center
Greenbelt, Maryland 29771

Contract No. NAS5-20796

TEXAS A&M UNIVERSITY
REMOTE SENSING CENTER
COLLEGE STATION, TEXAS

APPLIED REGIONAL MONITORING OF THE VERNAL ADVANCEMENT AND RETROGRADATION (GREEN WAVE EFFECT) OF NATURAL VEGETATION IN THE GREAT PLAINS CORRIDOR

Principal Investigator
John W. Rouse, Jr.
Remote Sensing Center
College Station, Texas

Author: D. W. Deering

Contributing Authors:
R. H. Haas, R. I. Welch
J. C. Harlan, P. R. Whitney

In cooperation with:
Texas Agricultural Experiment Station
Texas A&M University
College Station, Texas 77843

January 1977
Type III Report for Period
February 1975 - December 1976

Prepared for:
Goddard Space Flight Center
Greenbelt, Maryland 28771

Contract No. NAS5-20796

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Applied Regional Monitoring of the Vernal Advancement and Retrogradation (Green Wave Effect) of Natural Vegetation in the Great Plains Corridor		5. Report Date
		6. Performing Organization Code
7. Author(s) D.W. Deering (J.W. Rouse, Jr., R.H. Haas, R.I. Welch, J.C. Harlan and P.R. Whitney)		8. Performing Organization Report No. RSC 3018-6
9. Performing Organization Name and Address Remote Sensing Center, Texas A&M University, College Station, Texas 77843		10. Work Unit No.
		11. Contract or Grant No. NAS5-20796
		13. Type of Report and Period Covered Type III-Final Report Feb. 1975-Dec. 1976
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland 20771		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Landsat-2 follow-on investigation has shown that Landsat digital data products can be effectively employed on a regional basis to monitor changes in vegetation conditions. TVI6 (the normalized difference of Bands 5 and 6) was successfully applied to an extended test site and the Great Plains Corridor in tests of the ability to assess green forage biomass on rangelands as an index to vegetation condition. A strategy for using TVI6 on a regional basis was developed and tested.

The Great Plains Corridor investigations have shown that 1) for rangelands with good vegetative cover, such as most of those in the Great Plains, and which are not heavily infested with brush or undesirable weed species, the Landsat digital data can provide a good estimate (within 250 kg/ha) of the quantity of green forage biomass, and 2) at least five levels of pasture and range feed conditions can be adequately mapped for extended regions.

17. Key Words (Selected by Author(s)) Landsat, Rangeland, Great Plains, Green Biomass		18. Distribution Statement	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 220	22. Price*

ABSTRACT

The Great Plains Corridor project conducted by Texas A&M University as a part of the NASA Landsat-1 investigations laid a foundation upon which many applications of Landsat MSS data for rangeland management are being developed. The Landsat-1 investigation identified a Landsat-derived parameter, TVI6 (the normalized difference of Bands 5 and 6), for statistical estimation of the amount and seasonal condition of rangeland vegetation.

The Landsat-2 follow-on investigation has shown that Landsat digital data products can be effectively employed on a regional basis to monitor changes in vegetation conditions. TVI6 was successfully applied to an extended test site and the Great Plains Corridor in tests of the ability to assess green forage biomass on rangelands as an index to vegetation conditions.

A strategy for using TVI6 on a regional basis was developed and tested. The technique involves one-time preselection of a network of sample sites for which the Landsat digital radiance data are routinely extracted. The TVI6 parameter and model estimates of green biomass are then calculated and mechanically plotted as a contour map for the region. The computer software package was developed as a necessary part of this investigation.

The Great Plains Corridor investigations have shown that 1) for rangelands with good vegetative cover, such as most of those in the Great Plains, and which are not heavily infested with brush or undesirable weed species, the Landsat digital data can provide a good estimate (within 250 kg/ha) of the quantity of green forage biomass, and 2) at least five levels of pasture and range feed conditions can be adequately mapped for extended regions.

ACKNOWLEDGEMENTS

The Great Plains Corridor Landsat-2 Follow-On Project was accomplished through the assistance and expertise of a team of scientists and technicians coordinated by the Remote Sensing Center of Texas A&M University. Dr. J. W. Rouse, Jr. served as the Principal Investigator. Drs. R. I. Welch and J. C. Harlan shared the program management responsibilities with the author and provided scientific support. P. R. Whitney was responsible for the computer program development and processing of the Landsat MSS digital data. Dr. R. H. Haas, who was instrumental in the development of the TVI concept in the original investigation, provided the author with invaluable scientific advice and gave direction to the project.

The project is indebted to the researchers at the GPC test sites who unselfishly continued to provide ground support necessary for the accomplishment of the project objectives. These include: Dr. Larry Rittenhouse, Bill Rawlins and Jim Bluntzer of the Texas Experimental Ranch at Throckmorton; Dr. Bruce Blanchard* and Gene Gander, Chickasha, Oklahoma; E. H. McIlvain, Woodward, Oklahoma; Dr. J. L. Launchbauch, Hays, Kansas;

---

*Currently at the Remote Sensing Center, Texas A&M University.

Dr. Paul Seevers, Sand Hills, Nebraska; J. K. Lewis and Rod Smrcka, Cottonwood, South Dakota; and Drs. Russel Lorenz and Lenat Hofmann, Mandan, North Dakota.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

LIST OF TABLES

APPLIED REGIONAL MONITORING OF THE VERNAL ADVANCEMENT AND RETROGRADATION (GREEN WAVE EFFECT) OF NATURAL VEGETATION IN THE GREAT PLAINS CORRIDOR

1.0 Introduction and Background Summary of Landsat-1 Project

The Landsat follow-on investigation is a regional expansion of the Landsat-1 investigation entitled "Monitoring the Vernal Advancement and Retrogradation (Green Wave Effect) of Natural Vegetation." The scope of the initial study was limited to identifying and analyzing the status of natural vegetation at ten specific test sites within the Great Plains Corridor. The study reported herein is a logical extension of this research to a regional basis. The goal of this study was to develop and test procedures for mapping vegetation conditions on a regional basis using Landsat multispectral scanner (MSS) digital data and basic information and techniques derived from the Landsat-1 investigation. The results of this study provide a framework for the operational use of Landsat data to supply the 400,000 farmers and ranchers in the Great Plains with timely information on regional range forage conditions and crop production levels upon which to base their management decisions.

It was the purpose of the Landsat-1 project to explore the potential use of Landsat data for monitoring vegetation conditions throughout the Great Plains Corridor. Observations of natural vegetation systems were used as phenological indicators. It was hypothesized that the natural vegetation could be monitored using Landsat-1 imagery and digital data. It was further proposed that natural vegetation systems used as phenological indicators of seasonal development provide an important means of measuring bioclimatic effects on a regional basis. The study employed a network of ten test sites (Figure 1-1) at established range research stations in the six states extending northward from south Texas into North Dakota. Ground observations recorded every eighteen days at each site included green biomass, phenology of dominant species, moisture content of the vegetation, weather information, etc. Landsat-1 MSS data were acquired and analyzed for all ten sites for several dates. Because of the unique geographical location of the Great Plains Corridor with respect to the orbital path of Landsat, the inherent probability of obtaining cloud-free data during each cycle was maximized.

The Great Plains Corridor study emphasized quantitative analysis of Landsat-1 MSS spectral reflectance data as quantitative indicators of the amount and seasonal condition of rangeland vegetation. The Landsat-1 MSS data were computer processed for selected areas coordinated with the ground sample data from each test site. Spectral

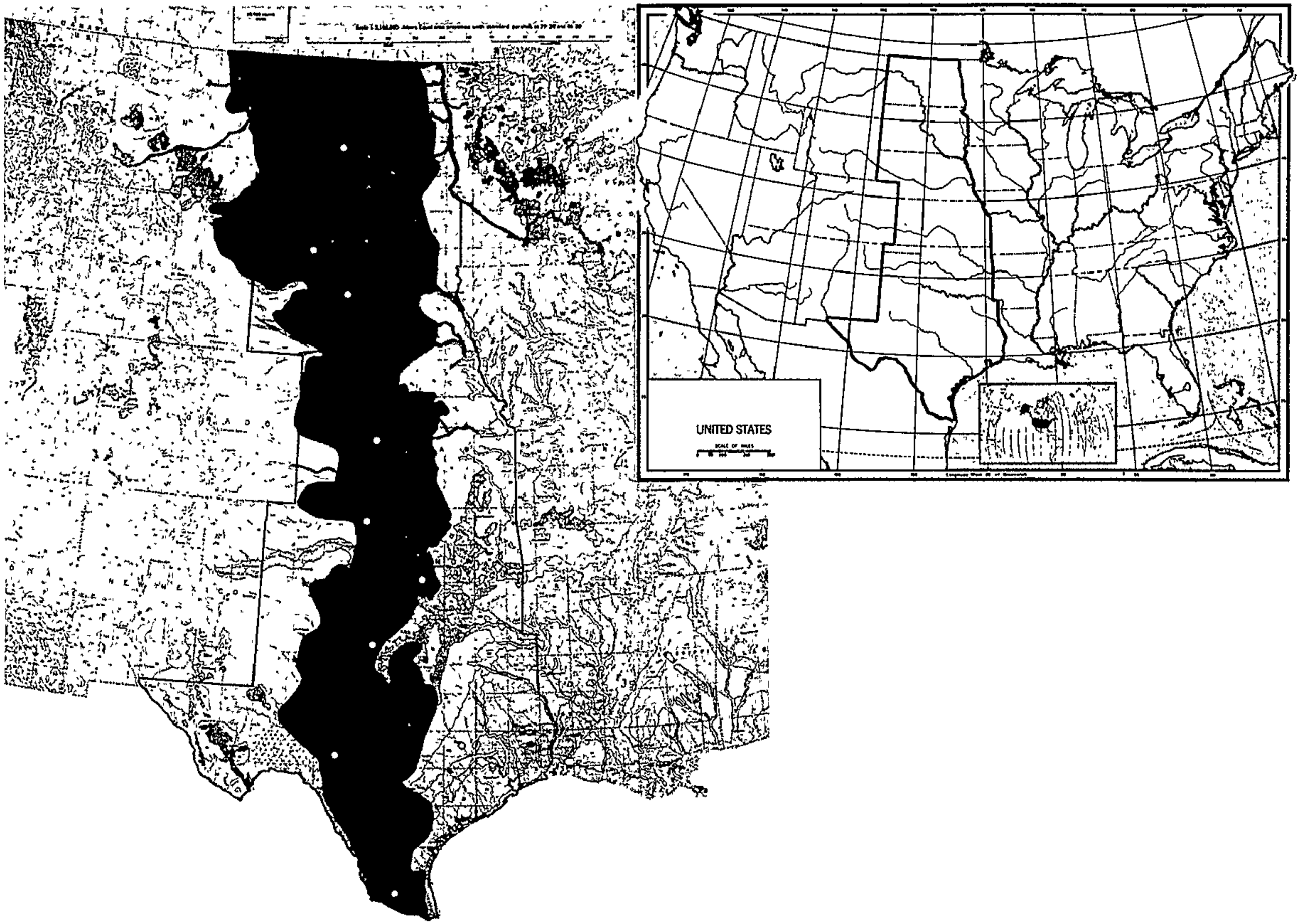


Figure 1-1. Great Plains Corridor and Landsat-1 Project test site network.

reflectance data were analyzed for each available date for each site from September 1972 through June 1974. The measurements were corrected for latitudinal and seasonal sun-angle differences to permit temporal comparisons. Correlations between ground measured parameters and Landsat-derived parameters were determined.

Investigations early in the project led to development of the hypothesis that the normalized difference between the red and infrared bands was potentially useful for the quantitative measurement of green biomass. This led to the development of the Transformed Vegetation Index (TVI) which incorporates the use of MSS Bands 7 and 5 values or Bands 6 and 5 values. In the final analysis, it appears that the difference between Band 5 and Band 6 is the most consistent for the detection and quantitative evaluation of green biomass differences. This parameter is called TVI6. TVI6 is calculated using sun-angle corrected radiance values in the following equation:

$$TVI6 = \sqrt{\frac{\text{Band 6} - \text{Band 5}}{\text{Band 6} + \text{Band 5}} + 0.5}$$

The TVI6 parameter provides a quantitative measure of the green vegetation on any given site. Although the parameter was more sensitive for measuring vegetation change at some sites than others, it was adequate for measuring the spring green-up throughout the Great Plains Corridor. It was concluded that there is apparently some threshold value of green biomass (approximately 500 kg/ha) below which the estimate may be unreliable. There is evidence that conditions at the time of satellite overpass influence the scene reflectance and, consequently, the vegetation index parameter. Fortunately, it appears that this influence can be easily corrected with weather variables in a regression model.

A green biomass estimation model for the Throckmorton test site in north central Texas was developed using weather variables and the satellite-derived TVI6 variable. Analysis of the Throckmorton test site data indicated that green biomass can be estimated in increments of 250 to 300 kg/ha with a 95% probability. In view of the fact that prior to the launch of Landsat-1 it was hoped that Landsat data quality would be adequate to measure phenological changes, these results relative to a Landsat-derived parameter for quantitatively measuring green biomass were significant. It was totally unexpected that a parameter would be derived which would quantitatively measure useful increments of green plant material.

Although Landsat imagery are adequate for manual interpretation of broad landscape types for observing critical growth periods, for distinguishing agricultural production types and for general assessment of vegetation conditions, implications for making quantitative measurements from Landsat data are apparent. For example, discrete increments of herbaceous green biomass, measured by Landsat, could be employed to quantitatively assess the stage of crop development, the amount of native and tame pasture forages available, the relative response of crops to environmental factors and also provide an index of plant growth for yield estimates. The techniques that were developed are viewed as viable, preferred alternatives to qualitative assessments made through image interpretation.

The results of the Landsat-1 Great Plains Corridor study represent a major breakthrough for the inventory and management of the nation's vast grazing resources. Possibly even more significantly, these results suggest that rangelands and other naturally vegetated areas can be used as phenological indicators for timing and management of cropping systems.

The follow-on investigation concentrates on developing a technique to map vegetation conditions over large areas using Landsat MSS digital data and testing the techniques developed in the initial investigation for applicability to regional vegetation monitoring.

2.0 Objectives and Approach

2.1 Study Tasks, Hypotheses and Objectives

The initial Landsat study was restricted to evaluating the discrimination of land use patterns and recognizing the phenological development at sites of known plant/soil composition. As expressed in the work statement of contract NAS 5-20796, three tasks were to be addressed during the course of this follow-on study. The first task involved the acquisition and analysis of satellite imagery and computer compatible data from natural vegetation systems in the Great Plains Corridor. The second task involved the acquisition of aerial photography, certain coordinated ground truth data and environmental data in support of the satellite imagery and digital data. The third task related to the correlation and analysis of satellite and support data for testing certain specific hypotheses important in evaluating the feasibility of an operational system for monitoring the status of natural vegetation in the Great Plains. The hypotheses to be tested that governed the nature and direction of the project were:

Hypothesis Number 1--Time is an important factor in the discrimination of broad landforms, soil associations, vegetation types and other natural resource features.

Hypothesis Number 2--The vernal advancement and retrogradation of vegetation (Green Wave Effect) can be discriminated on a regional basis using multispectral data.

Hypothesis Number 3--Vegetation systems parameters are adequately unique to provide a new information source for regional agri-business use.

Major decisions in agri-business are often based on regional weather and vegetation conditions. The quantity and quality of range and pasture vegetation often influence the market for livestock. Furthermore, seasonal changes in vegetation conditions on a local or regional basis are difficult to assess. Likewise, since dryland agriculture is usually closely tied to a characteristic climate for the region, adverse local or regional weather influences planting and harvesting dates, with important implications for yield forecasts.

Implicit in these hypotheses is the fact that the extent and the duration of favorable or adverse conditions can be regionally observed through an analysis of remotely sensed satellite data obtained from natural vegetation regions. It is well known that natural vegetation integrates the condition of its micro-environment. Consequently, an operational satellite provides the first opportunity to use regional vegetation systems data as "phenological indicators" or "growth condition indices" for agricultural uses. The follow-on study evaluated the plausibility of using Landsat-derived data as an index of vegetation conditions for forage condition reports and as a direct input into dryland crop yield forecasts.

To test the three hypotheses and to evaluate the application of data within the Great Plains Region as proposed, the following specific objectives had to be addressed:

Objective Number 1--To develop a data analysis methodology that will facilitate the use of Landsat digital data for regional monitoring of rangeland vegetation.

Objective Number 2--To identify and characterize an extended regional test site for collecting biological, climatological and Landsat data products.

Objective Number 3--To record the phenological events and collect specific biological and environmental data within the extended test site area to evaluate the effectiveness of Landsat data for measuring vegetational changes.

Objective Number 4--To chart the vernal advancement and retrogradation of natural vegetation in the regional test site area.

Objective Number 5--To evaluate the impact of environmental conditions, rangeland vegetation and soil types and other factors on the application of Landsat sensor measurements to regional monitoring of vegetation conditions.

Objective Number 6--To evaluate the feasibility of using Landsat-type data for modeling a range forage index of plant growth conditions.

2.2 Project Approach

The initial Landsat-1 Great Plains Corridor rangeland investigation incorporated the use of ten test sites throughout the Great Plains from south Texas through North Dakota. Vegetation parameters were measured at sampling sites at these test site locations in conjunction with Landsat-1 overpasses. The relationships between ground measurements of vegetation and Landsat multispectral scanner (MSS) measurements were established. A close relationship between MSS band ratios and ground measured green biomass prompted the development of a model for measuring rangeland vegetation conditions with satellite sensors.

The basic concept behind the follow-on investigation has been to apply the models and techniques from the Landsat-1 study for monitoring rangeland vegetation conditions on a regional basis. It is anticipated that satellite data have applicability for monitoring rangeland vegetation condition throughout the Great Plains. However, the validity of the MSS data measurements for evaluating vegetation condition had to first be tested across this large land area.

Budgetary constraints on the project precluded the processing of data and collecting necessary ground verification for all rangeland areas of the Great Plains. Therefore, large areas within the Great Plains Corridor (GPC), which included the established test site locations, were selected for conducting this investigation.

The nominal north-to-south Landsat tracks which provide coverage of each of the test sites were designated as defining the east-west boundaries of the follow-on investigation test areas. Essentially cloud-free Landsat-1 imagery acquired during the 1973 growing season within these tracks were selected to provide coverage of the test sites and for establishing the approximate north and south boundaries of the test areas. The test areas conform to the nominal Landsat-1 coverage as shown in Figure 2-1. The Landsat-1 images that were selected to establish these test areas are listed in Table 2-1. Sonora and Weslaco, Texas test sites were not used in the follow-on investigation due to the apparent influences of dense brush encountered during the initial investigation (reported in Final Report RSC 1978-4). Funding constraints did not permit the additional research required to resolve problems encountered with predominantly brush covered rangelands.

An area encompassing much of the Rolling Red Plains and North Central Prairies vegetation regions of Texas and Oklahoma was selected as the primary study site and was employed for extensive ground data collection for

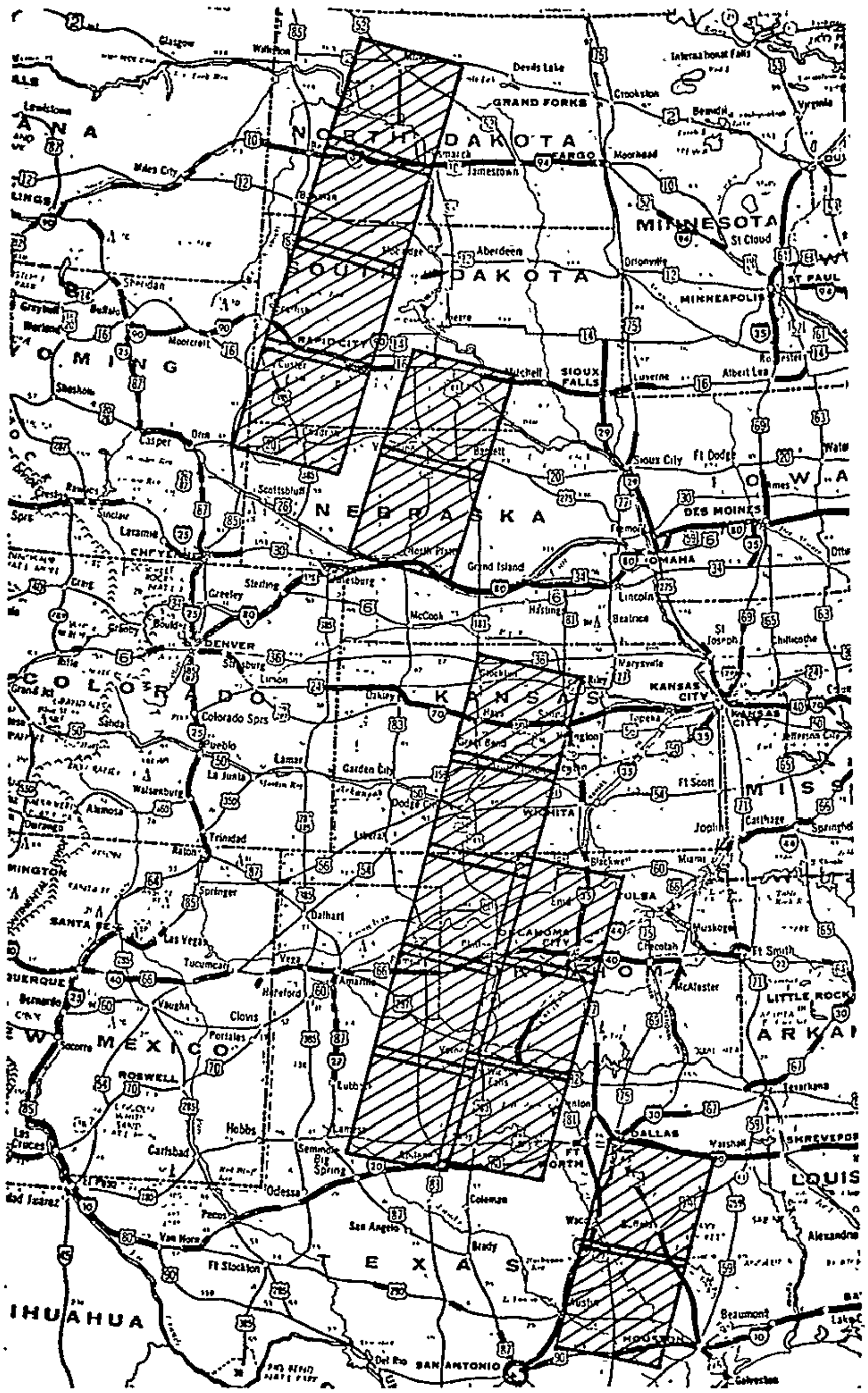


Figure 2-1. Great Plains Corridor test areas as defined by selected Landsat images.

Table 2-1. Base imagery set for test areas from Landsat-1 overpasses.

TEST AREA	OBS. I. D. NO.	DATE
Mandan, North Dakota	1297 - 17063	5-16-73
	1297 - 17065	5-16-73
Cottonwood, South Dakota	1297 - 17072	5-16-73
	1297 - 17074	5-16-73
Sand Hill, Nebraska	1295 - 16562	5-14-73
	1295 - 16564	5-14-73
Hays, Kansas	1329 - 16461	6-17-73
Woodward, Oklahoma	1329 - 16463	6-17-73
	1329 - 16463	6-17-73
Chickasha, Oklahoma	1454 - 16383	10-20-73
	1454 - 16385	10-20-73
Throckmorton, Texas	1454 - 16385	10-20-73
(ETSA)	1454 - 16392	10-20-73
	1455 - 16444	10-21-73
	1455 - 16450	10-21-73
College Station	1454 - 16282	10-18-73
	1452 - 16284	10-18-73

model testing and data processing technique and final index map evaluation. This study area is called the "Extended Test Site Area," hereinafter generally referred to as the ETSA. The ETSA is a 250 km by 250 km square which encompasses 6.25 million hectares (24,100 square miles or about 15.5 million acres). Figure 2-2 shows the ETSA which includes the Throckmorton test site near its center. A more complete characterization of the ETSA is given in Section 3.1 of this report.

Prior to the initiation of field sampling, it was deemed prudent to also delete the College Station site. The primary justification for this action was due to the shift in emphasis from GPC test areas to the ETSA. This resulted in being able to more effectively use the project personnel in the tasks of locating and sampling the vast ETSA, since the same personnel would have also had to sample the College Station sample sites.

The basic approach was to apply the previously developed techniques for determining the status of vegetation from Landsat data and map the vegetation conditions over the ETSA for two to four Landsat overpass periods. Coincident ground truth data collected at several locations, which are representative of the different vegetation/soil types, and distributed throughout the ETSA would then be used to evaluate the validity of the Landsat-derived map.

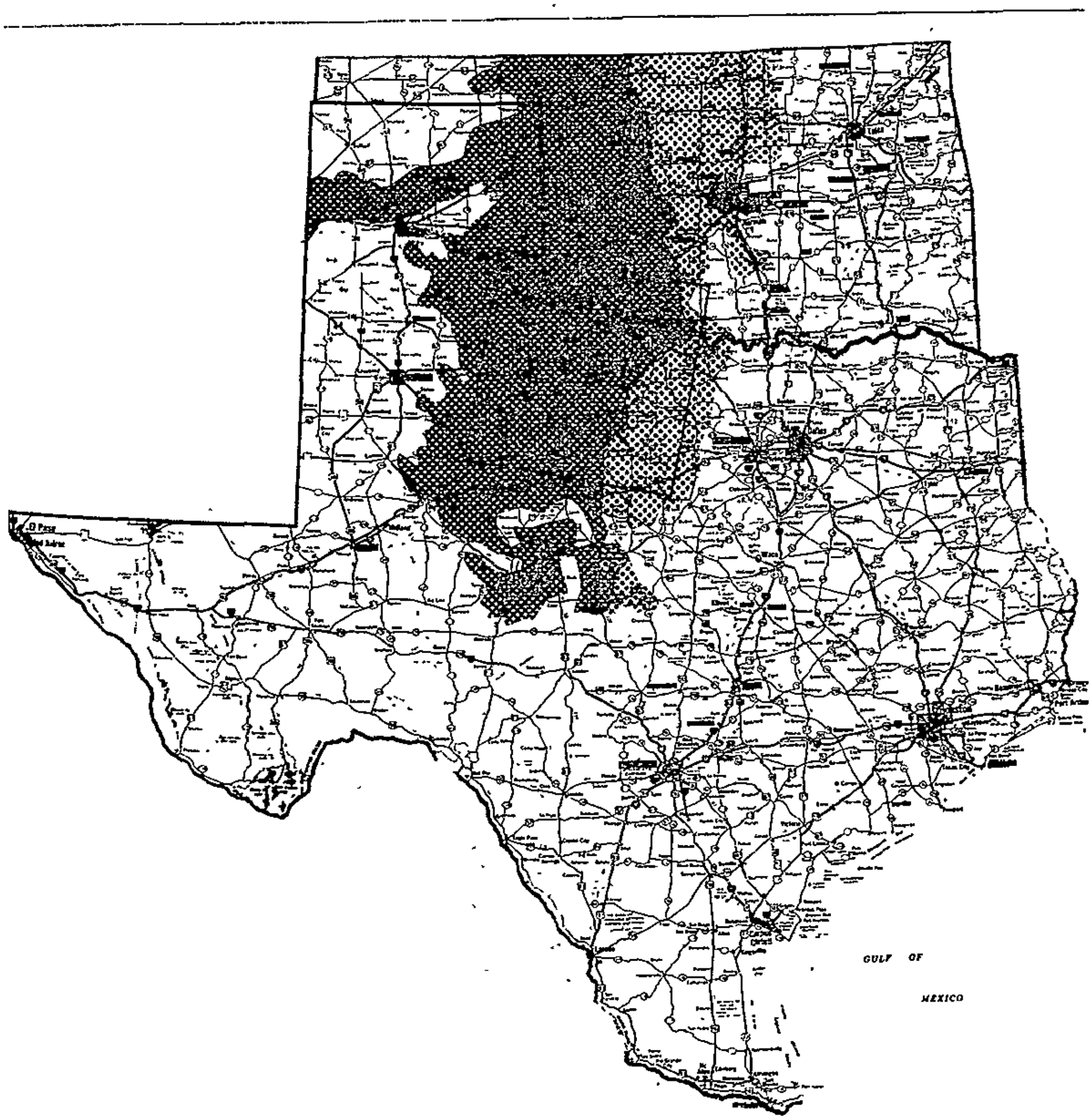


Figure 2-2. The Extended Test Site Area shown in relation to the Rolling Plains (darker area) and North Central Prairies (lighter area) vegetational areas in Texas and Oklahoma.

These data would also provide additional information on the reflectance characteristics of different vegetation/soil resource types.

Similarly, for one Landsat cycle coverage of the GPC test areas, the status of the vegetation would be assessed through the use of Landsat by applying the techniques developed for the ETSA. GPC test site ground data, available weather records and USDA Statistical Reporting Service Pasture and Range Feed Condition maps would then be used to evaluate the map information.

Specific details of the project approach, including selection of primary and secondary sites, ground data collection, software for computer mapping of Landsat-derived vegetation conditions and data evaluation, are given in Sections 3.0 and 4.0 of this report. The results are then related to agri-business information needs.

3.0 Data Acquisition and Processing

Locations and physical characteristics of the Extended Test Site Area, the GPC test areas, primary sampling sites and secondary sites are described in this section of the report. Procedures for locating primary and secondary sites, ground sampling procedures, kinds of ground data collected at the various sites and dates of sampling are elaborated. Remote sensor data that were acquired and processed to achieve the stated objectives are also summarized in this section of the report.

3.1 Extended Test Site Area

The Extended Test Site Area (ETSA) was developed to provide a regional unit that would enable efficient development and testing of mapping procedures and testing of the techniques developed under the Landsat-1 GPC project objectives.

3.1.1 Location and Physical Characteristics

The ETSA is a 250 km x 250 km area centered approximately on the Throckmorton, Texas GPC test site (Texas Experimental Ranch). The ETSA is a square rotated approximately 12.5 degrees east of north so that it lies essentially parallel with the Landsat orbit tracks. This 6.25 million hectare (15.5 million acre) area is contained completely within the nominal area of four mutually adjacent Landsat frames (see Figures 2-1 and 2-2). Consequently, Landsat data processing for the ETSA for any given time period (two-day, adjacent overpass sequence) requires only four sets of CCT's.

Topography of the Rolling Plains and North Central Prairies (national names are Central Rolling Red Plains and Central Rolling Red Prairies, respectively), which encompass the ETSA, is gently rolling to moderately rough. These regions are dissected by narrow intermittent stream valleys that flow to the east and southeast. Elevation within the ETSA ranges from about 275 m (900 ft) in the east to 750 m (2,400 ft) in the west, as generalized in Figure 3-1.

Figure 3-2 depicts the rainfall within the ETSA, which ranges from about 480 mm (19 inches) in the west to greater than 800 mm (32 inches) in the northeast. Seasonal precipitation is highly variable, but May and September are normally the high rainfall months. Based on precipitation effectivity, the west and southwestern one-third of the ETSA is classified as semiarid and the northeastern two-thirds is classified as subhumid. The dividing line is approximately the 24-inch precipitation for isoline in Figure 3-2; however, it would be slightly farther east in the south half and farther west in the northern one-third. Appendix A, Table 1 provides a list of the locations and long-term weather summary data for the 61 weather stations used for this study.

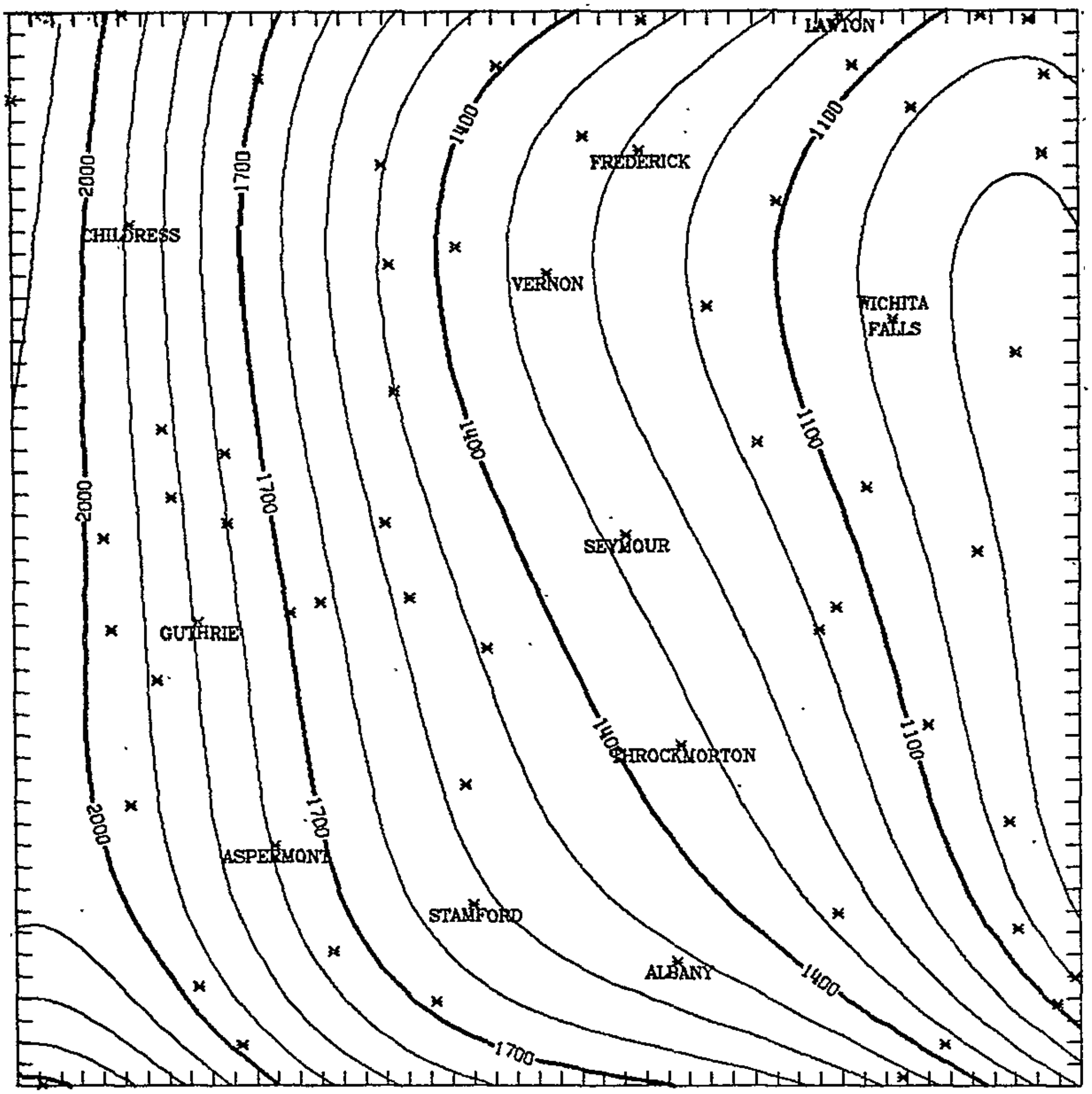


Figure 3-1. Generalized elevations in the ETSA in 50-foot contour intervals are plotted using elevations of 61 selected weather stations.

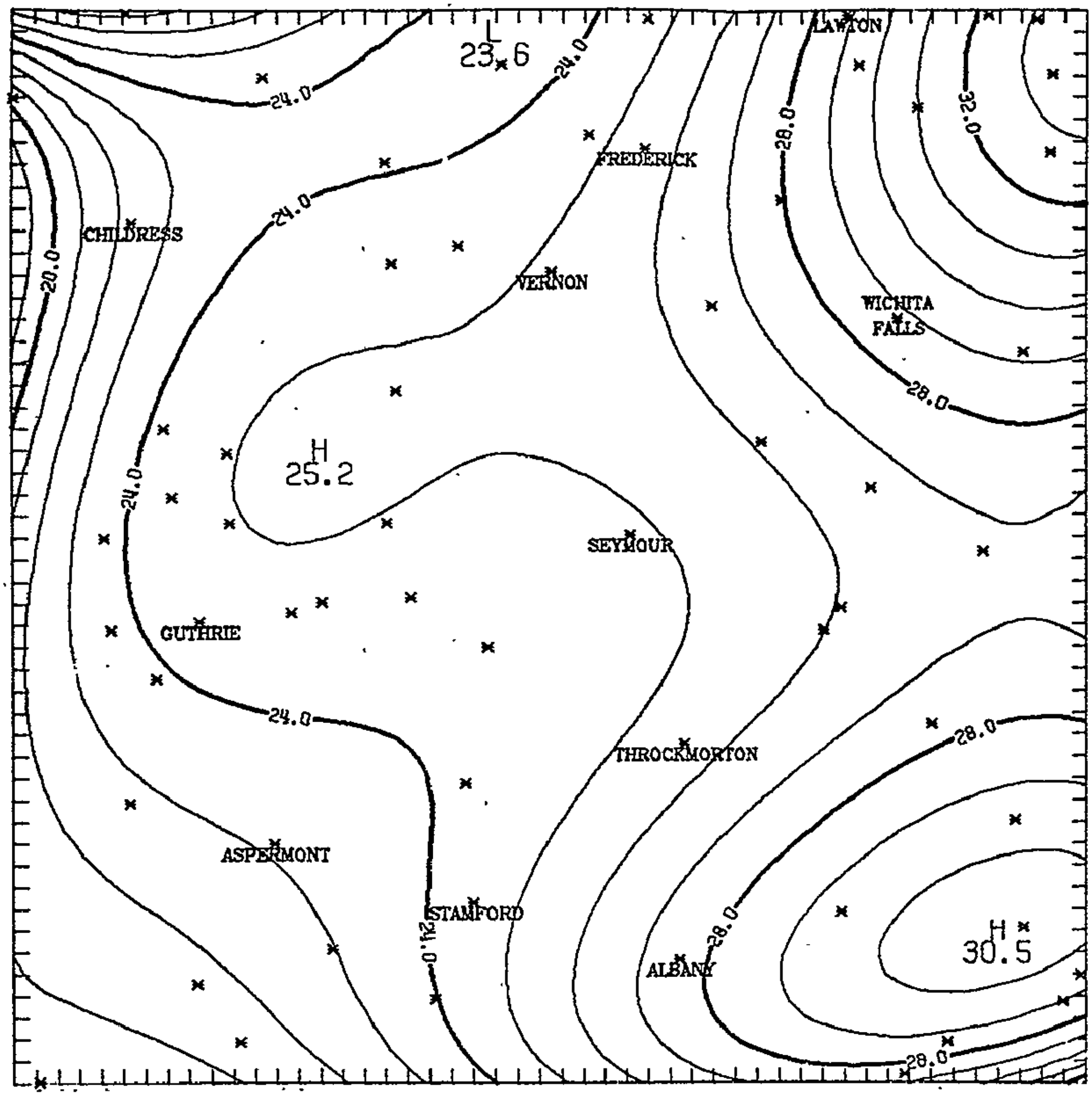


Figure 3-2. Isolines of long-term annual precipitation for the ETSA from data for 61 weather stations.

Soils of the ETSA vary from stoney and gravelly to tight, red-bed clays and shales. Mollisols, alfisols and inceptisols are characteristic of this region. Figure 3-3 portrays the nine general soil associations in the Texas portion of the ETSA. These soil associations are the following:

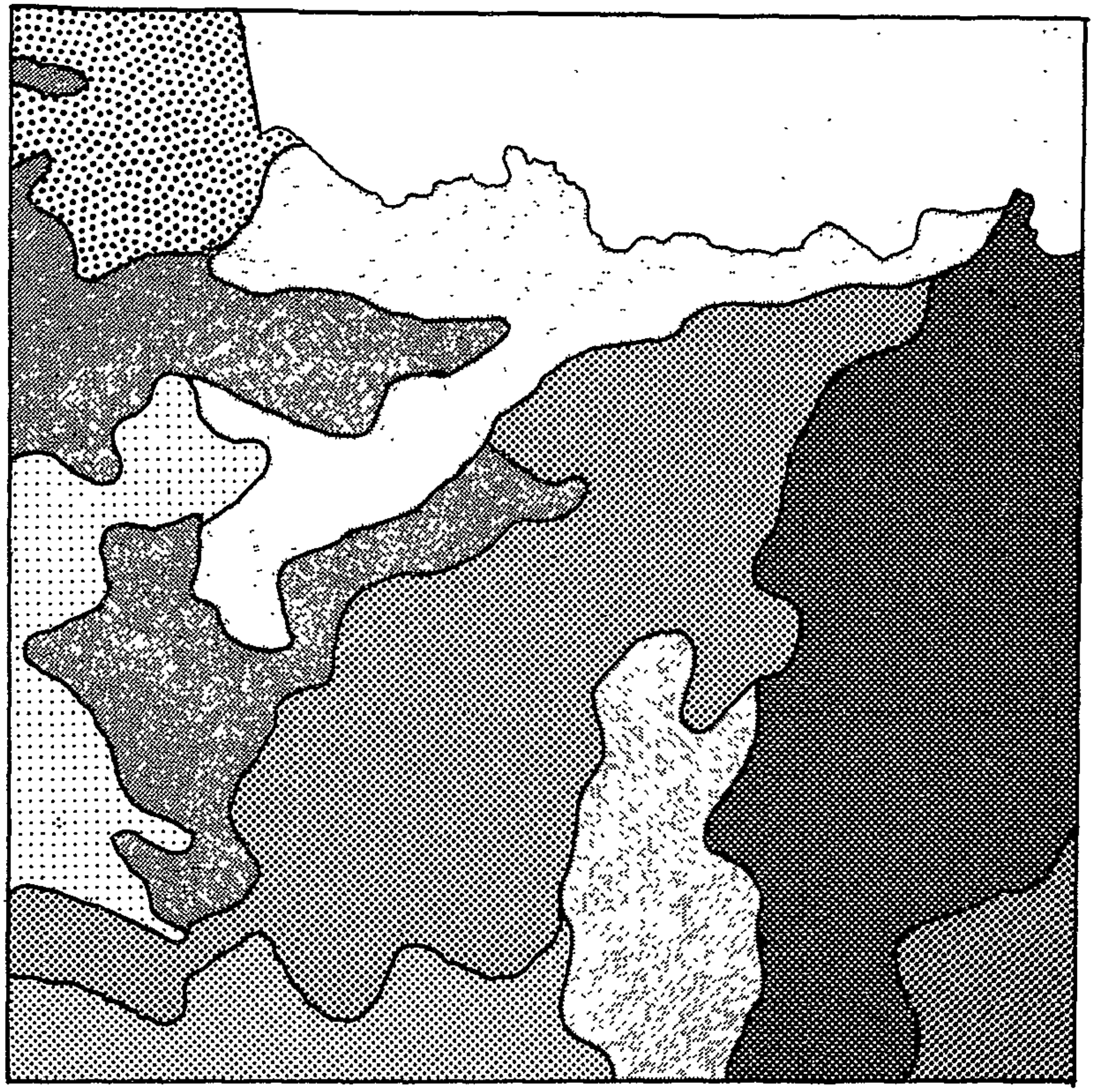
1. Abilene-Tillman Vernon Association and the Abilene-Rowena-Miles Association whose soils have loamy surface layers and clayey or loamy subsoils, cracking clayey soils and some shallow soils over indurated caliche.

2. Woodward-Quinlan-Vernon Association and the Tarrant-Kavett-Rowena Association whose soils are mostly shallow and moderately deep soils over limy earths, red beds or limestone; some deep soils with loamy surface layers and clayey subsoils.

3. Miles-Springer-Woodward Association, Miles-Brownfield-Olton Association and the Tillman-Miles-Springer Association whose soils are mostly loamy throughout but with some sandy surface layers and some soils with clayey subsoils.

4. Truce-Owens-Waurika Association and the Bonti-Truce-Vashti Association whose soils are moderately deep to deep with loamy surface layers and clayey subsoils and shallow clayey soils.

GENERAL SOIL MAP OF ETSA



Soil Associations

- Truce-Owens-Waurika
- Bonti-Truce-Vashti
- Abilene-Tillman-Vernon
- Abilene-Rowena-Miles
- Woodward-Quinlan-Vernon
- Tarrant-Kavett-Rowena
- Miles-Springer-Woodward
- Miles-Brownfield-Olton
- Tillman-Miles-Springer

Figure 3-3. General soil associations in the ETSA (adapted from General Soil Map of Texas, 1973, Texas Agricultural Experiment Station, Texas A&M University).

Range management practices are usually developed on the basis of range site characteristics which are inherently dependent on soil characteristics. Range sites are distinct kinds of rangeland or vegetation/soil landscapes. Range sites differ in kind or proportion of plant species or total productivity. For this project, it was desirable to relate the map products derived from the Landsat MSS data to a range site map of the ETSA in order to understand the influence of range site on these products. This type of map did not exist prior to this project.

In order to produce a range site map for the ETSA, the individual USDA Soil Conservation Service county soil surveys or general county soil maps had to be obtained for the 40 counties represented in the ETSA. These county soil association maps were compiled and generalized for the ETSA. Range site designations were given to these generalized soil associations according to soil survey information. Many judgmental compromises had to be made before the final map was produced, such as when gross differences in soil boundaries and nomenclature occurred between adjacent counties. However, it is believed that the Generalized Range Site Map in Figure 3-4 provides a reasonably accurate portrayal of the locations of the range sites characteristic of this region. It is inferred, then, that the majority of the range areas within a given

EXTENDED TEST SITE AREA

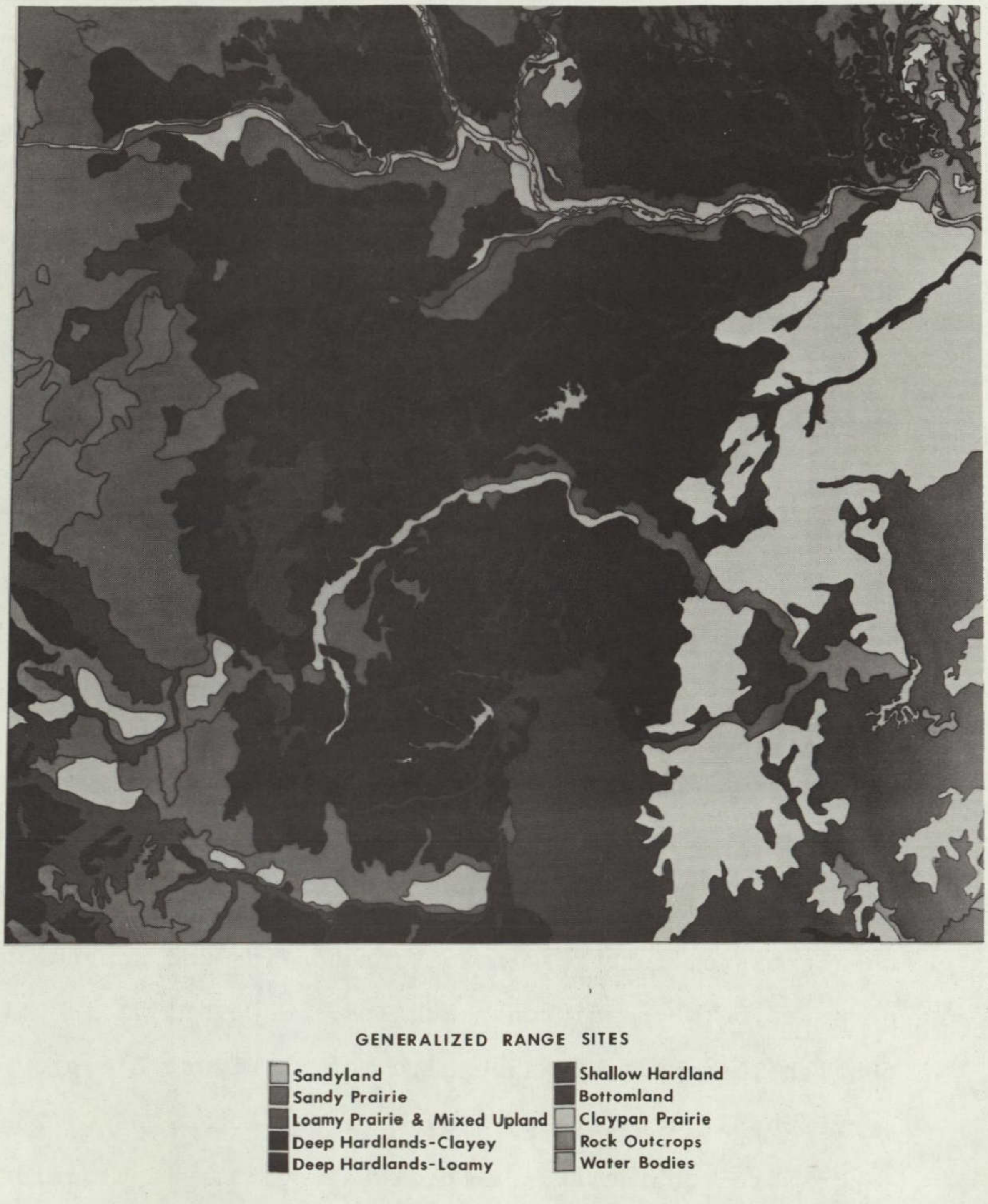


Figure 3-4. Range sites of the ETSA compiled and generalized from USDA/SCS county soil surveys and general county soil maps.

generalized range site are potentially different from those of the other range sites in productivity or plant species composition or amount.

The majority of the rangeland in the ETSA has in recent history been invaded by brush, particularly mesquite. The northeastern corner, however, is mostly treeless. The overstory in the southeastern edge is mostly the native post and blackjack oaks with some areas of heavy juniper or mesquite. The sandy soils of the western half are characteristically dominated by sand shinnery oak and other scrub oaks and occasionally by sand sagebrush and mesquite. The "rough breaks" common to the western half are dominated by juniper.

Heavy infestations of these brush species make remote sensing of the herbaceous understory difficult or impossible. Good range management, however, dictates periodic removal of much of this brush on most range sites for increasing grass production, and much of the rangeland in the ETSA has had brush control. Ranchers find that it is a constant battle to keep the brush down, however, and brush control remains the number one conservation problem throughout most of this region.

The predominant grasses of this region include the climax species little bluestem, Texas wintergrass, western wheatgrass, Canada wildrye, sideoats grama, blue grama and hairy grama, which generally respond as decreasers. The predominant increaser grasses are buffalograss, tobosagrass, several species of three-awn, curly mesquitegrass and sand dropseed. Under heavy grazing, many forbs including western ragweed and croton tend to increase or invade on these rangelands.

As can be observed in the Fall 1975 Landsat image mosaic of the ETSA in Figure 3-5, more than 60% of the land area is rangeland, most of which is used for grazing by beef cattle. The croplands are used mostly for winter wheat, cotton and grain sorghum, although alfalfa, peanuts and a few truck crops are important in some areas.

3.1.2 Primary Sample Sites and Sampling Procedures

Ground truth data including biomass measurements, phenology, plant and soil moisture, environmental conditions and photographs were taken for a network of primary sampling sites distributed throughout the ETSA. These ground sampling locations were selected utilizing a vegetation/soil resource map which was produced from the base Landsat imagery set (see Section 4.1), NASA high-flight aerial photography and field reconnaissance.

The Landsat-derived vegetation/soil resource map was used to identify broad areas of different range

EXTENDED TEST SITE AREA

LANDSAT MOSAIC

Figure 3-5. Landsat color composite image mosaic of the ETSA from four scenes (Obs. ID Nos. 5156-16131, 5156-16133, 5157-16185 and 5157-16181) in late September and early October, 1975.

types that lay within the coverage of NASA highflight aerial photography provided for this project. It was necessary to identify these broad areas in order to insure that ground sample sites would be properly distributed and would represent each of these major range types. Once these areas had been identified, the NASA highflight aerial photography was used to select a large number of potential sample sites that were then ground checked for verification and final site selection. During the field reconnaissance trip, county Soil Conservation Service offices were visited to obtain the land owners' names and addresses for the tracts of rangeland that were finally selected for ground sampling. The land owners and land managers were then contacted to secure their permission to sample on their property throughout the summer of 1975.

Several factors were considered in selecting the ground sample sites. The number of sample sites had to be kept to a minimum in order to enable the ground sampling to be completed within about five to seven days. A good spatial distribution of ground sample sites within the ETSA was desirable for final map evaluation. It was also important that each of the major types of rangeland be represented by at least one ground sample site. These sites had to be located near major highways and paved county roads for reliable and rapid access and egress. Range areas containing heavy stands of brush were avoided. In an effort to minimize the number of ground sample plots required to obtain an adequate sample of the forage conditions, relatively homogeneous areas no smaller than approximately 50 hectares were selected.

Seventeen ground sample sites or primary sites, in addition to the Throckmorton test site, were finally selected for documenting the vegetation conditions within the ETSA during the period of this investigation. Figure 3-4 shows the distribution of these sample sites with respect to the generalized range sites of the ETSA. Figure 3-6 presents these sites in relation to their locations within the counties and the major highways.

The range sites were delineated for each primary sample site with the aid of the NASA highflight aerial photography and soil surveys available for some of the counties. Boundaries of the primary sites were drawn to include only one or two range sites within the study area. Ground sample plots were selected within each of the range sites. Within each of these range site sample areas, three 1 m x 1 m plots were located to represent the plant community. Each of these three subsite areas were sampled for each sampling period. The one meter square

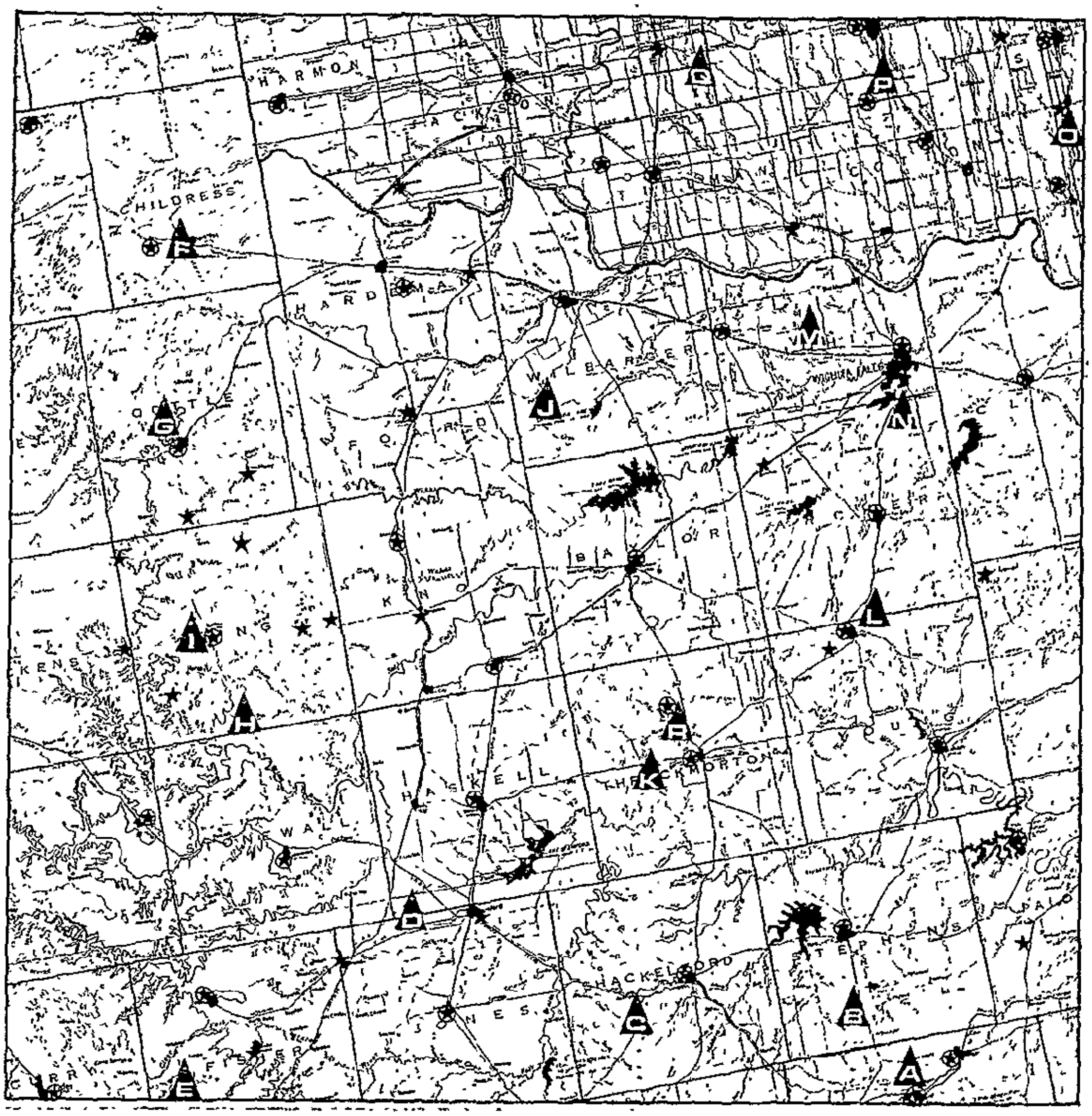


Figure 3-6. Locations of primary sites or ground sample sites (lettered triangles) and the 61 weather stations (stars) within the ETSA.

plot was divided into quadrants to enable use of a more efficient double sampling technique for biomass determinations.

Within each quadrant of the 1 m x 1 m plots, percent foliage projection cover estimates were made for green grass, green forbs, standing brown and litter components and bare ground. The dominant grass and forb species were recorded and the average height of the vegetation was measured. Visual estimates of the percent of the total biomass that was green (estimated on a dry weight basis) was determined, and the percentage of the green biomass that was the forb component was also estimated. The herbaceous vegetation was clipped from each of the four quadrants and placed in plastic bags before leaving the field. These samples were weighed, then oven dried and reweighed to determine the percent moisture content and the total herbaceous biomass. One of the four quadrants was randomly selected and the green grass, green forb and brown vegetation components were manually separated. These separation data were then used with regression techniques and whole plot data to derive estimates of green grass biomass and green forb biomass for the site. Soil samples were also taken at each plot to determine the soil moisture content at the surface and at a 30 centimeter (12-inch) depth. A weighted mean for each of the ground parameters was then calculated to represent the vegetation and soil conditions at the primary sample site. Vertical and oblique ground photographs were taken to document the vegetation conditions for each range site.

3.1.3 Secondary Sample Sites

Secondary sample sites, or simply secondary sites, are selected rangeland areas for which the Landsat digital data is extracted to provide a sample from which the vegetation conditions within the ETSA can be determined and mapped. Several factors had to be considered in locating the secondary sites. First, a large number of secondary sites were necessary in order to provide a good distribution of sample points across the ETSA for automated contour mapping. Second, the secondary sites had to be large enough to enable accurate location and data extraction. Third, the selected tracts of rangeland had to be relatively homogeneous with little or no brush canopy.

The NASA highflight aerial photography played a critical role in selecting these secondary sites. The first step was to observe the texture and tone of rangeland areas of known vegetation composition and physiognomy on the highflight color-infrared aerial photographs. The areas studied during the process of selecting the primary sites were used in this training activity. Through photointerpretation, suitable rangeland areas were then identified on the aerial photography within 26 pre-selected 32 km x 32 km areas (400 square miles) as shown in Figure 3-7. The 26 selected areas represent computer generated greymaps from Landsat data located within the ETSA to optimize the selection of secondary sites.

Greymap coordinates were used to identify and extract both primary and secondary site Landsat MSS digital data. For those portions of the greymaps not covered by the NASA highflight aerial photography, multidate Landsat color composite imagery was used to select the secondary sample sites through photointerpretation. One hundred and fifty secondary sample sites were selected within the ETSA. Universal Transverse Mercator (UTM) geographic coordinates and latitude and longitude were determined for each of these secondary sites. Either coordinate system can be used to plot the data obtained from Landsat for each of the secondary sites in their proper geographic locations within the ETSA using the automated mapping techniques described in Section 3-4. The distribution of the secondary sample

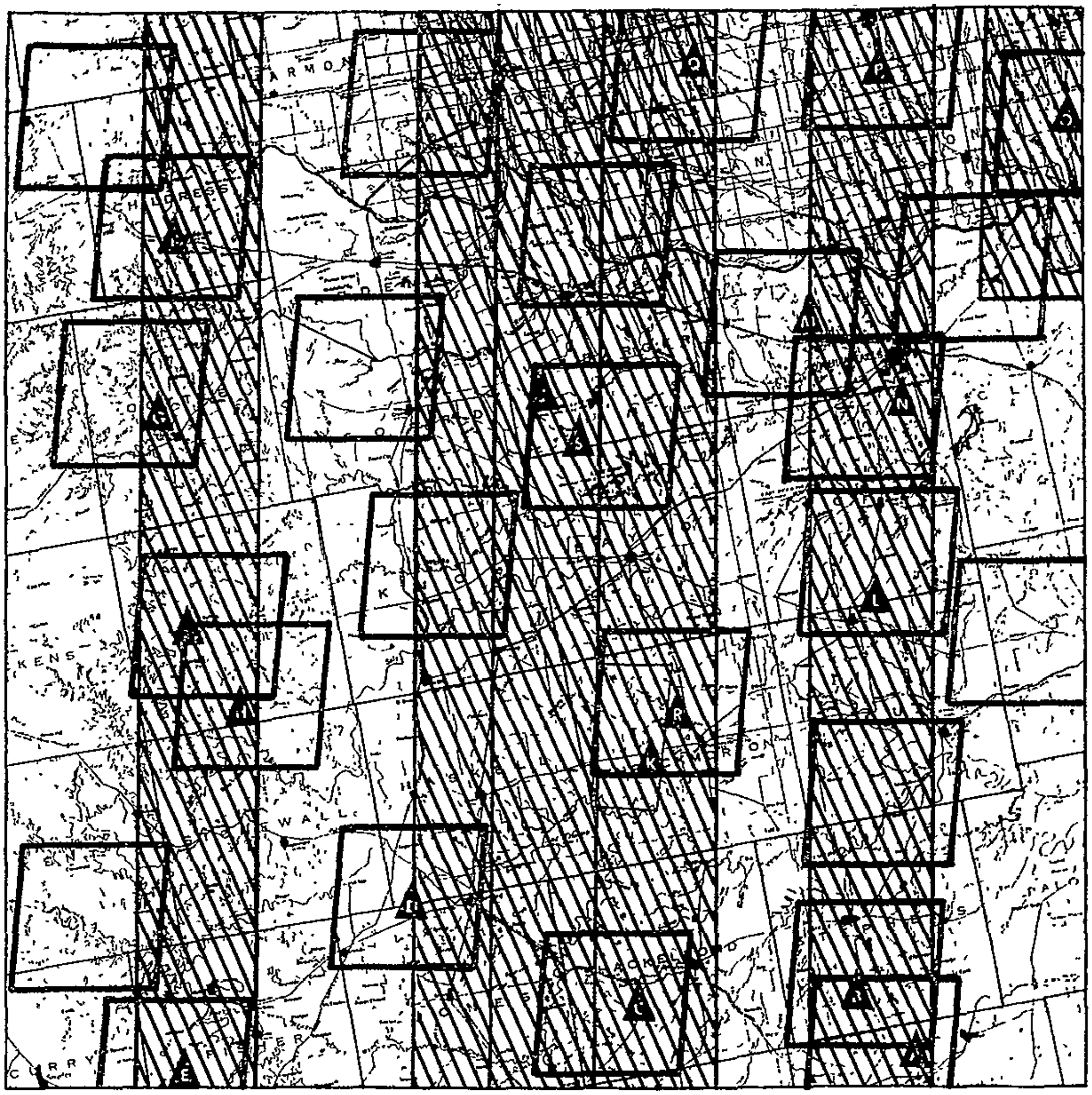


Figure 3-7. Location of 32 km x 32 km (20 mi x 20 mi) secondary site "greymap areas" (parallelograms) and NASA high-flight photo coverage (diagonal lines) within the Extended Test Site Area.

sites within the ETSA can be seen in the computer plot in Figure 3-8. The clustering that can be seen is due to the boundary restrictions of the greymaps with the technique that was used.

Although the secondary sample site selection approach was a rather lengthy, difficult manual process requiring aerial photographs, ground information and Landsat color composite images, it only had to be completed once. These same secondary sample sites could be used for many years with only occasional monitoring to determine that the land use or condition of the rangeland had not changed drastically.

3.1.4 Summary of Ground Data Acquired

Ground truth data collection within the ETSA coincident with Landsat overpass was designed to document the vegetation conditions at known locations for testing the adequacy of the Landsat-based monitoring technique used in this study. In addition to providing a ground check on vegetation conditions, these data also provided another opportunity for correlation analysis with Landsat data and development and testing of green biomass estimation models.

Permanent ground sample plots established at the Throckmorton test site during the initial Landsat

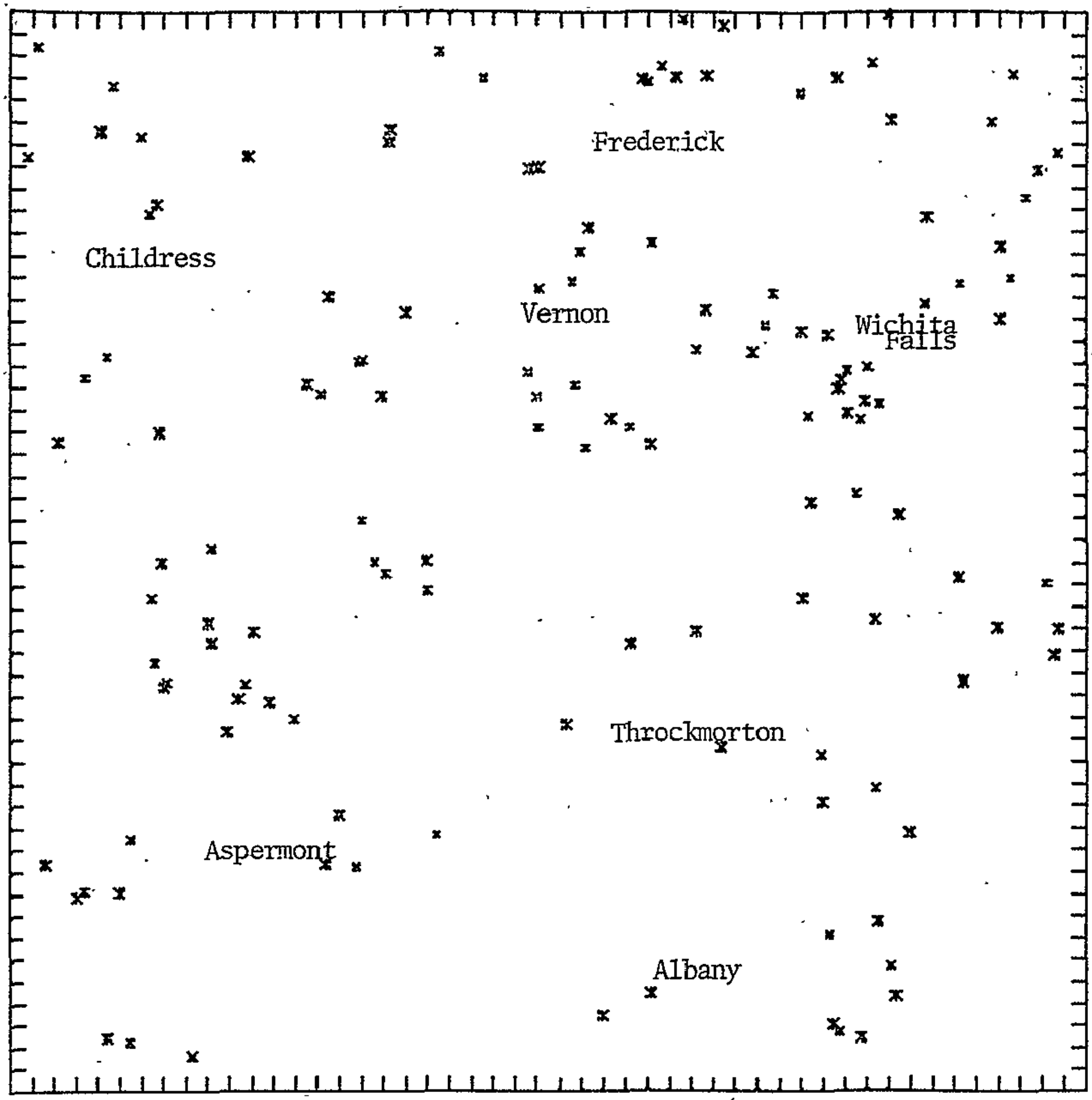


Figure 3-8. Computer plot of secondary sample site locations within the ETSA.

investigation were monitored throughout the 1975 growing season. These data were collected by the Texas Experimental Ranch research personnel and provided a "continuous" monitoring of vegetation conditions and changes typical of the 1975 growing season in this region. This record proved to be very valuable for relating the anomalies of the 1975 growing season with the phenological development recorded in the two previous growing seasons. The 12 dates of ground data collection coincident with Landsat overpass at the Throckmorton test site span the period from March 7 through October 1 (Table 3-1).

The ETSA primary sites were sampled three times in the 1975 growing season. The ground data were collected to correspond with Landsat overpasses in mid-June, early August and late September. Ground sampling of all of the primary sites in late June was accomplished in 11 days. The late July and early August ground sampling required 13 days because of rain. The period for fall ground data collection in the ETSA had to be compressed into a four day field sampling period (Table 3-1). In order to minimize the sampling time, a subset of the total sampling locations that had been established was selected to provide a measure of range vegetation conditions existing across the region. The sampling locations B, C, E, F, H, I, M, N, O and Q were sampled in the standard manner.

Table 3-1. Dates of ground data acquisition and corresponding Landsat coverage for the Throckmorton test site and primary sites within the ETSA.

Test Site	Ground Data	Landsat Overpass*	
Throckmorton	March 7	3-8-75	(1)
	April 4	4-4-75	(2)
	April 23	4-22-75	(2)
	May 9	5-10-75	(2)
	May 28	5-28-75	(2)
	June 6	6-6-75	(1)★
	June 16	6-15-75	(2)
	July 3	7-3-75	(2)
	July 21	7-22-75	(2)★
	August 8	8-8-75	(2)★
	August 25	8-26-75	(2)
	October 1	10-2-75	(2)★
ETSA	June 17-27	6-15&16-75	(2)★
		2144-16293**	
		2144-16300	
		2145-16352	
		2145-16354	
	July 21- August 2	8-8&9-75	(2)★
		2198-16285**	
		2198-16291	
		2199-16343	
		2199-16350	
	September 26-29	9-22&23-75	(2)★
		5156-16131**	
		5156-16133	
		5157-16185	
		5157-16191	

*Number in parentheses denotes whether Landsat-1 or -2.

★Denotes dates for which usable Landsat data are available for site.

**Landsat scenes (observation identifier numbers) used for the ETSA data analysis.

In addition, locations A, G, I and P were quickly visited, and the general vegetation conditions were documented by photographs. Of these 17 primary sites, only three were not visited during the sample period.

3.1.5 Summary of Aerial Photography Acquired

Color-infrared 9.5-inch format, NASA highflight aerial photography of five pre-selected flight lines providing approximately 650 linear miles of coverage within the Extended Test Site Area was flown on June 4, 1975. On June 15, shortly after the film was processed, the original photographs were previewed at JSC by TAMU personnel. At this time an assessment was made of the quality of the photography. Although scattered cumulus clouds covered much of the southern half of three of the flight lines, it was deemed unnecessary to photograph these lines again.

The photography was utilized during this initial viewing at JSC to make final primary site selections. The potential primary sites that had been selected from Landsat imagery and resource maps were located on the aerial photography. These areas were evaluated for site variability, brush cover, pasture boundaries, etc. and compared with areas that had been visited on the ground. This early preview enabled the ground sampling crew from the Remote Sensing Center to travel to the

ETSA on June 16 to begin ground data collection the next day.

The first roll of microfilm that contained preview copies of the early June NASA highflight aerial photography was received from the ASCS Western Aerial Photo Lab on August 22. A retrospective product order for 1) duplicate 9" x 9" color transparencies to provide coverage of the ETSA flight lines, and 2) color prints providing coverage of the primary sites was placed on September 23. These products were received from the ASCS Western Aerial Photo Lab on November 11, 1975. Two additional retrospective orders brought the total number of transparencies for the ETSA to 118 and provided complete coverage of the flight lines within the ETSA. Of these 118 frames, 20 were also ordered as color paper prints.

The NASA highflight aerial photos were an indispensable tool for primary and secondary site selection, and for precise location of these sites on computer greymaps of the Landsat data for coordinate location and data extraction.

3.1.6 Summary of Landsat Data Acquired and Processed

A standing order request for Landsat bulk black and white 9.5-inch positive transparencies for Band 5 was established with the ASCS Western Aerial Photo Lab at the beginning of the project. These standing order products were provided to enable a timely evaluation of the Landsat data coverage of the primary test sites. When the evaluation revealed that Landsat provided good coverage coincident with ground data collection at the test sites, a retrospective product order was placed for the MSS CCT data.

After the field data collection had ended and a large number of standing order products began coming in, it was discovered that many of the test site's positions had shifted to near the edges of the Landsat frames. With the test site coordinates that were used to locate the standing order product frames, often as many as two to four frames were sent for the same date of coverage for a given site. Several of the frames did not even contain the test site that was to be evaluated. This large number of standing order products that were being generated was absorbing a large portion of the budget established for Landsat imagery from ASCS. In order to limit cost overrun as much as possible, a request was made by TAMU in November to cancel the Landsat standing order with ASCS.

In addition to the reasons given above for canceling the standing order, it was also found that the standing order products were often received more than three months after the date of acquisition by the satellite.

Within this period of time, Landsat microfilm for the same coverage was being received in the Remote Sensing Center's Landsat Browse Facility. This meant that the Landsat data evaluations could be made from the Browse Facility microfilm at an earlier date than from the standing order products.

For the ETSA four image area and the Throckmorton test site, Landsat color composite imagery in the form of 9.5-inch paper prints and positive transparencies were ordered for the dates of Landsat coverage given in Table 3-1. These products were received from the ASCS Western Aerial Photo Lab. The corresponding Landsat MSS computer compatible tapes were ordered for these frames of coverage from the EROS Data Center.

Landsat Browse Facility microfilm of Landsat-1 and -2 coverage was evaluated for the ETSA nominal frames to determine the quantity and quality of MSS data acquired coincident with ground data collection at the sampling locations. The quality of imagery from Landsat-1 and -2 coverage of the ETSA is presented in Figure 3-9. Project personnel evaluated percent cloud cover from microfilm images and used MSS data quality ratings from NASA catalogs to select imagery for the ETSA. Using this procedure, 108 images were evaluated for the ETSA. Of these images, 20% had between 0-25% cloud cover; 18% had between 6-25% cloud cover; 20% had between 26-50% cloud cover; 11% had

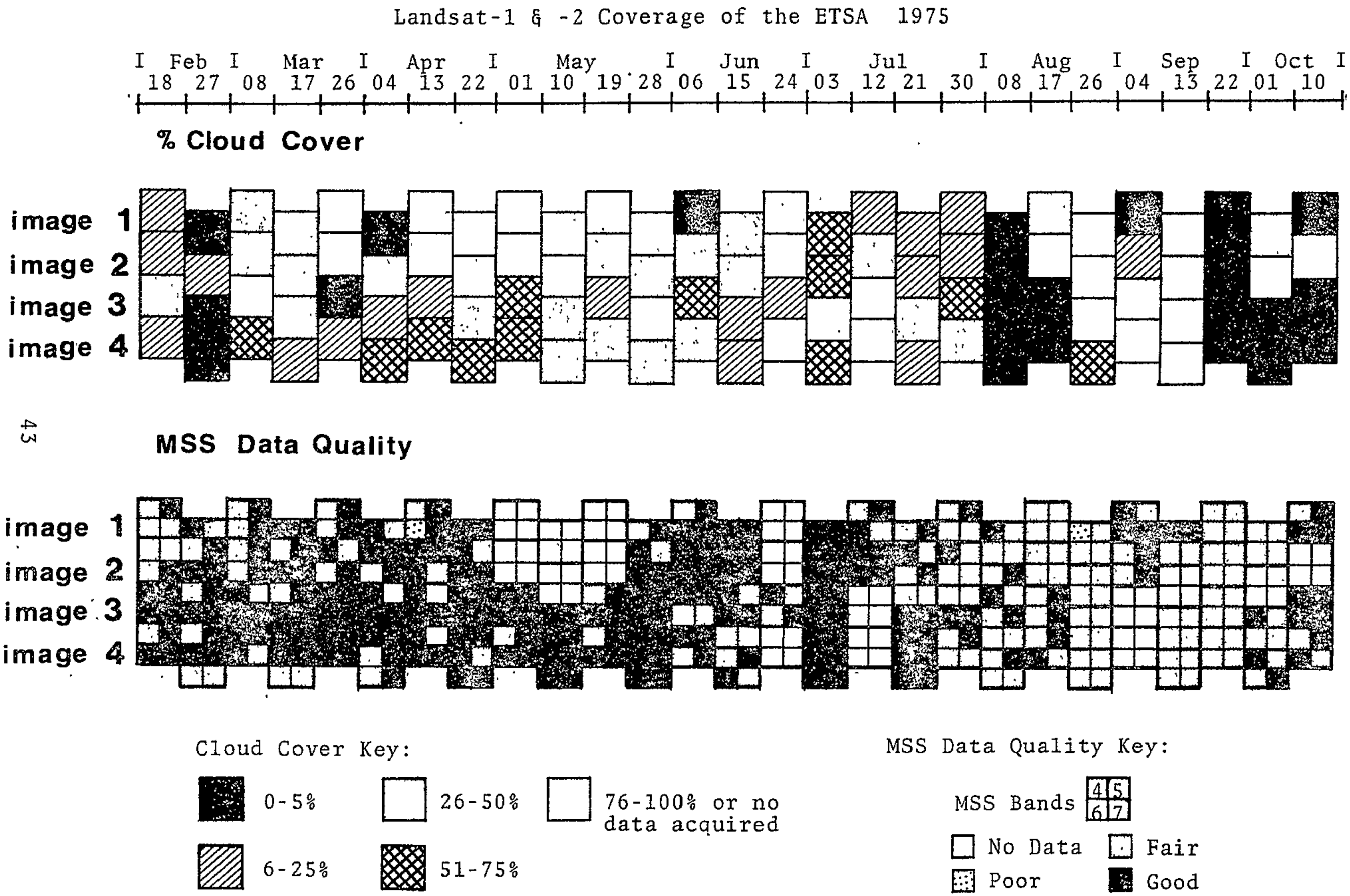


Figure 3-9. Landsat-1 &-2 coverage of the ETSA during the 1975 sampling period.

between 51-75% cloud cover; and 31% had between 76-100% cloud cover or no data were acquired by the satellite for the designated area and time period over the ETSA.

Evaluations of the MSS data for these 108 images reveal that only 50% of the MSS bands were of good quality, with the remaining 50% either fair or poor or no data were available for those images covering the ETSA.

Landsat-1 and -2 coverage of the Throckmorton, Texas test site was also evaluated for cloud cover (Figure 3-10). Twenty-seven overpass cycles from mid-February through mid-October were evaluated. Eleven cycles, or 41%, yielded 100% cloud-free conditions over the test site area. Seven percent of the cycles resulted in partially usable data with a few small clouds present over the test site. The remaining 52% of the potential satellite coverage periods had unfavorable cloud conditions over the test site or MSS data were not acquired by the satellites for this area.

3.2 Great Plains Corridor Test Areas

The Great Plains Corridor Test Areas were used to test on a one-time basis, throughout the Great Plains Region, the application of the forage condition mapping techniques developed for the ETSA. Primary test sites retained from the initial Landsat investigation were sampled for several dates to provide a ground check of

Throckmorton Test Site

Quality of Landsat-1 & -2 Coverage

1975

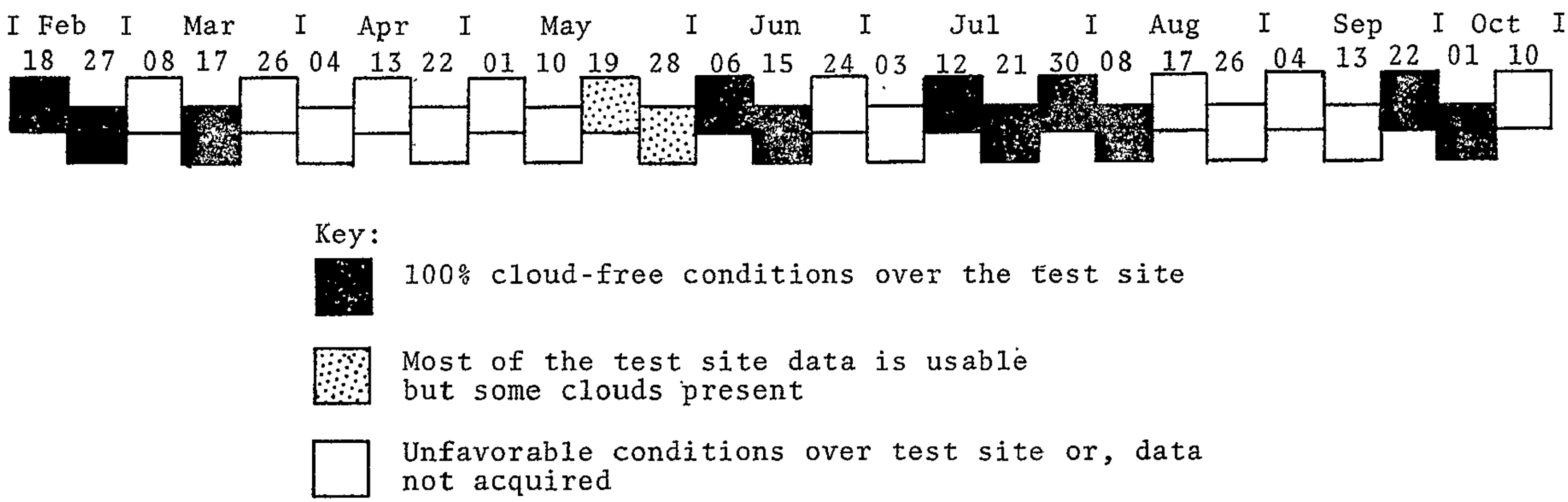


Figure 3-10. Quality of Landsat-1 & -2 coverage of the Throckmorton test site.

vegetation conditions, as well as provide another opportunity to evaluate the relationships between ground conditions and Landsat radiance parameters.

3.2.1 Modifications of GPC Landsat-1 Test Site Network and Sampling Procedures

The initial Landsat-1 GPC project effort concentrated on analyzing data from ten well documented test sites that were established within the Great Plains Region (Figure 1-1). The extension of the initial program to the regional emphasis in this follow-on study conceptualized the use of the existing network of test sites for ground observation points along belt transects called test areas (Figure 2-1). Because of the emphasis on the ETSA and for the reasons explained in Section 2.2, three of the test sites (College Station, Sonora and Weslaco) were deleted from this network for the follow-on study.

The minimum expectation for using these test areas was to obtain a near cloud-free Landsat data set during one overpass cycle for which ground conditions would be monitored at all of the test sites. Consequently, a coordinated schedule for sampling at the GPC test site was provided to the test site cooperators before the beginning of the 1975 growing season. This schedule called for ground sampling at the primary test sites coincident with four Landsat-1 or Landsat-2 overpasses during the growing season. Two of these sampling periods were scheduled for the spring (May-June), one in the summer (July-August) and one in early to mid-fall (September-October).

The Landsat data set that was chosen for the vegetation condition mapping technique application and evaluation within the GPC was acquired in the fall. This time period resulted in the best Landsat data for the test areas, with four of the six test sites providing ground data to evaluate the vegetation conditions. However, because of scattered cloud cover over part of the original test areas defined in Figure 2-1, a slightly modified test area arrangement was necessary. Figure 3-11 shows the test areas as modified for mapping the vegetation conditions within the GPC in early October 1975. The GPC test sites which provided ground condition verification data still lie within these modified test areas. These test sites are described or characterized in final report RSC 1978-4.

Ground truth data collections at the test sites were performed by the on-site cooperating research personnel as in the initial GPC project. However, a few changes were made in the kinds and amount of data collected in 1975. In order to provide a more accurate record of biomass and vegetation conditions, the number of sites was at least double that used in the initial Landsat-1 study. RSC personnel visited each test site prior to

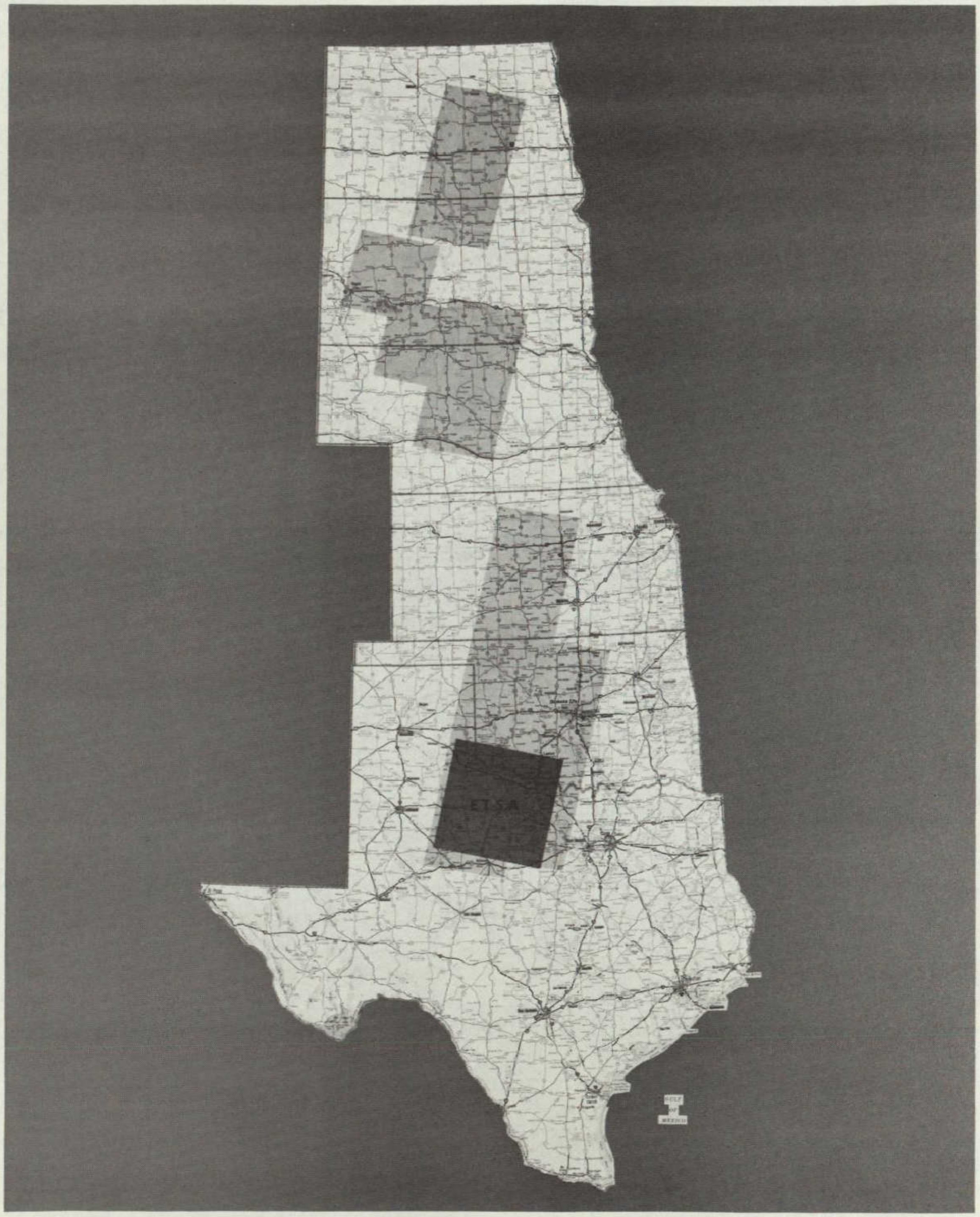


Figure 3-11. Test areas defined by Landsat frames used in the October 1975 GPC vegetation condition mapping evaluation.

field sampling and assisted the cooperators in establishing the additional sampling sites. The information that was taken for each sampling period at the ground sample sites included herbage production, visual estimates of several ground parameters, ground photographs and weather data.

Total aboveground herbaceous fresh and dry biomass and moisture content of the vegetation were obtained from clipped plots. Visual estimates of the percentage of standing herbage that is green matter (on a dry-weight basis), visual estimates of the percentage of bare ground as viewed from the vertical and measurements of the average height of herbaceous vegetation were made on each sample plot prior to clipping. The length of time that the sample areas had been grazed at the time of the sampling and qualitative ratings of the current utilization were recorded. The three dominant species, their relative dominance and phenological stage were also determined. Weather data included precipitation and temperature records for weather stations nearest each of the test sites. Oblique and vertical color ground photographs provided a permanent documentation of the vegetation conditions at each site for each of the sampling periods.

3.2.2 Secondary Sample Sites

Secondary sample sites are defined as rangeland areas selected for Landsat digital data extraction to provide a sample from which the vegetation conditions within the GPC can be determined and mapped. The same techniques used in the ETSA for secondary site selection (see Section 3.1.3) were applied to the GPC test areas. The process of locating these secondary sites within the GPC was somewhat more difficult than for the ETSA because a smaller percentage of the test areas was covered with NASA highflight aerial photography. Consequently, more photointerpretation was required from color composite Landsat imagery.

A lower density of secondary sites was used for the GPC technique application demonstration than for the ETSA multiple date study. Within the test areas north of the ETSA, 216 secondary sample sites were located (Figure 3-12). The clustering of the secondary sites observed in this figure results from the greymapping technique used in locating the areas for data extraction.

Since the GPC secondary site location activity was conducted toward the end of the project when allocated computer processing funds were almost depleted, a less-than-optimum number of secondary sites were processed. This factor, along with some cloud cover problems, resulted in the rather sparse distribution of data points seen in Figure 3-12, especially in the northern portion where 78 secondary sites are located in only 17 greymap areas.

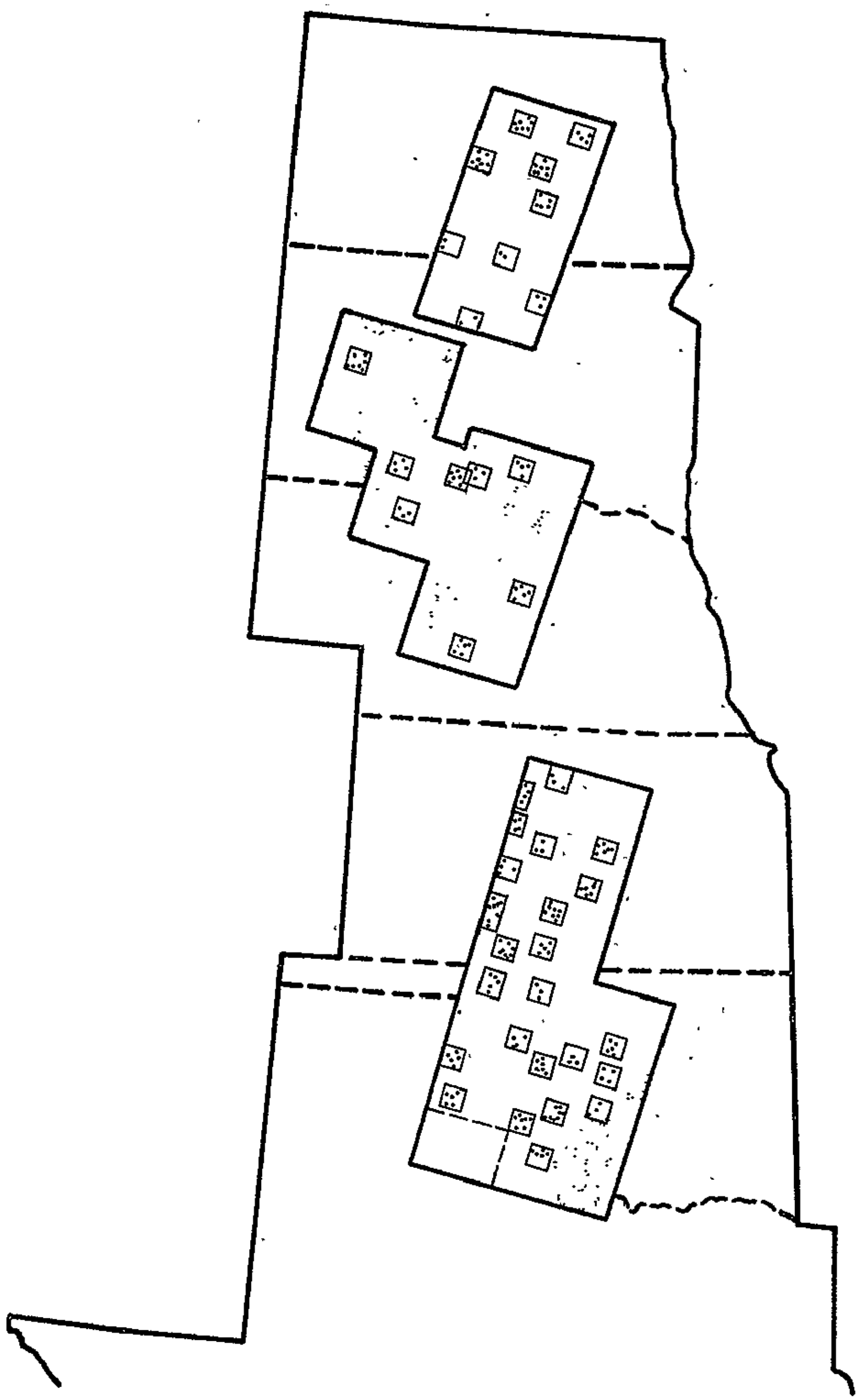


Figure 3-12. Locations of secondary sample sites (dots) within 32 km x 32 km site location greymaps used for mapping vegetation conditions within the GPC test areas. Cloud cover is indicated for the October Landsat data set.

The Remote Sensing Center's Data Analysis Facility has developed new interactive data processing capabilities that will enable much more efficient and economical site location and data extraction for future work.

3.2.3 Summary of Ground Data Acquired

Ground truth data collection at the GPC test sites, coincident with Landsat overpass, was designed to document vegetation conditions at known locations for evaluating forage condition maps produced from Landsat data within the test areas. It was anticipated that during the period of the study a variety of forage conditions would be experienced in different portions of the GPC test areas during at least one of the scheduled sampling periods. It was expected that this range of forage conditions could be mapped from the Landsat data and the ground data would be used as checkpoints for verification. In addition to providing a ground check on vegetation conditions, these data also provided another opportunity for correlation analysis with Landsat data and evaluation of green biomass estimation models.

Although four sampling periods were originally scheduled for each of the GPC test sites, the number of times that each test site was sampled ranged from two at Mandan to six at Sand Hills. Table 3-2 shows the dates

Table 3-2. Dates of ground data acquisition and Landsat coverage for GPC test sites.

Test Site	Ground Data	Landsat Overpass
Woodward	June 13	6-16-75 (2)★
	July 22	7-22-75 (2)
	October 2	10-2-75 (2)★
Chickasha	June 6	6-6-75 (1)
	June 26	6-24-75 (1)
	July 31	7-30-75 (1)
	October 1	10-1-75 (2)★
Hays	May 23	5-21-75 (1)★
	July 14	7-14-75 (1)
	Sept. 24	9-24-75 (1)★
Sand Hills	May 14	5-14-75 (2)★
	June 1	6-1-75 (2)
	June 17	6-19-75 (1)
	July 17	7-16-75 (1)
	August 20	8-20-75 (1)★
	Sept. 17	9-17-75 (2)★
Cottonwood	June 1	6-1-75 (2)★
	June 19	6-19-75 (2)★
	July 26	7-26-75 (2)★
	August 29	8-29-75 (2)★
Mandan	June 3	6-2-75 (2)★
	June 20	6-20-75 (2)★

*Number in parentheses denotes whether Landsat-1 or -2.

★Denotes dates for which usable Landsat data is available for the site.

on which ground samples were taken along with the corresponding Landsat overpass. Fourteen of these Landsat overpasses yielded usable data for the test site.

3.2.4 Summary of Aerial Photography Acquired

Approximately 750 flight line miles of NASA highflight color-infrared aerial photography (1:120,000 scale) was provided for the GPC test areas north of the ETSA (Figure 3-13). The Woodward, Oklahoma and Hays, Kansas flight lines were flown on June 5, 1975. Both flight lines in the Nebraska sand hills, covering the Valentine, Nebraska and Merritt Reservoir areas, were flown on June 12 along with the Cottonwood flight line. However, cloud cover on the Valentine, Nebraska flight line on June 12 required that this strip be reflown. Consequently, flight line 12 was flown again on June 28 when the Mandan, North Dakota coverage was acquired.

Microfilm containing preview copies of the NASA Mission 310 highflight aerial photography was received from the ASCS Western Aerial Photo Lab on August 22, 1975. The microfilm containing NASA Mission 312 aerial photos was received on September 26, 1975. A total of 80 duplicate color-IR transparencies were ordered after evaluating the microfilm. The normal turnaround was approximately six weeks to two months from the date the order was placed until the photos were received.

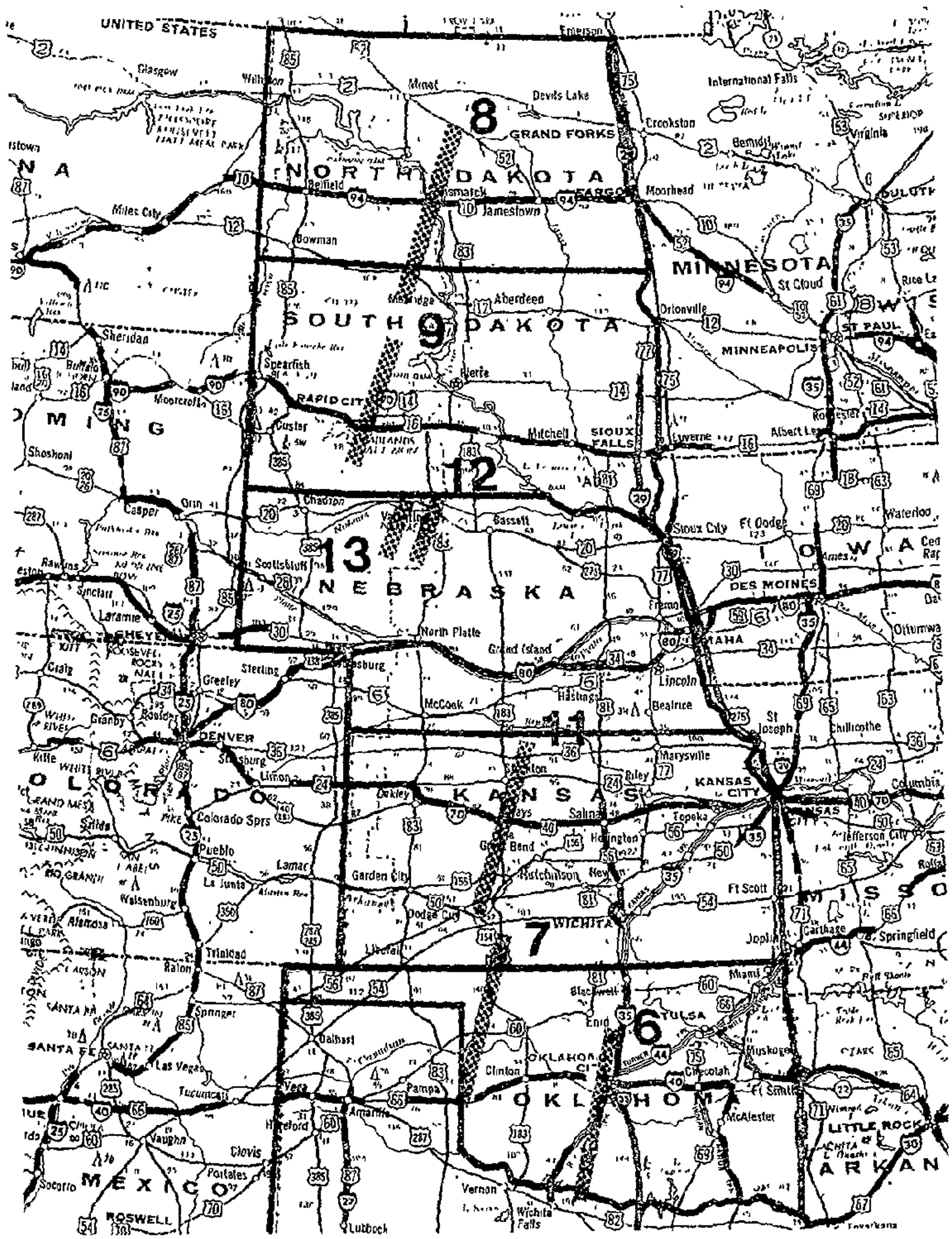


Figure 3-13. Coverage of NASA highflight 1:120,000 scale color-infrared aerial photography for GPC test areas north of the ETSA.

In addition to the NASA highflight aerial photography acquired for the GPC test areas as they were finally established, aerial photography was acquired for the flight line containing the College Station test site. Twenty-five transparency duplicates and two color prints were ordered and received for this flight line.

The NASA highflight aerial photography was an indispensable tool for secondary site collections and for precise location of these sites on Landsat greymaps for coordinate location and data extractions.

3.2.5 Summary of Landsat Data Acquired and Processed

Standing order Landsat bulk black-and-white 9.5-inch positive transparencies for Band 5 were received and handled for the GPC test areas in the same manner as they were for the ETSA described in Section 3.1.6.

For the GPC test areas, Landsat color composite imagery in the form of 9.5-inch positive transparencies and the corresponding Landsat MSS computer compatible tapes were ordered for the dates of Landsat coverage given in Table 3-1. In addition, color composite prints and transparencies and MSS computer compatible tapes were ordered and received for the Landsat-2 scenes listed in Table 3.3. The digital data for these imagery were analyzed to produce the GPC vegetation condition map

Table 3-3. Landsat-2 scenes from which the digital data were analyzed to produce the GPC vegetation condition map for October 1975.

Date	Observation ID No.	Image Center Coordinates (degrees-minutes)	
		Latitude	Longitude
10-1-75	2252-16274	36-05	97-48
10-1-75	2252-16281	34-40	98-15
10-2-75	2253-16324	38-45	98-21
10-2-75	2253-16330	37-20	98-49
10-2-75	2253-16333	35-54	99-16
10-4-75	2255-16425	43-02	99-43
10-4-75	2255-16432	41-36	100-14
10-5-75	2256-16472	47-16	99-30
10-5-75	2256-16475	45-51	100-05
10-5-75	2256-16484	43-01	101-11
10-6-75	2257-16535	44-25	102-07

for October 1975. These 11 scenes span the period from October 1 through October 6, 1975.

3.3 Landsat Data Handling and Processing

Several routine data handling and processing functions were performed with the Landsat data in accomplishing the regional monitoring project objectives. Most of the routine data handling follows the procedures established in the initial Landsat project. Computer software for generating Landsat MSS data greymaps (used in sample site selection) and for generating Site Processing Reports (containing sun-angle corrected mean radiance values in each of the four bands) and calculating special parameters (e.g., TVI6) were refined. However, the procedures remain basically the same as originally developed. A considerable amount of new software had to be developed, however, for the regional parameter mapping technique described in Section 3.4.

Upon receipt of the Landsat CCT data, the scene reference information was entered into a computer search and retrieval file and the tapes were stored in the RSC tape storage facility. An acetate overlay was prepared for the Band 5, 1:1 million scale Landsat image which accompanied the Landsat CCT data. The primary and secondary sites were located and identified on this acetate overlay. Thirty-two kilometer by thirty-two kilometer boundaries were scribed about these sites on the image overlay and the approximate line-and-cell location coordinates were determined for computer greymap generation.

When the 32 km x 32 km computer greymaps for these areas containing the primary or secondary sites were generated, prominent features were identified with the aid of the Landsat image and drawn on the greymaps. Such features included field boundaries, drainage patterns, rivers, lakes, towns, roads, pipelines and other prominent cultural and natural features. With these landmarks and with the aid of 1:24,000 scale topographic maps, the primary and secondary sites were located quite accurately; generally within one or two pixels. Once the sites were located on the greymap, line-and-cell location coordinates were determined for the sites. The standard Site Processing Reports (Figure 3-14) were then processed for each site.

The data from the Site Processing Reports were used in several ways. The data were used in correlation analyses with ground truth data collected at the primary sites. In the follow-on project, calculated parameters given on the Site Processing Report were plotted using the regional parameter mapping technique. In a more refined application, these Landsat parameters were employed in a model with weather data to calculate a vegetation parameter, which was then plotted as an isoline map using the regional parameter mapping technique.

Processing of Landsat CCT's was more expensive as well as time consuming than it should have been during the follow-on project because of an increase in the occurrence of "data checks" on the tapes. Whenever data checks or bad spots exist on the EROS Data Center-produced CCT's, the TAMU computer cannot accurately read an information record. This results in the loss of part or all of the record currently being read, depending on

```
***************************************************************
*                                                             *
*                 **************************                  *
*                 *                        *                  *
*                 *         LANDSAT        *                  *
*                 *                        *                  *
*                 * SITE PROCESSING REPORT *                  *
*                 **************************                  *
*                                                             *
*  SITE DESIGNATOR:  GP 3 1Q         CELLS   967 TO   978     *
*  IMAGE IDENTIFIER: 5156-16131      LINES  1200 TO  1204     *
*  DATE ACQUIRED:    22SEP75         TOTAL  POINTS     60     *
*                                                             *
*    ***CORRECTED FOR SUN ELEVATION    43 DEGREES***          *
*                                                             *
*        RADIANCE(MWATTS/SQCM-STR-MICROMETER)                 *
*                                                             *
*                   MEAN     STANDARD   WAVELENGTH            *
*                            DEVIATION  (MICROMETERS)         *
*        BAND 4     7.51       0.36     .5 - .6               *
*        BAND 5     5.25       0.22     .6 - .7               *
*        BAND 6     6.54       0.34     .7 - .8               *
*        BAND 7     5.60       0.26     .8 -1.1               *
*                                                             *
*                  NORMALIZED COVARIANCES                     *
*                                                             *
*                  BAND 4    BAND 5    BAND 6    BAND 7       *
*        BAND 4     1.000     0.382     0.344     0.434       *
*        BAND 5     0.382     1.000     0.296     0.347       *
*        BAND 6     0.344     0.296     1.000     0.461       *
*        BAND 7     0.434     0.347     0.461     1.000       *
*                                                             *
*                 TVI6= 0.780     TVI7= 0.730                 *
*                                                             *
*          5/4= 0.700      7/4= 0.746      7/5= 1.067         *
*                                                             *
* 16.0  +                                                     *
*       .                                                     *
*       .                                                     *
*       .                                                     *
*       .                                                     *
*       .                                                     *
*       .                                                     *
*       .                                                     *
*  8.0  +    *                                                *
*       .      -         *                                    *
*       .         -    -               -         *            *
*       .           *                                         *
*       .                                                     *
*       .                                                     *
*       .                                                     *
*       .                                                     *
*  0.0  +---------+---------+---------+---------+---------+   *
*      0.5       0.6       0.7       0.8       0.9       1.0  *
*               RADIANCE VS WAVELENGTH                        *
*                                                             *
*  PREPARED BY:TEXAS A&M UNIVERSITY, REMOTE SENSING CENTER    *
*            DATA ANALYSIS LABORATORY  07MAR76                *
*                                                             *
***************************************************************
```

Figure 3-14. Example of the RSC standard Site Processing Reports routinely generated for study sites from Landsat MSS CCT data.

where the data check occurred. These tapes must be recopied to another tape to remove the data checks. This special purpose program reads the tapes, and upon encountering a bad spot on the tape, salvages what good data it can and continues on. This additional program must be run for every CCT that is found to have data checks.

At the time of this report, new techniques have been developed and are being used in the Remote Sensing Center's Data Analysis Facility in which an interactive dynamic color display system is used to locate sites and extract data from Landsat CCT's. This capability provides a much more economical and efficient technique for obtaining the required data.

3.4 Regional Parameter Mapping Technique

The function of the regional parameter mapping technique was to enable computer plotting of specified parameters (e.g., TVI6) for a geographical region from sample point data taken within the region. The final output products were two-dimensional isoline contour maps depicting variations in the parameters across the region. There were three basic steps in the routine mapping process: 1) identifying sample point geographic locations within the area to be mapped, 2) generating a function to describe the parameter across the entire area based on the sample point data (three-dimensional surface) and 3) plotting specified regular interval variations in the parameter across the region as a two-dimensional map with reference locations.

Computer software was developed to enable sample point geographic locations in one of three alternative ways. The location coordinates can be described in terms of the Universal Transverse Mercator (UTM) projection, latitude and longitude or X-Y coordinates of a 50 x 50 grid (accurate to two decimal places) that represent the region to be mapped.

UTM or latitude and longitude coordinates are more easily obtained since they can be pulled directly off USGS topographic maps on which the sample point locations have been identified. However, the use of either of these coordinate systems for mapping a rectangular region aligned with the Landsat track requires a 12.5 degree rotation and expansion of the sample points to fill the mapping area. Figure 3-15A shows the ETSA as it appears in relation to true north. Figure 3-15B depicts the final configuration of sample points within the X-Y grid which can be scaled and accurately overlayed on Landsat imagery products or other maps.

The sparse matrix of sample data is then used as input to a regression analysis routine of the Statistical Analysis System (SAS, developed by the

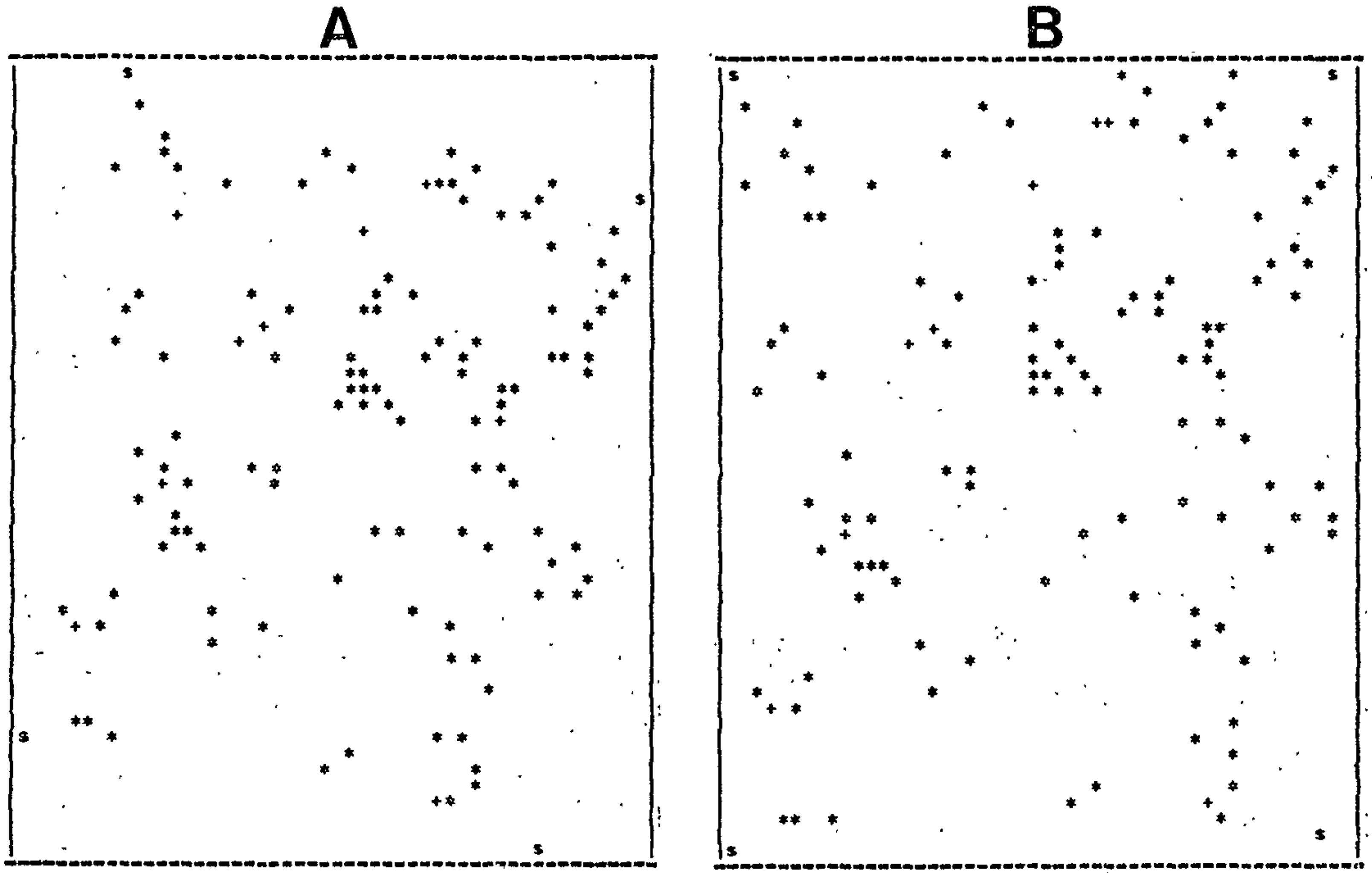


Figure 3-15. A - UTM coordinate locations of ETSA secondary sites referenced to an X-Y matrix oriented to true north.

B - Final sparse matrix of sample points in a 50 x 50 X-Y matrix for parameter mapping.

Department of Statistics at North Carolina State University). The regression analysis routine derives data values (coefficients) for n^{th} order equations which define a surface that passes through the sample data points. Statistical analysis of the coefficients and the closeness of fit of the function to the given values are also determined. The program then goes back with the function and predicts the dependent variable for each of the given X and Y values. The resulting value for each F(x,y) is not always identical with the given F(x,y), although they are statistically very close. The coefficients for a fourth order least squares fit were determined to provide the best map data for this study. The lower orders "smoothed" the data too much, and higher orders created abnormal values for areas containing no sample data points. Figure 3-16 is a surface created through this procedure.

An existing contouring program (CONREC*), which produces contours from data stored in a rectangular array, was then implemented to generate the final map product. With this program, a cubic spline is applied to lines connecting similar values that will form an isoline. Thereby, the final product (e.g., Figure 3-2) contains smooth curved lines instead of connected straight line segments.

---

*NCAR, Colorado

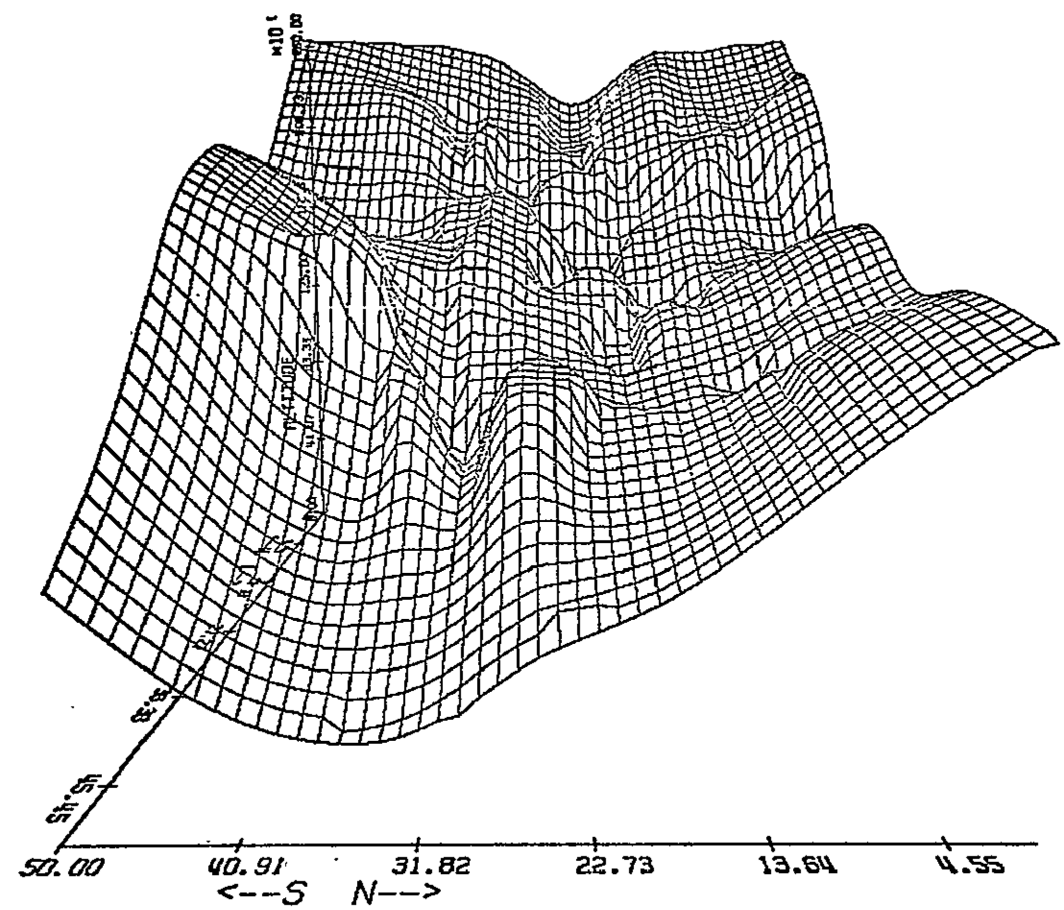


Figure 3-16. Typical three-dimensional surface produced in the second step of the regional parameter mapping technique. Hard copy products are not normally generated for this interim activity.

The mechanical map plotting for this project was accomplished on the Remote Sensing Center, Data Analysis Facility's Versatic electrostatic printer/plotter and the TAMU central computer facility's calcomp plotter. Resolution for both plotters is one hundredth of an inch.

The regional parameter mapping technique is versatile. Maps can be produced for counties, states or larger regions with equal ease and accuracy when data for a sufficient number of well distributed sample points are available. The accuracy of data fit is available from the routine processing. The computer plotting eliminates the human bias that can occur with hand-drawn contour maps.

4.0 Data Analysis and Results

The primary analysis effort of the Landsat Great Plains Corridor Follow-On Project involved an evaluation of the accuracy and adequacy of regional vegetation condition maps produced from Landsat MSS digital data. Landsat color composite imagery was used at the beginning of the project in an analysis of the vegetation and soil characteristics of the Extended Test Site Area. Ground truth data collected at the ETSA primary sites and GPC test sites were analyzed to determine the vegetation conditions at the sample sites, as well as determine the variations in condition across these regions. These ground measurements and other records of vegetation conditions within the Great Plains Region were used in an analysis of the Regional Range Feed Condition contour maps produced from the Landsat MSS digital data.

4.1 Vegetation Resource Mapping from Landsat Imagery

4.1.1 Vegetation/Soil Information Requirements

At the beginning of the follow-on project, after the Extended Test Site Area had been established, it was necessary to gain a better understanding of the vegetation and soil resources within this region. Ground sampling sites and secondary sites for digital data extraction and parameter mapping had to be properly located and well distributed within each of the major vegetation associations in the region. In addition, management influences such as brush control or over grazing on the rangelands being considered for primary or secondary sites had to be recognized.

Using Landsat imagery taken during the four seasons over most of three consecutive years, general cultural and natural resource features were mapped on four, 1:250,000 scale color composite images. Land surface features that could be mapped from this imagery with a minimum amount of ground truth included urban and agricultural land, water resources, rangeland and woodlands.

Rangeland is the predominant land type in this region and can be readily detected from the imagery. It became apparent from examining rangeland on the Landsat images that different vegetation associations could be distinguished by their unique "photo signature". The Landsat imagery was effectively used to manually interpret and map the broad rangeland vegetation associations of this north central Texas area. The vegetation categories mapped were checked by a rapid ground reconnaissance technique and a land classification legend system compatible for use with space imagery was developed.

4.1.2 Approach for Mapping from Landsat Imagery*

There were five basic steps followed in producing the vegetation maps and the hierarchal classification and legend systems for the Extended Test Site Area. These phases are: 1) Landsat imagery and map acquisition, 2) preliminary mapping, 3) ground reconnaissance survey, 4) compilation and analysis and 5) final mapping and verification.

Existing Landsat imagery covering the ETSA was searched for and then evaluated via Landsat Browse Facility microfilm to select a good base imagery set for resource mapping. The four images covering the ETSA, selected early in the project as the base image set, were acquired by Landsat-1 on October 20-21, 1973 (Observation I.D. Nos. 1454-16385, 1454-16392, 1455-16441, 1455-16450). Color balanced 1:250,000 scale color composite paper prints (from Bands 4, 5 and 7) of these four images were ordered from the ASCS Western Aerial Photo Lab. For these images and imagery covering the ETSA on three additional dates, color composite transparencies at 1:1 million scale were also acquired. In addition, as many available maps as possible providing information on the cultural, physical and vegetative features within the ETSA were examined.

---

*The approach for mapping from Landsat and the preliminary map were developed in large part by K. C. McDaniel. This early work was done as a part of his Ph. D. dissertation.

Preliminary mapping was done on acetate overlays upon the Landsat imagery in two basic steps. First, generalized land surface features which could be easily stratified with reasonable certainty were delineated. Second, areas within rangeland and forest and woodlands were examined for unique photo signatures which appeared to be uniform and which could be easily distinguished from other areas. Changes in photo signatures such as color and textural difference usually corresponded closely with marked changes on the ground surface, such as difference in vegetation, physiography and soil type.

When the preliminary stratification and pretyping was completed, preparation for a field survey to refine the mapping and classification was initiated. A reconnaissance travel route was designed to cover as much of the study area and as many of the pre-stratified mapping units as possible. With Landsat images and maps in-hand, the predetermined ground reconnaissance route was traveled and major changes in vegetation or soil encountered were marked on the imagery and maps. These changes were generally easy to recognize with Landsat imagery in-hand. Within each of the major vegetation associations, stops were made and notes were taken on the physiographic and vegetative characteristics of these sites.

With the knowledge gained from the original mapping effort and the notes compiled from the ground reconnaissance trip, a preliminary land resource classification scheme was developed (Appendix C). The classification was hierarchically based, which allows the photointerpreter to map at various levels of intensity. For example, the interpreter may be reasonably certain that a shrub-dominated rangeland is being mapped but uncertain as to the kind of shrubland it is. Thus, he would classify the area to a second level of classification.

This tentative land classification system is a preliminary step in the development of a larger computer compatible legend system to describe the delineated land units and will ultimately be expanded to encompass all natural vegetation areas in Texas and possibly the Great Plains Corridor states.

Following the completion of the ground survey and the development of the legend system, a more detailed map of the rangeland resources was produced using the four Landsat color composite enlargements at 1:250,000 scale. The rangeland vegetation types were delineated and annotated on the photos with the proper legend code. A final activity that would be necessary prior to publishing a map of this type would involve final field checking for map accuracy. It was not an objective of this project to publish a vegetation resource map for this area. The level of resource information required for this project was reached without a determination of the map accuracy. NASA highflight aerial photography was used, in most cases, to provide the more detailed site evaluations. The Landsat imagery alone could not have provided the level of detail required for the final site selections.

4.2 ETSA Ground Observations

Ground measurements taken at the Throckmorton test site, approximately every 18 days throughout the growing season, characterized the phenological development of the vegetation of this region in 1975. The ground measurements taken at ETSA primary test sites documented the vegetation conditions, provided estimates of biomass at specific locations for three time periods and characterized the variations in vegetation conditions across the ETSA for each line period. Weather records from 61 National Weather Service reporting stations distributed throughout the ETSA provided additional documentation concerning growing conditions within this region.

4.2.1 Throckmorton Test Site Conditions

Spring green-up in 1975 at Throckmorton progressed in the expected manner with peak, green biomass occurring about the second weed in May (Figure 4-1). Herbaceous green biomass

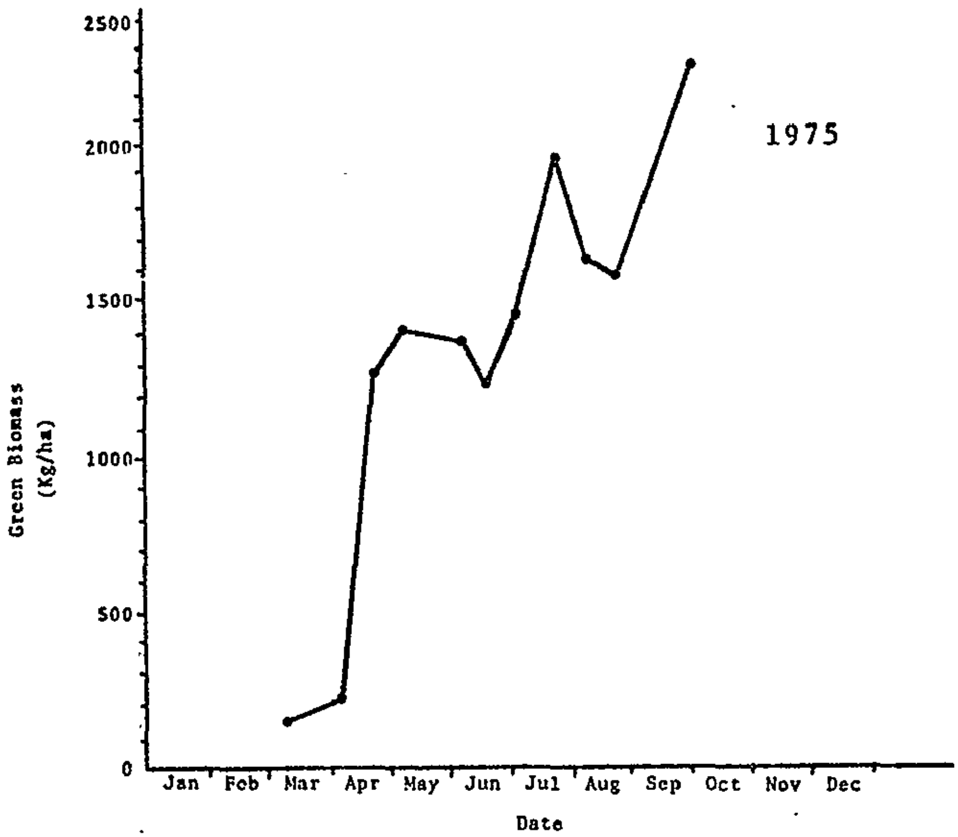


Figure 4-1. Green biomass measured at the Throckmorton test site for seven months in 1975.

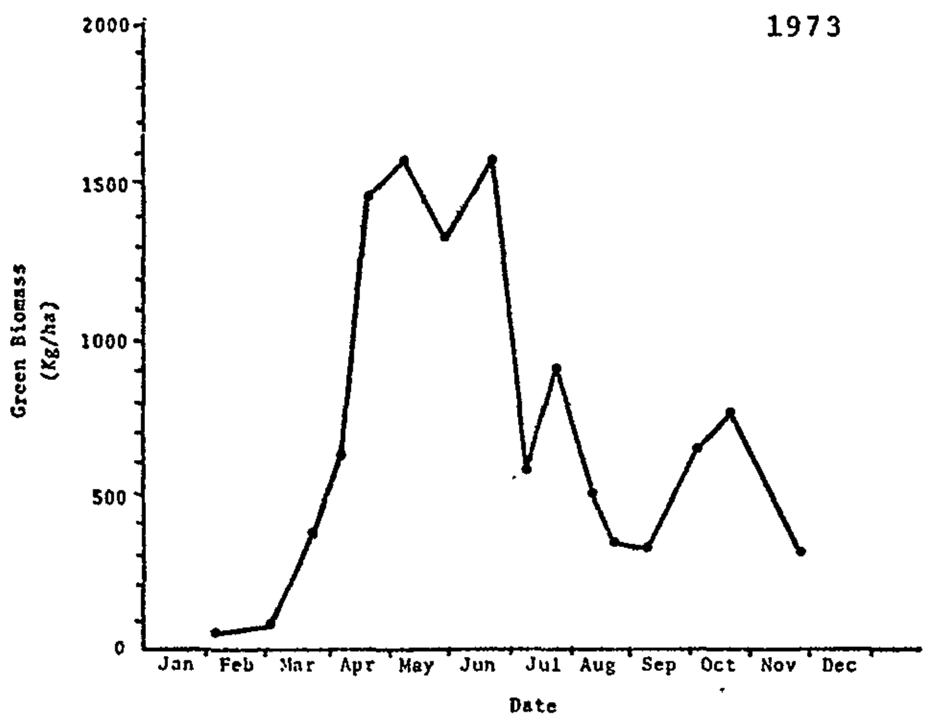


Figure 4-2. Green biomass measured at the Throckmorton test site in 1973.

was measured at 1400 kg/ha at this time. This compares with about 1600 kg/ha at the same time in the "wet" spring of 1973 and 1150 kg/ha in the "dry" spring of 1974.

Typically, in late May and early June, the very hot dry winds and infrequent showers begin to dessicate the herbaceous vegetation and crack the surface of the clay loam soil. The result is a significant reduction in green biomass. Occasional showers may revitalize the warm season grasses throughout the summer, but the general trend is a progressive reduction in green biomass until mid-to-late September and early October. The fall rains cause another significant green-up period. These "normal" developments are depicted in the 1973 green biomass data shown in Figure 4-2. The July-September data for 1975 (Figure 4-1), however, do not show the expected trends.

Following peak green-up in May, a slight reduction in green biomass was recorded by late June. However, instead of continuing with an erratic decline throughout the summer months, an increase was observed. Green biomass remained above the mid-May level (1400 kg/ha) throughout the sampling period. There are two main reasons for this. First, an unusually long and heavy rainy spell occurred in July causing considerable new growth. Second, and most important, is that the rolling plains experienced what is commonly called a "broomweed year".

Occasionally, adequate soil moisture and ideal temperature conditions enable prolific germination of annual broomweed (<u>Xanthocephalum dracunculoides</u>) in this region. Favorable spring weather, including adequate moisture and relatively mild temperatures, then result in "dog-hair" stands of immature seedlings--looking very much like tiny pine trees. They retain much this same form for many weeks, growing in height at an increasing rate as the temperatures get warmer. Beginning in late May, the plants begin profuse branching at the apex and the lower stem sheds its leaves. The result is a single-stemmed, broad-canopied, needle-leafed plant that may grow 80-100 cm high with a crown diameter in excess of 40 cm. Billions of these broomweed plants dominated much of the Texas Rolling Plains including the ETSA and Throckmorton test site throughout the summer and fall of 1975. This contribution to the green biomass component of the vegetation is in large part responsible for the maintenance of the high green biomass levels from June-October recorded in Figure 4-1. Unfortunately, this species is almost worthless as a cattle forage.

The total aboveground herbaceous biomass expressed on a dry-weight basis increased from 600 kg/ha in early April to 1500 kg/ha in mid-June, to 2300 kg/ha by October.

The vegetation moisture content at the Throckmorton test site ranged from 19% in early March, in the winter dormant period, to 58% in mid-May when more than 90% of the herbaceous vegetation was green plant material (Figure 4-3). Plant moisture was unusually high due to the atypically frequent and substantial rains beginning in mid-June and lasting through July. The maintenance of the relatively high plant moisture content throughout the latter part of the 1975 growing season can also be related to the abundance of annual broomweed. Plot clippings were separated into the broomweed and grass components at ETSA sites J and D in June and early August. These data indicate that annual broomweed generally has 25-30% more moisture/unit of dry matter than does the grass component.

4.2.2 Primary Test Site Measurements

The Throckmorton test site provided an excellent record of the progression of phenological development during the 1975 growing season and provided a reference with which to compare the other ETSA primary sites. Each of the primary sites, however, are different from all the others in some aspects. Inherent differences include such things as soil texture, species composition and average annual rainfall. Other important factors include brush management practices, the grazing system employed and the stocking rate. Super-

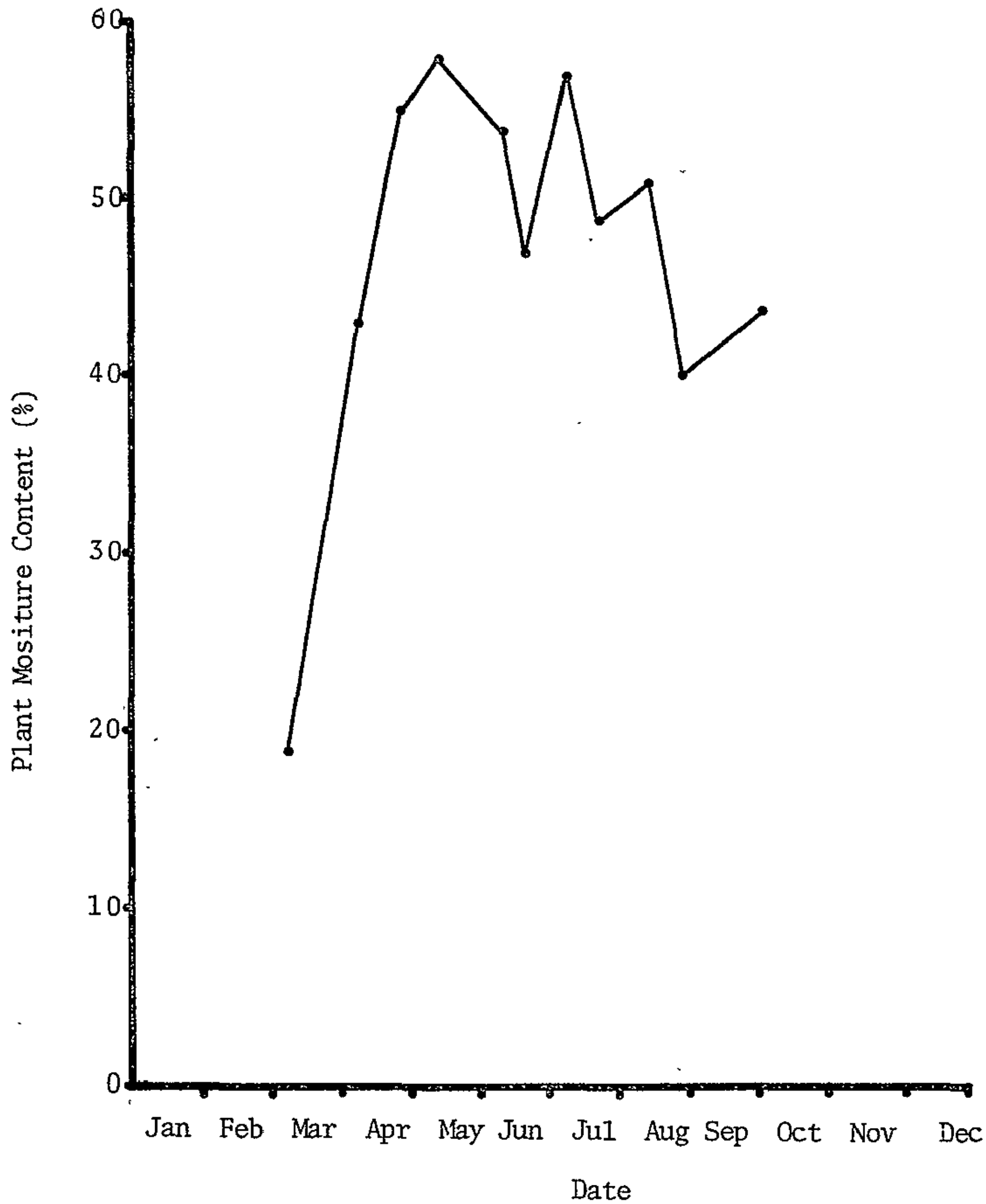


Figure 4-3. Percentage moisture content of the herbaceous vegetation at the Throckmorton test site in 1975.

imposed on this complex of determinates is local current rainfall. The amount and timing of rainfall received at a site are very important in determining the similarities between ground parameters measured at each of the sites.

From Figure 4-4, it can be concluded that total aboveground herbaceous biomass production (total biomass) was quite high within the ETSA in 1975. This is due primarily to two factors. First, abnormally high forb production occurred early in the spring, and second, abundant summer rainfall caused high production of both grasses and forbs during normally dormant periods. At the primary sites where the broomweed did not predominate, other forbs such as western ragweed, curlycup gumweed and kochia were generally dominant. Only two of the primary sites did not have a serious forb problem. These were sites N and Q in the northeast quadrant of the ETSA.

Of primary interest in this study was the determination of vegetation conditions within the ETSA and determining the areal extent of variations in vegetation conditions across the ETSA. It was important then to measure some parameter of the vegetation that would reflect differences in vegetation condition. Both green biomass and plant moisture content are useful indices of vegetation conditions. Both of these parameters have some drawbacks, however.

TOTAL BIOMASS

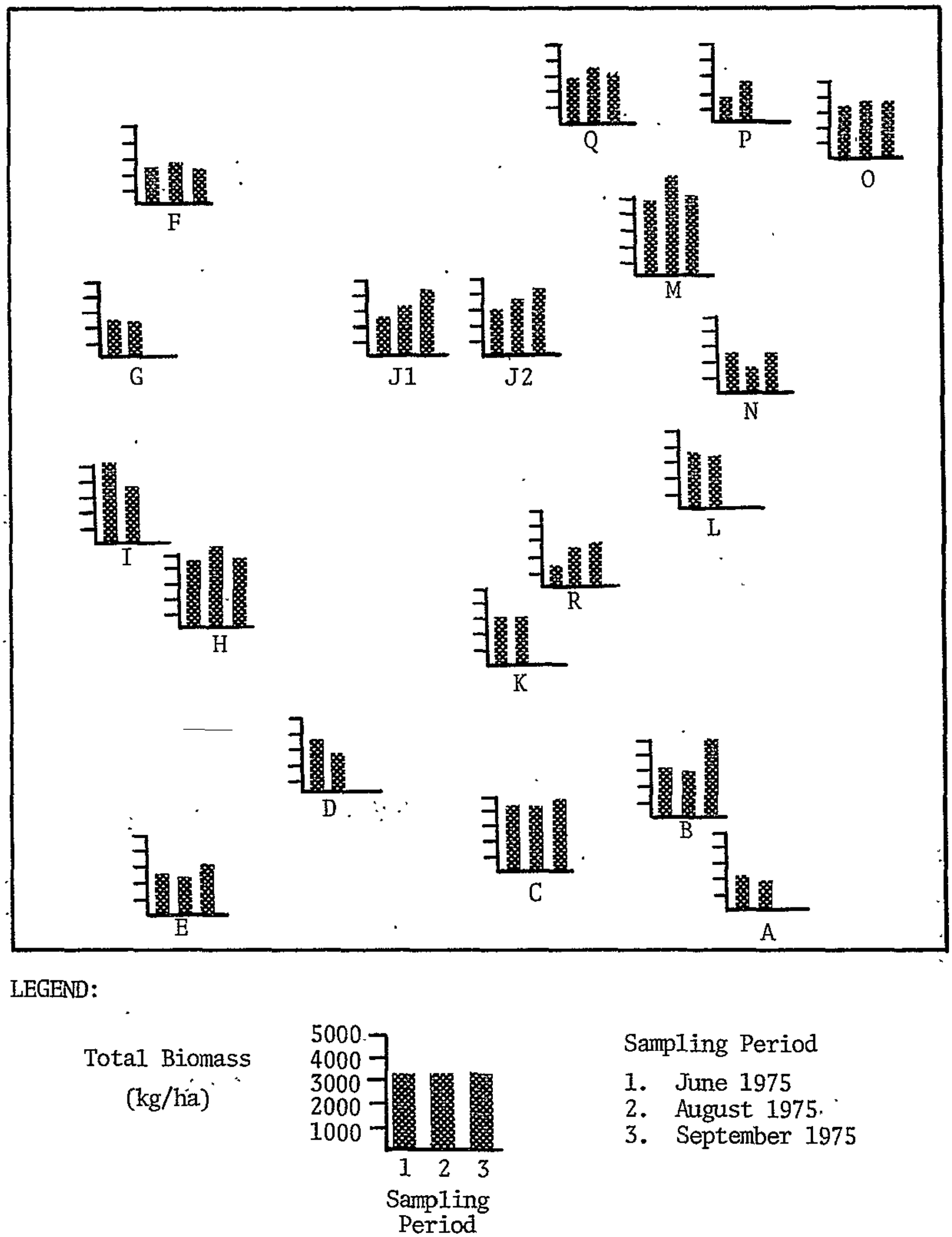


Figure 4-4. Total aboveground herbaceous biomass expressed on a dry-weight basis at the 18 ETSA primary sites.

Green biomass is probably the most sensitive for measuring significant changes, but the quantity of herbaceous biomass on the ground that will be green at any given time at different locations is not only dependent on growing conditions at that time but is also dependent on the plant species (e.g., short grass species vs. tall grass species) and their proportions (e.g., proportion of cool season plants to warm season plants), management practices and previous growing conditions. Moisture content of the vegetation is generally indicative of growing conditions, with higher moisture contents indicating better growing conditions. Since the amount of moisture in the vegetation is greatly influenced by the quantity of green plant material, graphs of these two vegetation indices are often similar. However, weather factors such as high humidity and cool temperatures can cause the moisture content to be relatively high irrespective of the quantity of green plant material present. In addition, as revealed in Section 4.2.1, different plant species may contain different amounts of plant moisture under the same growing conditions.

Green biomass, or the quantity of aboveground herbage that is green and expressed on a dry-weight basis, was measured separately for grasses and forbs at the ETSA primary sites (Figure 4-5). Total green biomass in June ranged from about 700 kg/ha at site G to over 2200 kg/ha at sites H and I.

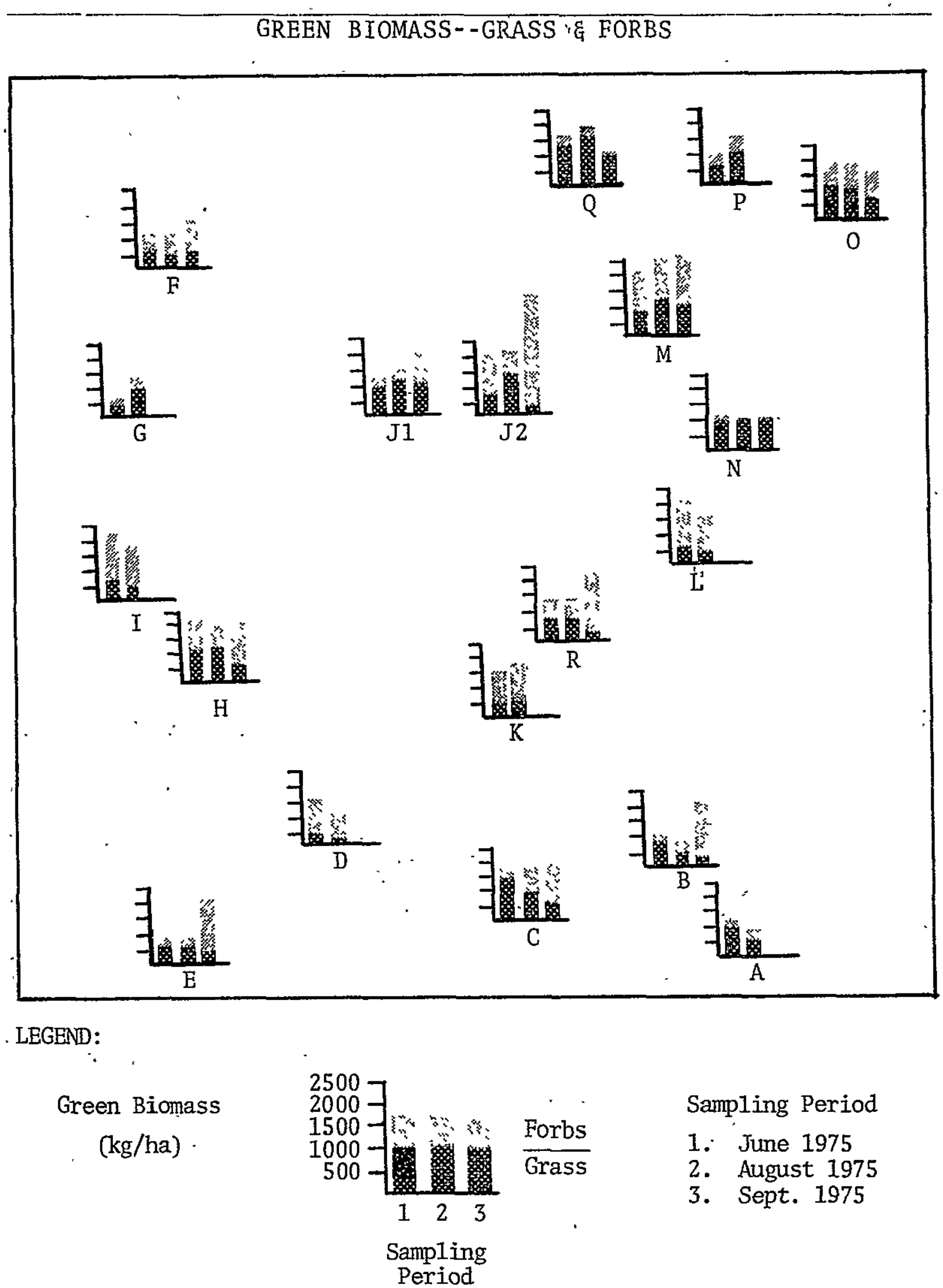
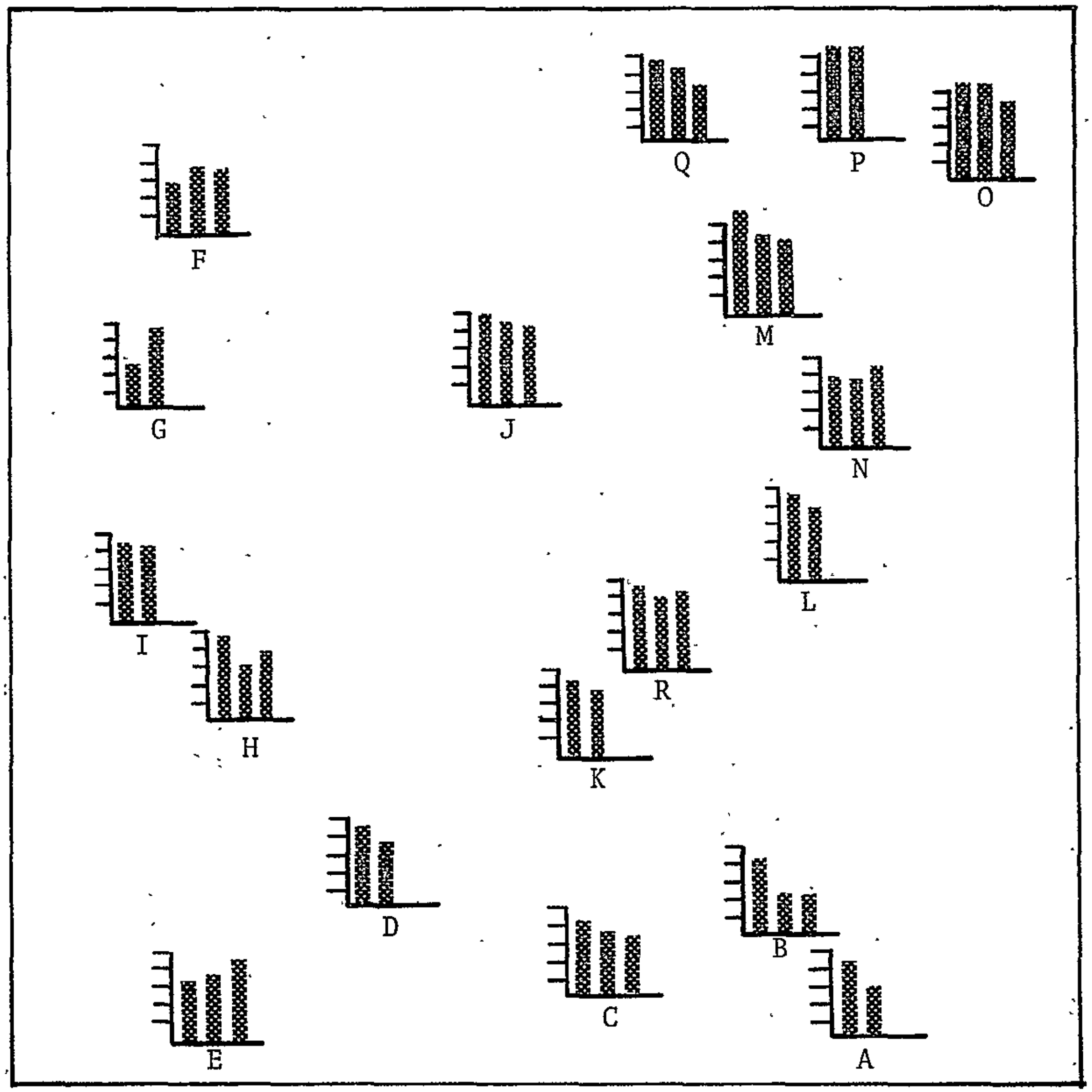


Figure 4-5. Herbaceous green biomass of grasses and forbs (dry-weight basis) at the ETSA primary sites for all three sample periods. The total column height represents total green biomass.

Vegetation moisture content data for these sites (Figure 4-6) confirmed that the vegetation conditions were indeed poorer at site G than at either H or I. The plant moisture content at site G was 28%, whereas, sites H and I showed 47% and 45%, respectively. Site F in the northwest corner and site E in the southwest corner also had relatively low green biomass (1200 kg/ha and 1000 kg/ha, respectively) and relatively low plant moisture content (28% and 32%, respectively). All of the remaining ETSA primary test sites showed 40% or greater vegetation moisture content in June. Most of these sites had well over 1500 kg/ha of total dry green biomass. Notable exceptions were sites A and B in the southeast corner which only supported approximately 1100 kg/ha of total dry green biomass.

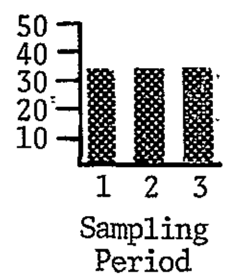
By late July and early August, a sharp decrease in the amount of green biomass and vegetation moisture content is generally expected in the Rolling Red Plains. However, measurements of these parameters at the ETSA primary sites during this summer period in 1975 indicated that conditions were generally changed very little from June. Most of the sites recorded a slight increase in total green biomass and a small decrease in vegetation moisture content. Notable exceptions to this general rule were in the southeast quadrant where a reduction in total green biomass was observed at sites A, B and L. Sites A and B also had a substantial reduction in moisture content (35%). Sites D, H and I in the southwest

VEGETATION MOISTURE CONTENT



LEGEND:

Vegetation
Moisture
Content
(%)



Sampling Period

1. June 1975
2. August 1975
3. Sept. 1975

Figure 4-6. Percentage moisture content of the vegetation at the ETSA primary sites at three sampling periods.

quadrant also showed decreased green biomass, but only site H showed a significant decrease in plant moisture content. Three primary sites, E in the southwest corner of the ETSA and G and F in the northwest corner, showed substantial increases in vegetation moisture content in August. The majority of these changes in vegetation conditions within the ETSA from June to August can be accounted for, in the most part, by the precipitation patterns that occurred in July and early August as described in Section 4.2.3.

Large increases in the forb component of green biomass caused the total green biomass to increase at all of the primary sites except F from August to late September. The grass component of green biomass declined substantially in most cases. Typically, the green forb component comprised 70-90% of the total green biomass by late September. At most sites, the vegetation moisture content decreased slightly from early August to late September. However, four sites that lie on a diagonal from southwest to northeast across the ETSA (E, H, R and N) all showed a 15-20% increase in vegetation moisture content. All four of these sites also showed an increase in green biomass. Site E showed the greatest increase; going from just under 1000 kg/ha in early August to well over 2000 kg/ha in late September.

By late September, Site J2 had a total green biomass of over 4000 kg/ha. More than 90% of this green biomass was annual broomweed. Site J1 at the same time had slightly more than 2100 kg/ha, and less than one-half of the green biomass was broomweed. These two sites were located adjacent to each other on the same range site. However, in April of 1975, a commercial application of the herbicide 2, 4-D was applied to J1. The herbicide not only reduced the amount of annual broomweed and other forbs, but also enabled increased grass production as shown in Figure 4-5.

Because different textured soils have different water holding capacities, measurements of soil moisture content more accurately reflect changes in moisture content from one date to the next for a given site than for different sites with different soil textures. Soil moisture measurements do provide a measure of growing conditions that has certain advantages over the other two techniques mentioned. Soil moisture content is less affected by the influence of herbage removal by grazing as is green biomass or other biomass measurements. Soil moisture content measurements are generally less affected (particularly under good ground cover conditions) by daily variations in temperature and humidity than vegetation moisture content measurements.

Soil moisture measurements taken within the ETSA for the three sampling periods show a general trend toward increased soil moisture, particularly at the 30 cm depth at primary sites located in the south and west (Figure 4-7). The primary sites in the northeast quadrant of the ETSA generally decreased in soil moisture from June through late September, with the exception of site N which showed a steady increase in soil moisture content at both the surface and 30 cm depth.

4.2.3 Weather Observations

Daily precipitation and temperature data from 61 weather stations in the ETSA were acquired in the form of U. S. Department of Commerce monthly reports. The precipitation data were summarized by month and plotted in the form of contour maps (Appendix B) for the ETSA using the regional parameter mapping technique described in Section 3.4. In addition, the accumulated precipitation for the 18-day period prior to the Landsat overpasses corresponding with the June, August and September ETSA ground sampling periods were also plotted as contours in the ETSA.

The weather data collected for the ETSA weather stations were used for two primary purposes. These data provided a documentation of the quantity and areal distribution of rainfall within the ETSA. This provided a certain

SOIL MOISTURE CONTENT

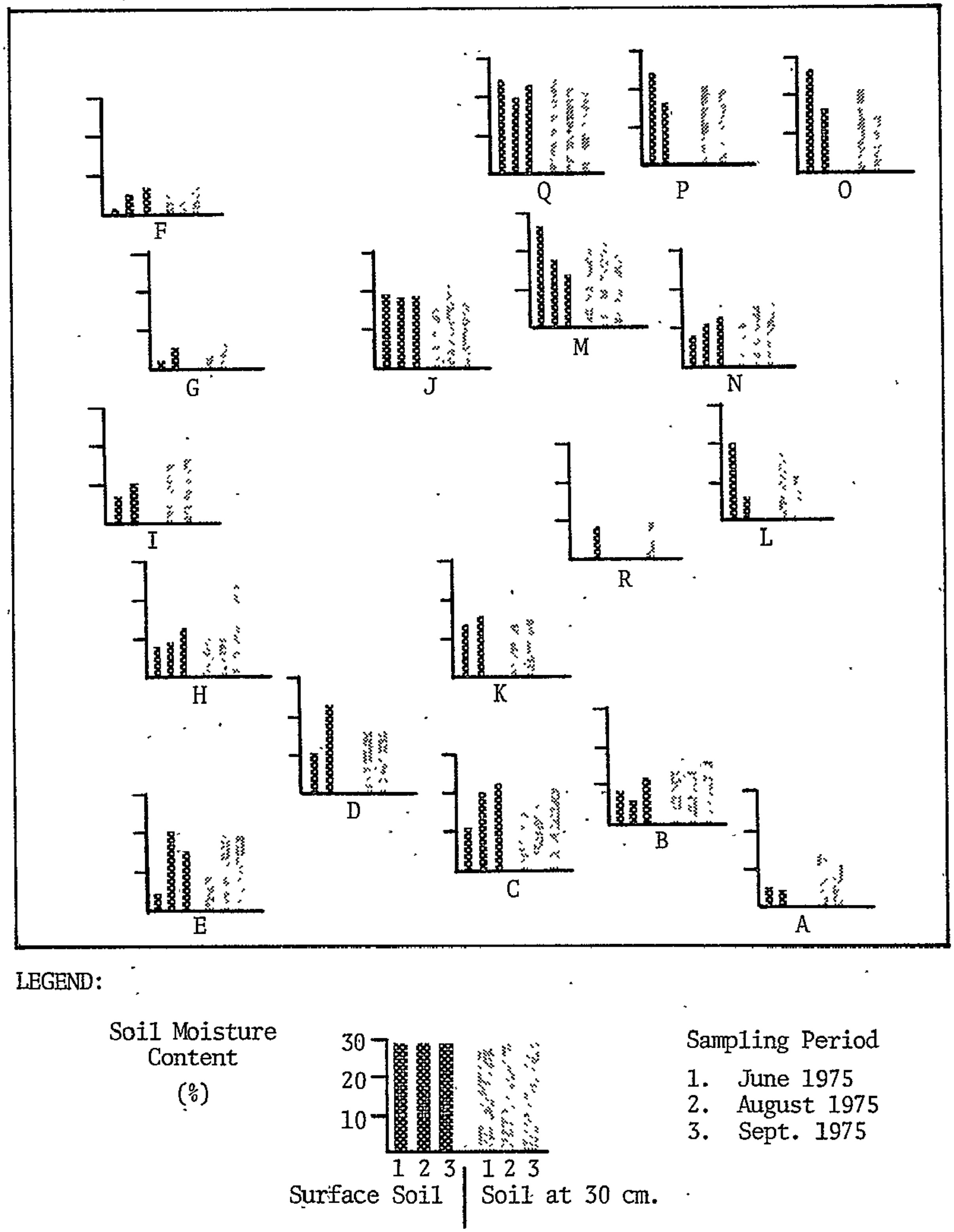


Figure 4-7. Soil moisture content at the surface and 30 cm depth at ETSA primary sites for three sample periods.

amount of ground truth about the growing conditions and, consequently, the vegetation conditions. The weather data were also used as adjustment factors in green biomass estimation models using the Landsat-derived TVI6 parameter. This aspect is discussed in Section 4.3.3.

In the Rolling Red Plains, the total monthly precipitation in January, February and March is usually between one and one and a half inches. April, May and June are generally the wettest three months with most of the rainfall (approximately 4-5 inches) occurring in May. July and August are typically hot and dry with less than two inches of rainfall in each of these months. September rainfall is generally much greater with three inches or more. In 1975, the precipitation in January through June in the ETSA followed these characteristic patterns except that they were wetter than the long-term averages would suggest. For example, in the month of May, most of the ETSA received between six and ten inches of rain (Figure 4-8; Appendix A, Table 2). The months of August and September also followed the expected trend. The outstanding anomaly is the month of July when more than 80% of the ETSA received greater than two inches of rainfall and approximately 70% received greater than four inches. Consequently, the seasonal drought that is normally experienced in July and August did not exist in 1975 over most of the ETSA.

1975 ETSA MONTHLY RAINFALL

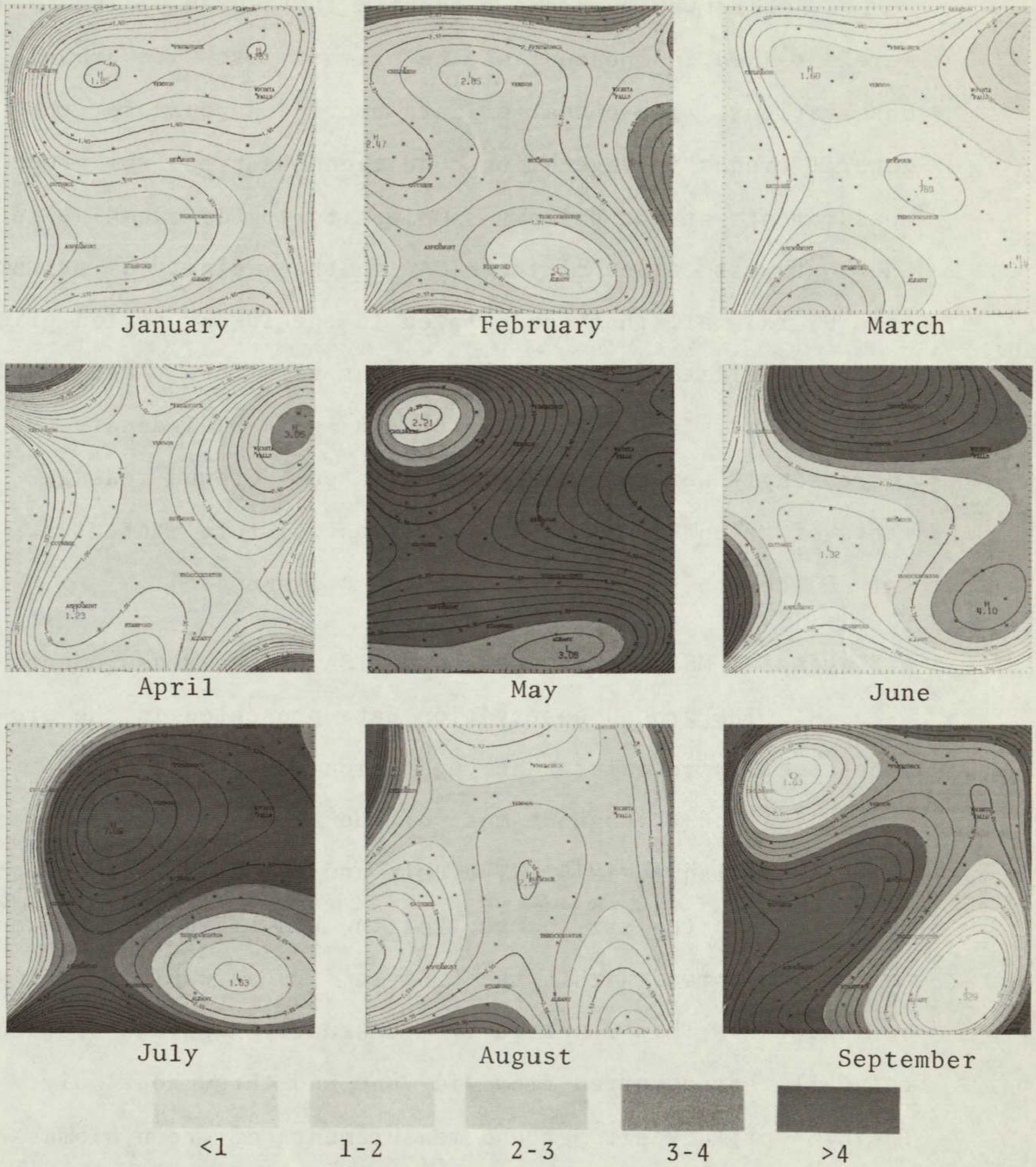


Figure 4-8. Monthly accumulated precipitation in the ETSA from 61 weather stations for January through September 1975.

The weather data presented in Figures 4-8 and 4-9 were obtained independent of the primary test site ground observations. These weather data provide support for the general trends in vegetation condition observed from ground measurements at the primary sample sites. For example, in the southwest corner of the ETSA (in the vicinity of primary site E) rainfall that accumulated in the 18-day period prior to the satellite overpass in June was very low. August and September rainfall data (Figures 4-8 and 4-9) indicate an increasingly wet condition in this area. Ground measurements of green biomass and vegetation moisture content at site E show this same trend (Figure 4-5 and 4-6).

4.3 Landsat MSS Digital Data and ETSA Ground Measurements

The ground observation data presented in the previous section revealed that vegetation conditions were generally good throughout most of the ETSA during the three periods sampled in 1975. The July and August summer drought periods characteristic of the Rolling Red Plains region was not as widespread within the ETSA in 1975 as would normally be expected. This resulted from unusually high and frequent rainfall that occurred from mid-June and throughout July. The ETSA primary site ground measurements of green biomass and vegetation moisture content did show, however, that there were differences in vegetation conditions within the ETSA.

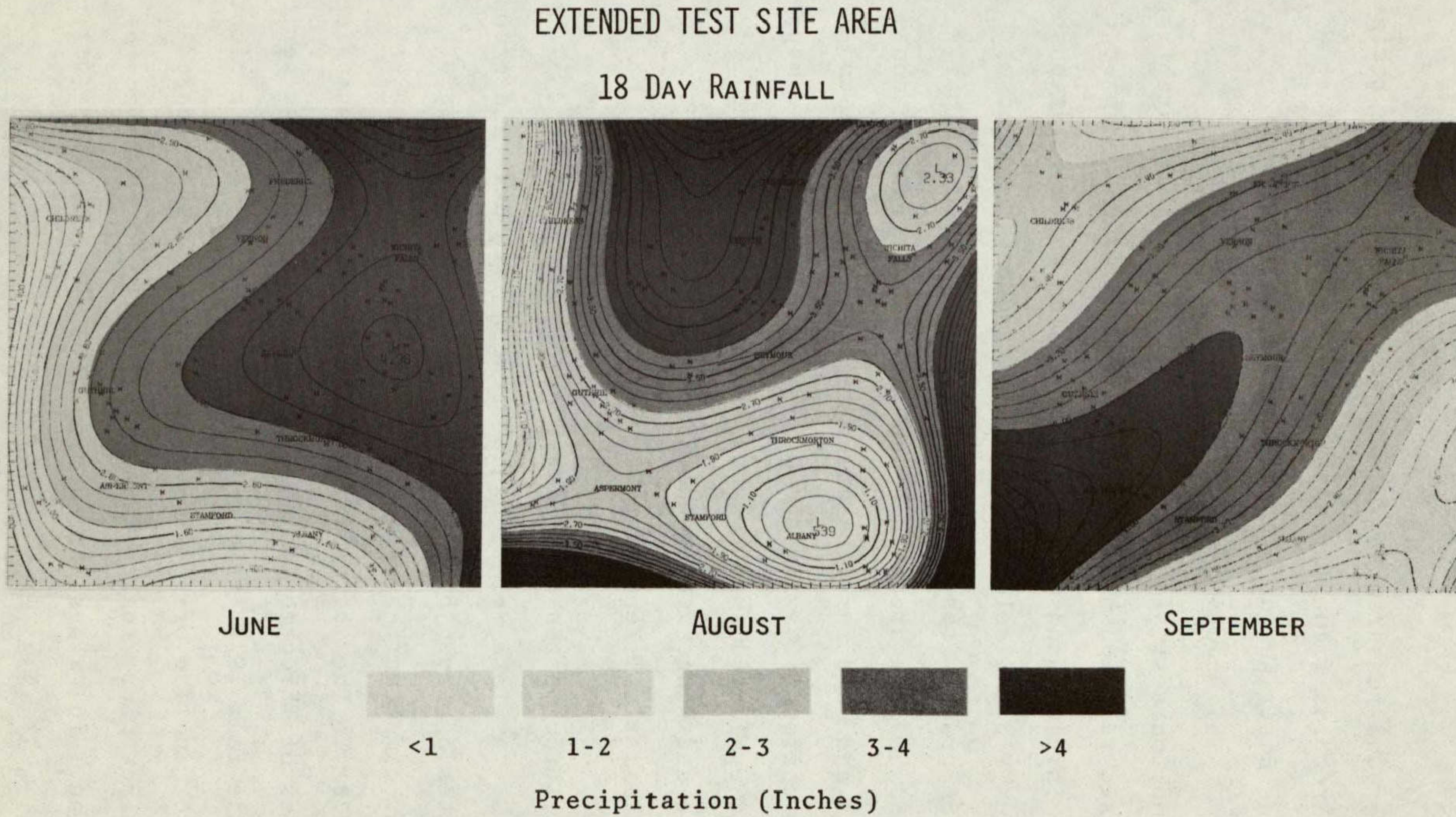


Figure 4-9. Accumulated precipitation from 61 weather stations for the 18-day period prior to Landsat overpasses in the ETSA corresponding with the June, August and September sampling periods in 1975.

These ground measurement results were supported by precipitation records from 61 Department of Commerce weather stations distributed throughout the ETSA.

This section presents an update of the Throckmorton test site correlation analysis that established the basic relationships between TVI6 and ground parameters in the initial Landsat GPC investigation. The relationships between TVI6 and selected ground parameters measured at the ETSA primary test sites are also presented. Finally, the Landsat data are used as an index of vegetation conditions and used for generating regional range feed condition contour maps for the ETSA. Validity of these maps is then evaluated and the maps are compared with the Pasture and Range Feed Condition maps generated by the USDA Statistical Reporting Service.

4.3.1 Throckmorton Test Site Update

A close relationship between TVI6 data and ground estimates of green biomass from vegetation clippings at the Throckmorton test site was reported in Final Report RSC 1978-4. The regression of TVI6 on green biomass using 18 dates of Throckmorton test site data spanning the period from the fall 1972 through June 1974 yielded a coefficient of determination of 0.825. Green biomass values ranged from almost zero to approximately 1600 kg/ha. The corresponding TVI6 values ranged from .677 (February 10, 1973) to a high of .838 (May 29, 1973).

Because of the unusually frequent rainy weather and the attendant cloud cover experienced throughout the Rolling Red Plains in the 1975 growing season, only four of the 12 Landsat overpasses coincident with ground data collection provided usable data for the Throckmorton test site (Table 3-1). These Landsat data were acquired on June 6, July 22, August 8 and October 2, 1975 (Observation I.D. Nos. 5048-16195, 2181-16352, 2198-16291 and 2253-16342, respectively).

The addition of the 1975 green biomass data to the original 18 date data set provided a new dimension to the analysis. Three of the four new data points represented higher levels of green biomass than had been experienced in the previous study. Green biomass for the four dates ranged from 1400 kg/ha to over 2100 kg/ha. TVI6 values were discovered to be increased accordingly with the highest value at .887 on October 2, 1975, when the tremendous annual broomweed production was at its peak. The regression of TVI6 on green biomass for this 22 date data set resulted in a coefficient of determination of .903. From Figure 4-10, it can be seen that the addition of the 1975 data did not significantly change the relationship previously described between TVI6 and green biomass.

Moisture content of the vegetation was also previously shown to be highly correlated with TVI6 (R^2 = .768; Final Report RSC 1978-4). In the 1972-74 sample period,

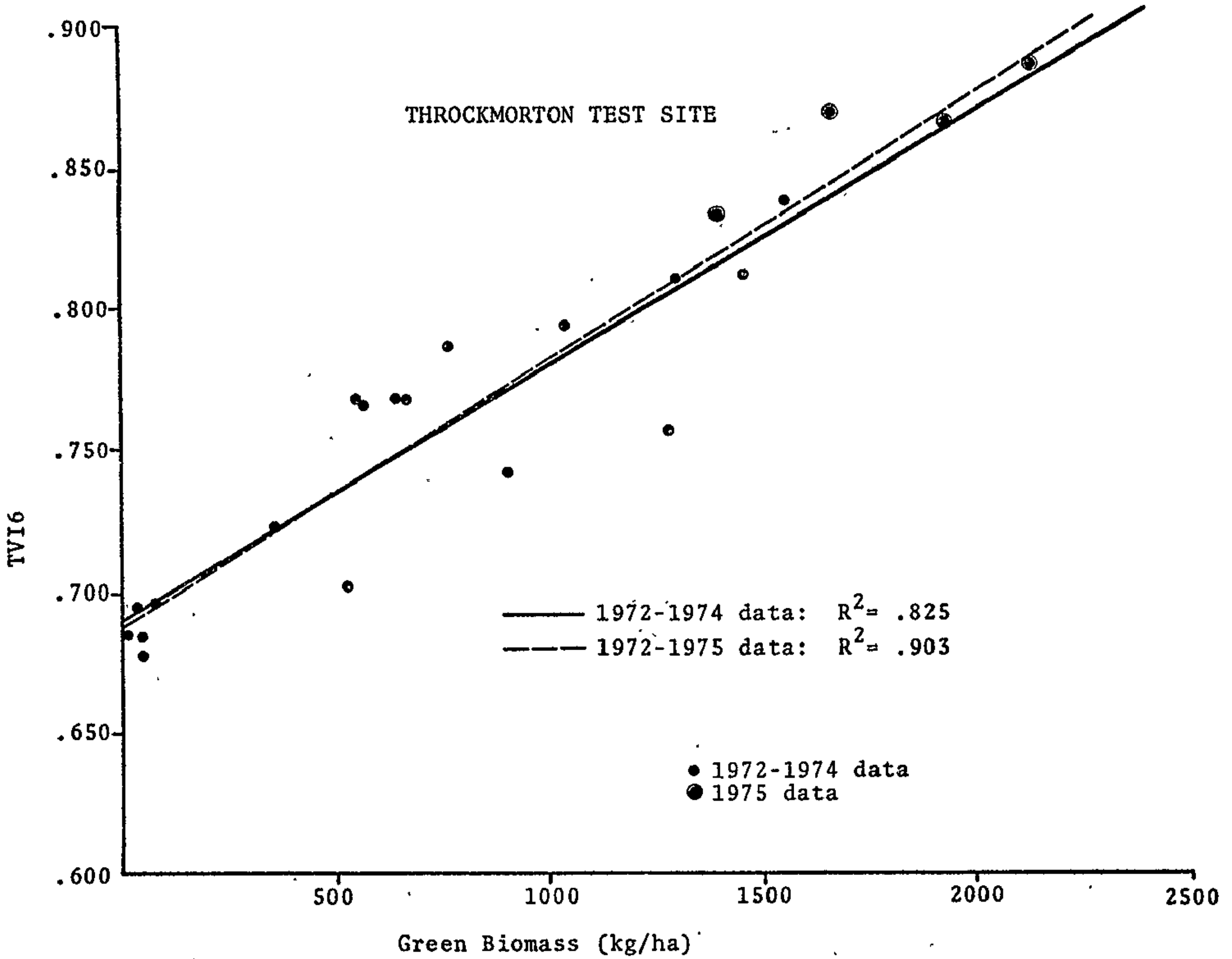


Figure 4-10. Linear regression of TVI6 on herbaceous dry green biomass at the Throckmorton test site.

moisture content typically ranged from 10% to 50% although one winter sample recorded moisture content close to zero. High vegetation moisture content was recorded on all four sample dates in 1975. The moisture content ranged from a low of 44% on October 2 to a high of 54% on June 6. From the discussion in Section 4.2.1 concerning the moisture content of annual broomweed, it would be expected that higher than normal moisture contents would be recorded at the Throckmorton test site on all four dates. It should also be remembered that 1975 was a wetter than normal year.

Linear regression analysis showed that the addition of the 1975 data to the original 18 date data set did not show an appreciable change in the coefficient of determination for moisture content. The R^2 value was increased only slightly to .780. A small increase in the slope of the linear regression line was observed along with a slight decrease in the Y-intercept value (Figure 4-11).

The data collected at the Throckmorton test site in 1975 supported the original hypothesis that Landsat MSS measurements in the form of TVI6 are highly correlated with herbaceous dry green biomass and vegetation moisture content. Since these two ground parameters describe vegetation conditions, the Throckmorton test site data provide convincing evidence that the TVI6 parameter can be used to monitor vegetation conditions within the ETSA using 1975 Landsat MSS digital data.

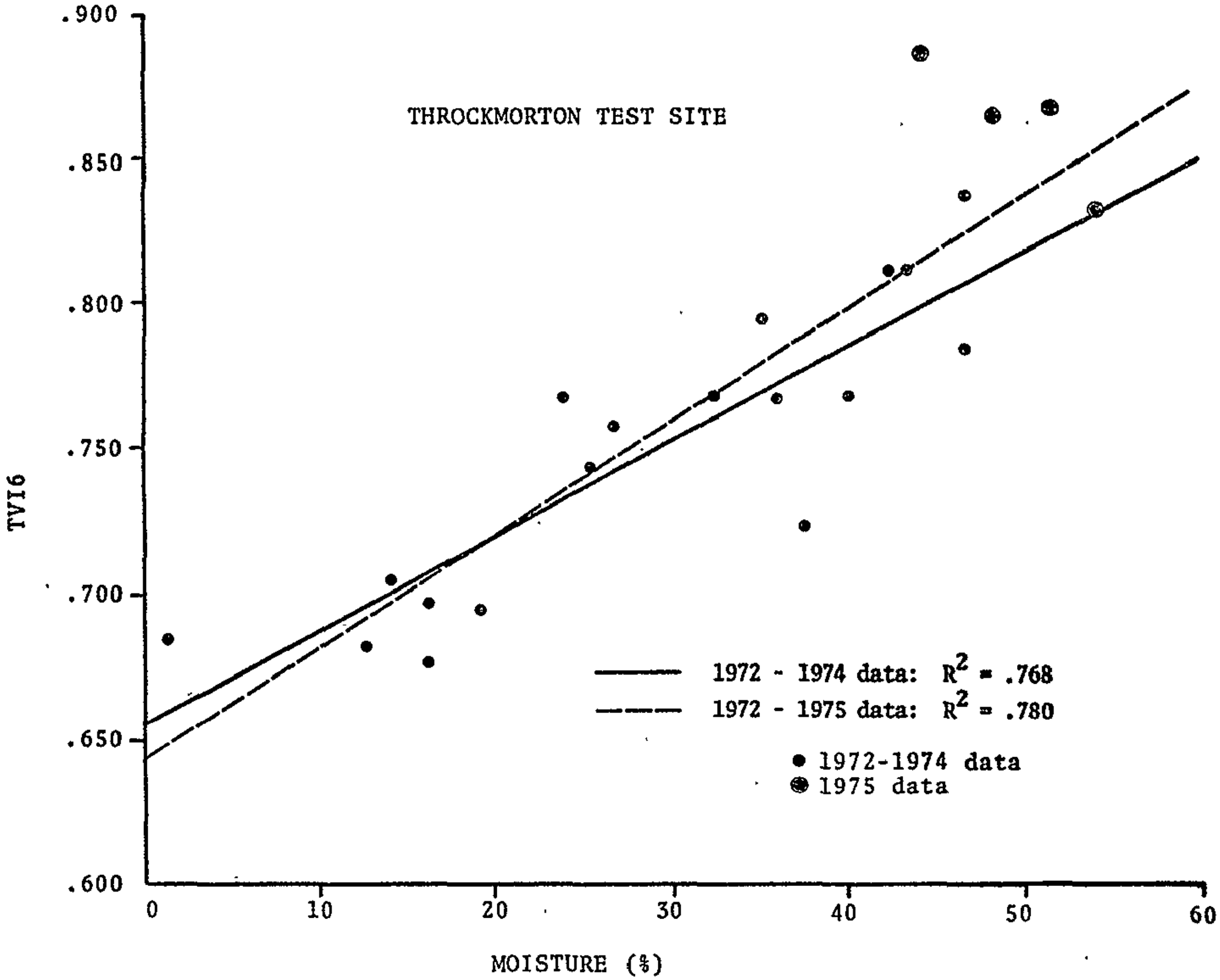


Figure 4-11. Linear regression of TVI6 on percentage moisture content of the vegetation at the Throckmorton test site.

4.3.2 TVI6 vs. Primary Site Ground Measurements

The principal quantitative ground measurements taken at the ETSA primary sites include several classes of biomass, ground cover and moisture content of the vegetation and soil. Results presented in the final report of the initial Landsat GPC investigation and data presented in Section 4.3.1 of this report reveal that changes in certain ground parameters, particularly green biomass, cause predictable changes in the TVI6 parameter determined from Landsat MSS digital data. Since the ETSA primary sites represent the wide variety of vegetation and soil types that occur within the ETSA, it was desirable to evaluate the relationships between the TVI6 parameter and quantitative ground measurements taken across these different types.

Regression analyses were performed to assess the degree of association between the Landsat-derived TVI6 parameter and the quantitative ground measurements (Appendix D) from each primary site for each of the three sampling periods. The ground parameter of primary importance in this investigation, of course, is the herbaceous dry green biomass which has been identified as an indicator of vegetation condition. In addition, vegetation moisture content also generally serves as an indicator of vegetation conditions and, in ground sampling, is determined independently of green biomass estimation. It is important to understand the interrelationships between these two vegetation condition parameters.

Vegetation moisture content is typically strongly related to green biomass when plants are actively growing. Consequently, it seems reasonable to assume that if green biomass and vegetation moisture content are measured with good accuracy and precision, they will be observed to be highly correlated. Likewise, if these two vegetation parameters are highly correlated and green biomass is responsible for a high degree of correlation with a Landsat measurement parameter (e. g., TVI6), then, it is expected that the moisture content will be similarly correlated with the Landsat parameter. If moisture content of the vegetation is responsible for a high degree of correlation with a Landsat parameter, green biomass may or may not be well correlated with the Landsat parameter. The situation where disagreement exists is not unlikely, especially when the time of day of the Landsat overpass is considered (approximately 9:30 a.m.). Moisture content of vegetation is determined from the total clipped biomass (live and dead plant material). When a considerable amount of standing dead plant material is present, it can absorb much moisture. The vegetation moisture content at the time of sampling will depend heavily on the length of time since precipitation occurred, the humidity, wind speed, time of day, etc. This effect would be expected to be greatest on the more mesic (moist) sites and sites supporting a large quantity of standing dead plant material.

The regression of TVI6 on total herbaceous dry green biomass was significant at greater than the 99% level of probability for the ETSA primary site data in June and August (Table 4-1; Figure 4-12; Figure 4-13). Green biomass accounted for 45.3% of the variation in TVI6 in June and 45.9% in August. Both the highest and lowest value of TVI6 were recorded in June. Site E in the southwest corner of the ETSA had a TVI6 value of .759 and site O in the northeast corner had a TVI6 value of .924.

The linear regression of TVI6 on green biomass for the September data reveals a considerably poorer relationship (R^2 = .307) between these two variables (Figure 4-14). Inclusion of the September data along with the June and August data in a regression analysis with TVI6 (Figure 4-15) yields a coefficient of determination of .218, which is similar to the September data alone. However, the regression using the data from all three dates was highly significant (PR > F = .0006).

The relationship observed between green biomass and TVI6 for the June and August data is interpreted as being consistent with that documented for the Throckmorton test site. In the final report for the initial Landsat GPC project, it was stated that green biomass could be estimated with TVI6 data in increments of 250 to 300 kg/ha with a 95%

Table 4-1. Coefficients of determination (R^2) and statistical significance for the regressions of the Landsat-derived TVI6 on selected ground parameters for primary sample site data in the ETSA in 1975.

Ground Parameter	Sampling Period							
	June		August		September		All Dates	
	R^2	PR>F	R^2	PR>F	R^2	PR>F	R^2	PR>F
Dry Green Biomass (Grass + Forbs)	.453	.0043	.459	.0005	.307	.062	.218	.0006
Fresh (Wet) Green Biomass	.397	.0089	.457	.0006	——	——	.420	.0001
Dry Green Grass Biomass	.143	.1483	.231	.0237	.312	.0592	.126	.0113
Dry Green Forb Biomass	.185	.0963	.047	.3342	.089	.3460	.052	.1122
Vertical Projection Cover-percent:								
Green Grass	.078	.2938	.105	.1405	.010	.7538	.053	.0365
Green Forbs	.192	.0899	.115	.1149	.183	.1651	.084	.0416
Brown Herbage	.068	.3278	.159	.0660	.231	.0505	.149	.0056
Bare Ground	.213	.0716	.012	.6211	.235	.1103	.013	.4246
Moisture Content of Vegetation:								
Percentage Basis	.597	.0005	.443	.0007	.561	.0051	.489	.0001
Weight Basis	.384	.0105	.540	.0001	.497	.0104	.416	.0001
Soil Moisture Content-percent:								
Surface Soil	.545	.0011	.524	.0001	.027	.6081	.361	.0001
Soil at 30 cm	.474	.0032	.385	.0021	.111	.2898	.255	.0002

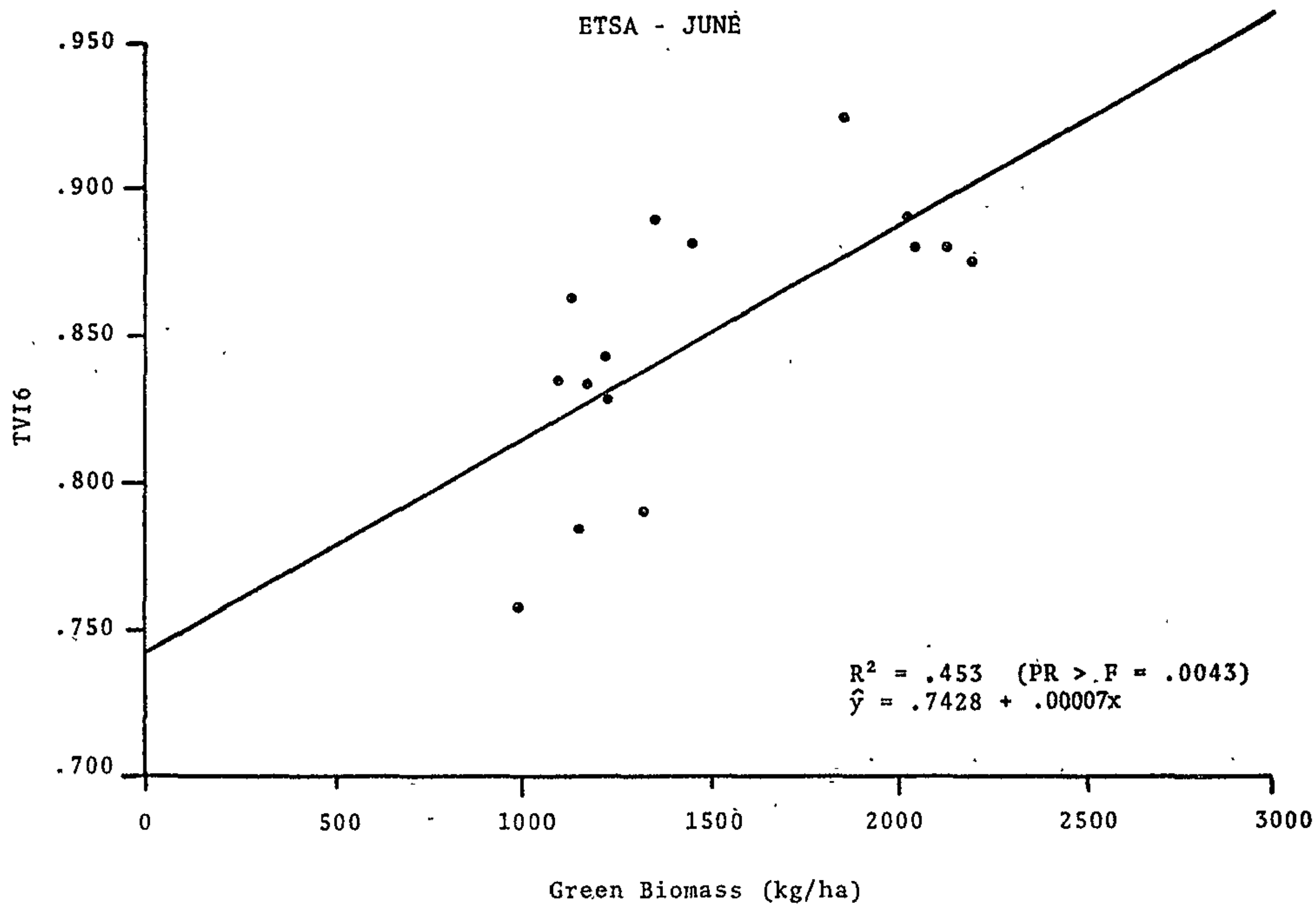


Figure 4-12. Linear regression of TVI6 on dry herbaceous green biomass at the ETSA primary sites in June 1975.

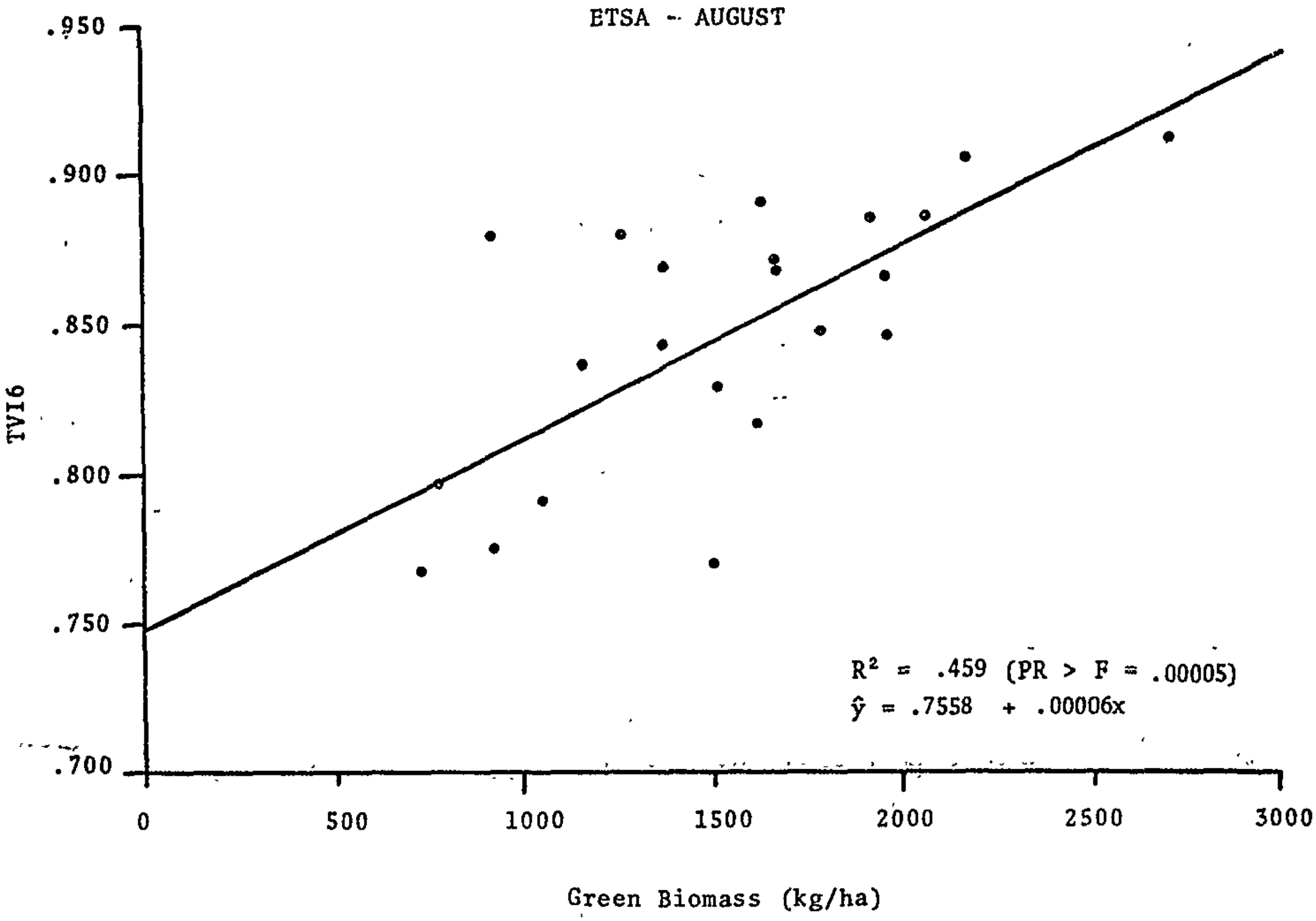


Figure 4-13. Linear regression of TVI6 on dry herbaceous green biomass at the ETSA primary sites in August 1975.

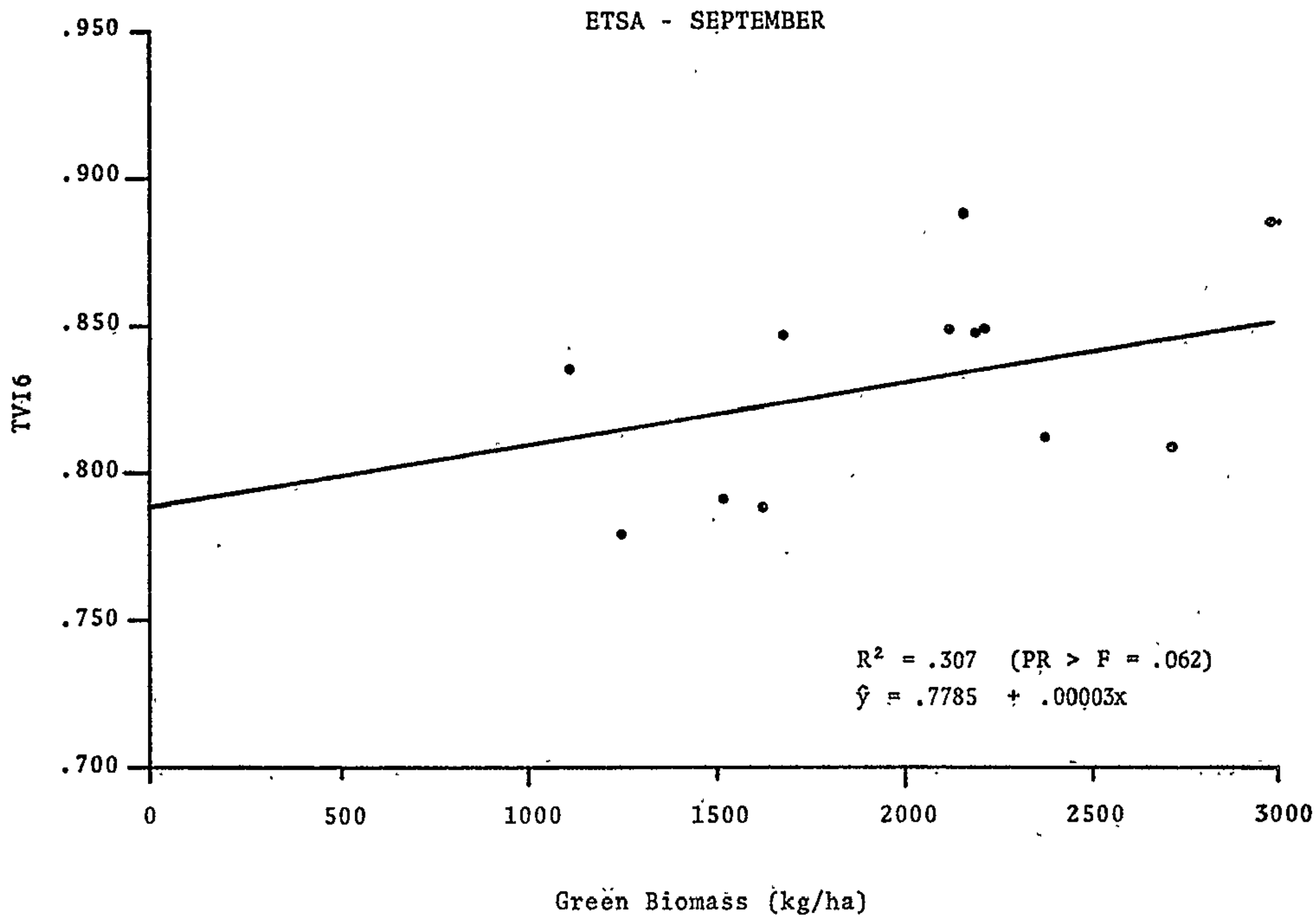


Figure 4-14. Linear regression of TVI6 on dry herbaceous green biomass at the ETSA primary sites in September 1975.

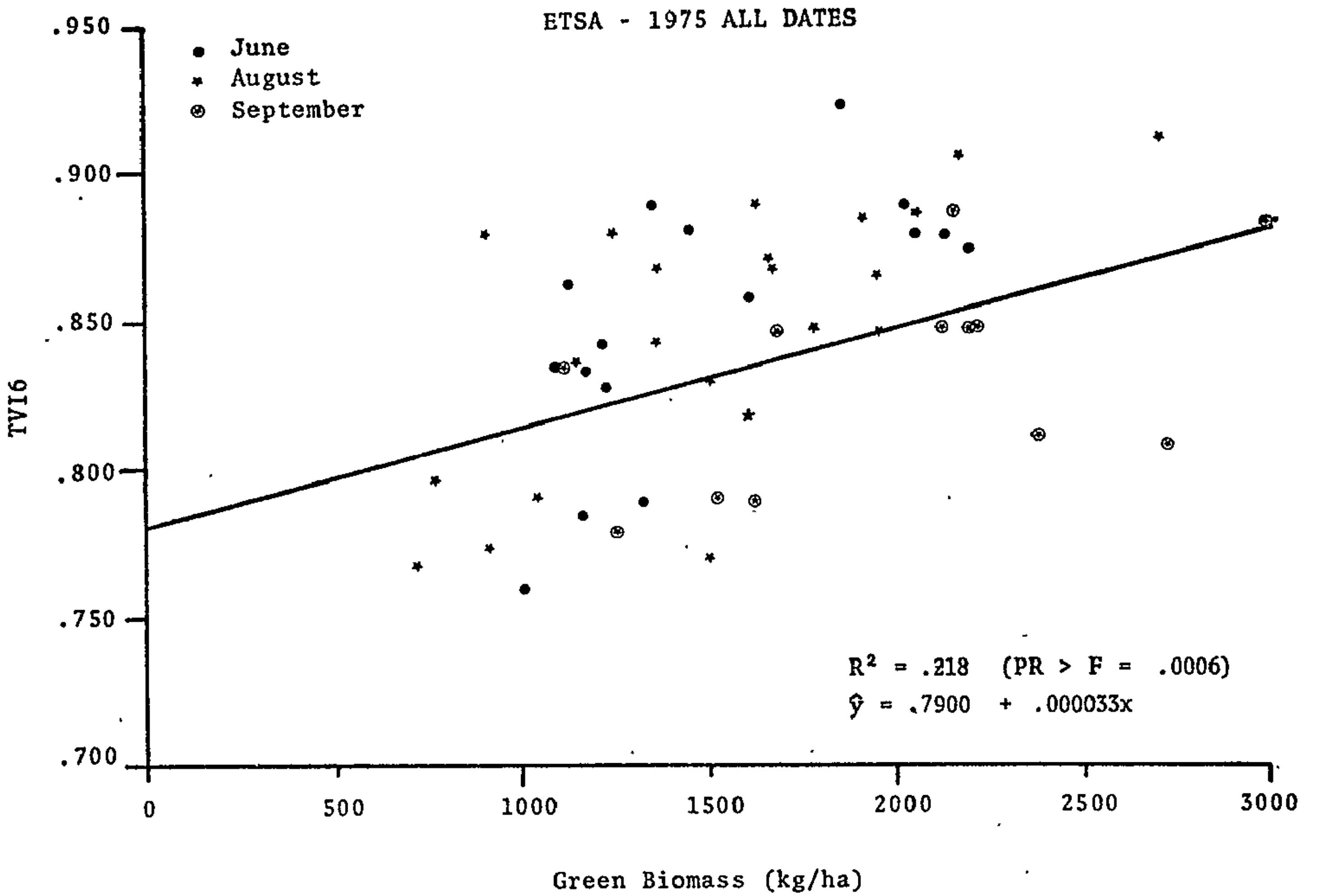


Figure 4-15. Linear regression of TVI6 on dry herbaceous green biomass at the ETSA primary sites for all three sample periods in 1975.

probability. The Throckmorton test site regression line shows that a TVI6 value of .850 is equivalent to 1700 kg/ha of green biomass. Regression lines through the June and August ETSA primary site data show a TVI6 value of .850 as equivalent to 1500 and 1600 kg/ha, respectively (Figure 4-12 and 4-13). The relationship is not quite as consistent at lower values of TVI6, primarily because the June and August regressions did not include any green biomass measurements below 750 kg/ha. It is expected that the Y-intercept would be lower and the slope of the regression line almost identical to that for the Throckmorton test site if green biomass below 250 kg/ha had been observed.

It is believed that most of the large deviations about the regression line for June and August are primarily due to sampling error. The extensive nature of the Extended Test Site Area, with the widely distributed primary sites from which ground data were collected, necessitated that only a short period of time be spent at each location collecting the ground data. Consequently, although the ground sampling was adequate to monitor vegetation conditions at each site, it was impossible to sample an adequate number and distribution of ground plots to accurately measure the green biomass for the rangeland vegetation complex varying across the several hundred acres at each primary site.

Herbaceous green biomass was also evaluated as expressed in three additional forms. The fresh or (wet) green biomass was shown to be correlated with TVI6 in June and August, essentially the same as the dry green biomass (Table 4-1). September data could not be evaluated for this green biomass parameter since the field sampling schedule did not allow field separation of clip and plot samples into green and brown components. The grass and forb components of dry green biomass, when evaluated independently of each other, did not show a high degree of correlation with TVI6 (Table 4-1).

The vertical projection cover was estimated within the sample plots for the green grass, green forb, brown herbage and bare ground components, expressed as a percentage of the total plot area. None of these cover classes were shown to have a high degree of correlation with the TVI6 parameter. This can probably be attributed to the inadequacies of the ground data for accurately measuring these parameters over the large acreages involved.

Moisture content of the vegetation recorded at the ETSA primary sites was also compared with TVI6 at these locations. Vegetation moisture content was expressed both as a percentage of the total clipped plot fresh weight and as the quantity of plant moisture on a per area basis (weight of plant water per unit of ground area). Moisture content in the vegetation, expressed as a percentage, was described earlier as being an indicator of vegetation conditions, although several drawbacks for using this parameter for monitoring vegetation conditions were recognized.

The linear regressions of TVI6 on percentage moisture content show the highest most consistent correlations for all three sampling periods within the ETSA of any of the ground parameters measured. The regressions for each date, analyzed independently, and all three dates combined were highly significant with a probability greater than F of more than 99% in all cases (Table 4-1). Coefficients of determination were .597, .443 and .561 for June, August and September, respectively. The relationship of vegetation moisture content on a weight per unit area basis to TVI6 was similar; however, this parameter generally accounted for slightly less of the total variation observed in TVI6 than the percentage moisture content parameter. The vegetation moisture content analyses lend considerable support to the hypothesis that TVI6 can be used as a quantitative parameter for monitoring vegetation conditions within the ETSA.

Soil moisture content at the surface and 30 cm depth showed a close relationship to TVI6 in June and August but showed virtually no correlation in September. High soil moisture content is generally reflected in the vegetation as high plant moisture content.

The correlation between TVI6 and several ground parameters, including green biomass and soil moisture content, was generally lower in September than in June or August. The principal reason for this lower correlation is probably the abundant annual broomweed that had completely dominated many of the primary sites by September. By late September, most of the broomweed had turned from green to a yellow-green color, and in many areas, the plants were beginning to display a dense canopy of small, yellow flowers. Field measurements of green biomass included the large quantities of annual broomweed in the hand-separated green biomass component of the vegetation. Sites supporting dense canopies of annual broomweed, consequently, had large amounts of green biomass.

The visual scene reflectance of most of the region, particularly in the central ETSA on sites supporting large quantities of broomweed, had changed from green to a yellow-green color by late September. Corresponding with this phenological change in the vegetation were lower values for TVI6 despite the higher quantities of green biomass in September than in August. The ground documentation was also not as complete in September as in June and August.

4.3.3 TVI6, Green Biomass, Vegetation Conditions and Response Zones

Results from the initial Landsat investigation and the results presented in Sections 4.3.1 and 4.3.2 of this report clearly indicate that TVI6 is very closely correlated with the quantity of green herbaceous vegetation and its moisture content on these rangelands. High values of TVI6 indicate good plant moisture content and considerable amounts of green biomass. Conversely, low TVI6 values reveal the absence of much green plant material and generally drier vegetation conditions.

The limits for the different condition classes will undoubtedly vary for certain different kinds of rangeland areas which for this discussion will be called "response zones". The response zone concept is based on the hypothesis that different types of vegetation, which may have different growth responses to similar weather influences, will exhibit different relationships between ground parameters and the composite scene spectral reflectances. The response zones are a product of climatic and physiographic factors that determine the vegetation, including such factors as precipitation, temperature, potential evapotranspiration, elevation, topography and soil type. Different response zones may have different potential productivities and plant development (phenology and rates of development) and may show different susceptibility to stress (e.g., drought stress).

It was anticipated that the response zone concept could be tested in the Extended Test Site Area during the follow-on project investigation. For example, within the ETSA, primary sites G and O are believed to lie within different response zones. Site G is a sandy prairie range site having an overstory dominated by sand sagebrush with some shinnery oak and mesquite. The understory contains fall witchgrass, sideoats grama, western ragweed and numerous annual forbs. In most years, throughout the year, 25% to 50% bare ground is exposed. The average annual precipitation is approximately 22 inches. Site O is a loamy prairie range site containing essentially no woody overstory plants. The site contains a wide variety of grasses and forbs, including several grama grasses, drop-seeds, paspalums, bluestems, panicums, Indiangrass, legumes and numerous composites. The amount of bare ground exposed is typically less than 20%. The average annual rainfall is greater than 33 inches.

It is expected that the response of the vegetation (e.g., for producing a certain quantity of green biomass) to a given amount of rainfall would likely differ at sites G and O. Soil water holding capacities are important in this respect, as well as the rapidity with which individual species can uptake plant moisture and produce dry matter. These factors are important in remote sensing in relation to the frequency of monitoring operations.

More important in this consideration, however, is that with the same amount of green biomass on both areas, the scene spectral reflectance will likely be different. Among the factors that are expected to cause these differences in scene reflectance, when the quantity of green biomass is the same, are the soil type and the amount of soil exposed, the physiognomy, species composition and the proportion of plant species.

The fairly wide deviations about the regression lines in Figures 4-12 and 4-13 were suggested to be in large part due to sampling error. Some of this variation, however, is probably due to response zone differences. Because of the vegetation anomalies of 1975 and because of an inadequate number of samples within the sampling area (primary sites), it was not possible to evaluate the response zone concept.

For the purposes of this project, the relationships between TVI6 and green biomass at the Throckmorton test site were used to establish TVI6 condition classes. The ETSA primary site analyses present in Section 4.3.2 confirmed that this relationship applies generally across the ETSA. A study of the Throckmorton test site data indicates that TVI6 values less than .700 correspond with green biomass values less than 250 kg/ha and indicate <u>severe</u> drought or dormant vegetation conditions. TVI6 of .700 up to .780 corresponds with 250-750 kg/ha of green biomass and <u>very poor</u> vegetation conditions. TVI6 from .780 to .800 corresponds with 750-1300 kg/ha of green biomass and fair to poor vegetation conditions. TVI6 from .800 up to about .830 corresponds with 1300-1500 kg/ha of green biomass and good to excellent vegetation conditions. Excellent vegetation conditions are indicated by TVI6 greater than .830 and generally corresponds with greater than 1500 kg/ha of green biomass.

4.3.4 Regional Range Feed Condition Contour Maps

The final phase of the study of the Extended Test Site Area involved mapping the vegetation conditions within this region for the three selected Landsat overpass periods and then evaluating the accuracy and adequacy of these maps. TVI6 values were determined from the Landsat MSS digital data for each of the ETSA secondary sites. These data were then plotted as isoline contour maps using the regional parameter mapping technique described in Section 3.4. Vegetation condition classes were then assigned to the maps in the increments described for TVI6 in Section 4.3.3.

Finally, a more refined approach to mapping vegetation conditions was then applied which employed the Throckmorton model for green biomass estimation from TVI6. In this procedure, green biomass was calculated for the secondary sites using the TVI6 parameter and local weather data. Vegetation condition classes were then assigned to the maps based on the green biomass estimates. These maps were then compared with ETSA primary site measurements, weather station precipitation records and USDA, Statistical Reporting Service maps of pasture and range feed conditions.

Early in the analysis phase of the investigation TVI6 data from 17 ETSA primary sites were used to generate a "first look" TVI6 isoline contour map of vegetation conditions with the ETSA. This preliminary map (Appendix E), which was generated from the very sparse data set, portrayed the vegetation conditions reasonably well and demonstrated the potential of this technique. This first look activity was described in Progress Report RSC 3018-5.

Isoline contours of secondary site TVI6 data for June 1975 are plotted for the ETSA in Figure 4-16. The map shows TVI6 values to range from less than .760 in the southwest and southeast corners to greater than .900 in the northeast corner. The increments of green biomass that correspond with the five vegetation condition classes described in Section 4.3.3 are color coded in Figure 4-17 to depict the areal extent of the different vegetation conditions within the ETSA in June, August and September 1975. The uncoded maps for August and September are presented in Appendix F.

The June, August and September "Range Feed Condition Map" (Figure 4-17) indicates that severe drought did not occur in any area of the ETSA during the 1975 growing season. The June map shows that the southeast

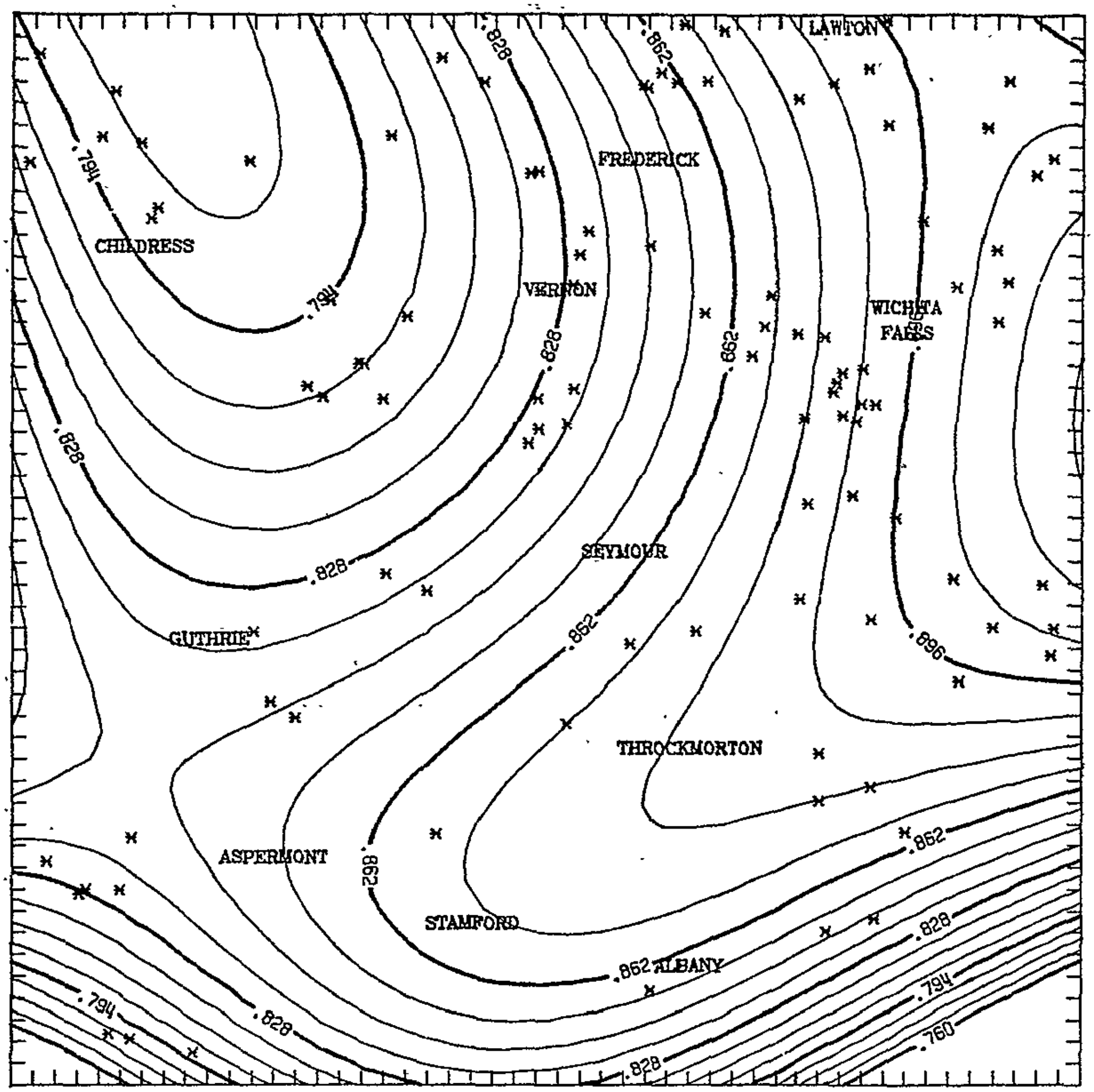


Figure 4-16. Variation in TVI6 within the ETSA in June 1975 as represented by 103 secondary sites.

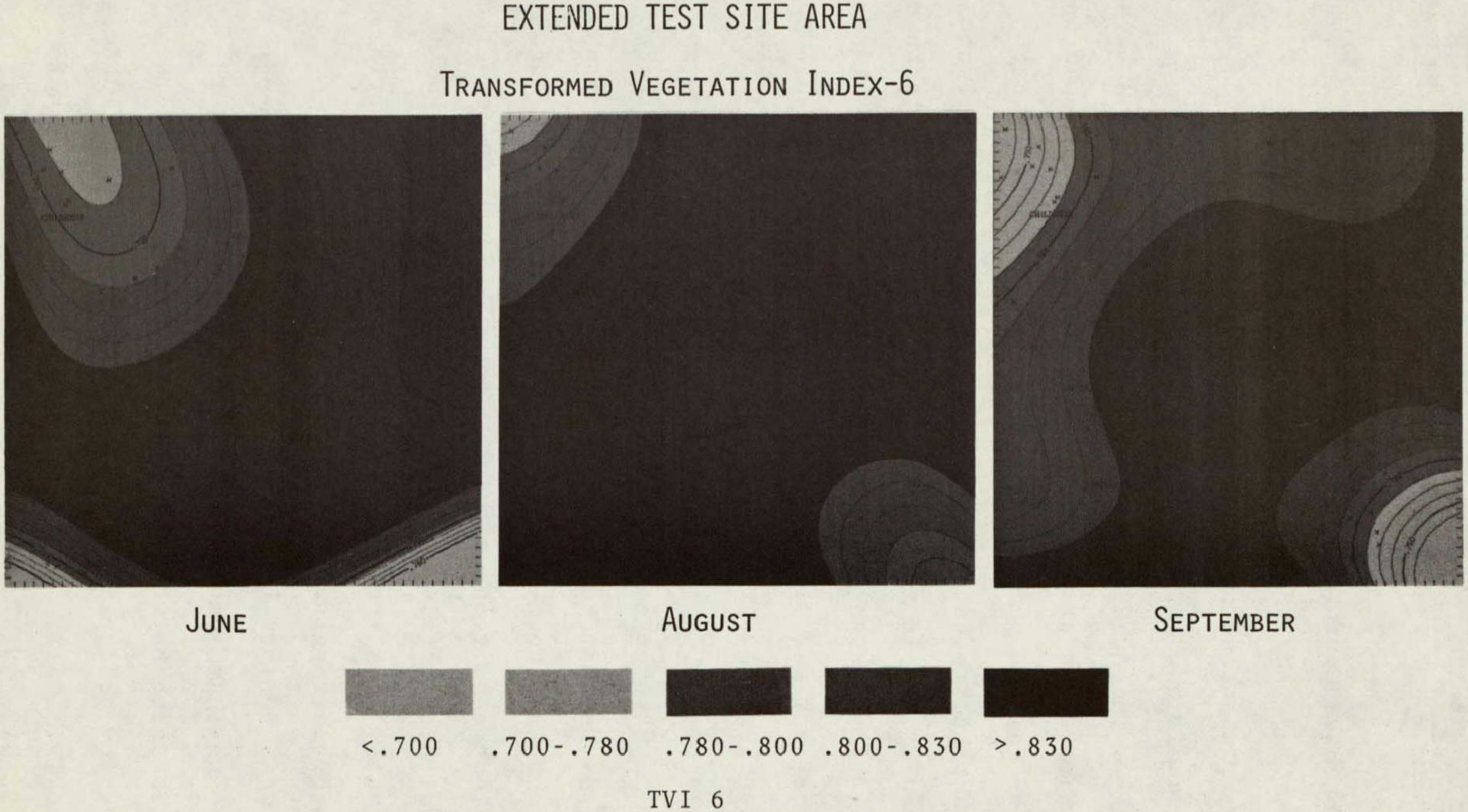


Figure 4-17. Range feed conditions within the ETSA in June, August and September 1975 as recorded by Landsat and represented as TVI6. Vegetation condition classes are severe, very poor, fair to poor, good to excellent and excellent, respectively.

and southwest corners and a larger portion of the northwest quadrant of the ETSA experienced fairly dry conditions, however, as these areas were shown to be in fair to very poor condition.

The August map shows that vegetation conditions had improved to excellent in the southwest corner and the area of fair to very poor conditions in the northwest quadrant had receded to encompass only a very small area. The conditions in the southeast corner are shown to have generally improved, but some of the area formerly classified as excellent was classified as good to excellent in August. The northeast quadrant of the ETSA remained classified as excellent.

By September, vegetation conditions in the northwestern one-third of the ETSA and in the southeastern quadrant are shown to be generally poorer than in August. Excellent conditions are shown to be reduced to less than one-half the total area and occupy a belt extending diagonally from the south-southwest to the east-northeast through the region.

During the initial Landsat-1 investigation, it was shown that some of the variations observed in the relationships between TVI6 and green biomass could be removed by accounting for some of the weather influences on the TVI6 data. Weather factors such as the length of time since the last precipitation, the amount of precipitation over a given period and temperature (drying effect) would be important in determining the color of the surface soil, dead vegetation, etc., and likewise, the reflectance of these ground scene components as measured by Landsat. Under certain moisture temperature conditions, dew may be present on the leaf and soil surfaces at the time of the satellite overpass. Although the skies may be clear, the free moisture on these surfaces may drastically affect the spectral response. In addition, since vegetation systems are intrinsically related to environmental functions, weather data also provide some information about growing conditions such as soil moisture, atmospheric moisture and plant stress without direct measurement of these parameters.

During the initial investigation, the weather influence was evaluated at the Throckmorton test site. After adjusting the TVI6 data for the effects of three weather parameters, a significant improvement in the relationship between TVI6 and green biomass was observed. From this analysis, a green biomass estimation model for the Throckmorton test site was developed and was reported in Final Report RSC 1978-4 as follows:

$$\hat{Y} = -508.89 + 648.89\, X_1 + 6.09\, X_2 - 56.15\, X_3 + 1.10\, X_4$$

where

$\hat{Y}$ = green biomass (kg/ha)

X_1 = TVI6

X_2 = precipitation since last satellite overpass (18 days) (inches)

X_3 = precipitation on the day before the overpass (inches)

X_4 = maximum temperature on the day of the overpass (°F).

The Throckmorton green biomass estimation model was applied to the ETSA secondary site data for June, August and September. The weather data for each secondary site was obtained from the nearest weather station if a weather station was within a 5-mile radius of the site; otherwise, weather data was interpolated from the nearest two or three weather stations. The calculated green biomass values (Appendix G) were then plotted for the Extended Test Site Area using the regional parameter mapping technique. Estimated green biomass was then used as an index to the vegetation conditions within ETSA according to the relationships described in Section 4.3.3. The color-coded maps of vegetation conditions for June, August and September 1975 are presented in Figure 4-18.

The green biomass maps for June and August show vegetation conditions across the ETSA to be very similar to those indicated by the maps from TVI6 parameter alone (Figure 4-17). The primary differences are that the

EXTENDED TEST SITE AREA

Green Biomass - Throckmorton Model

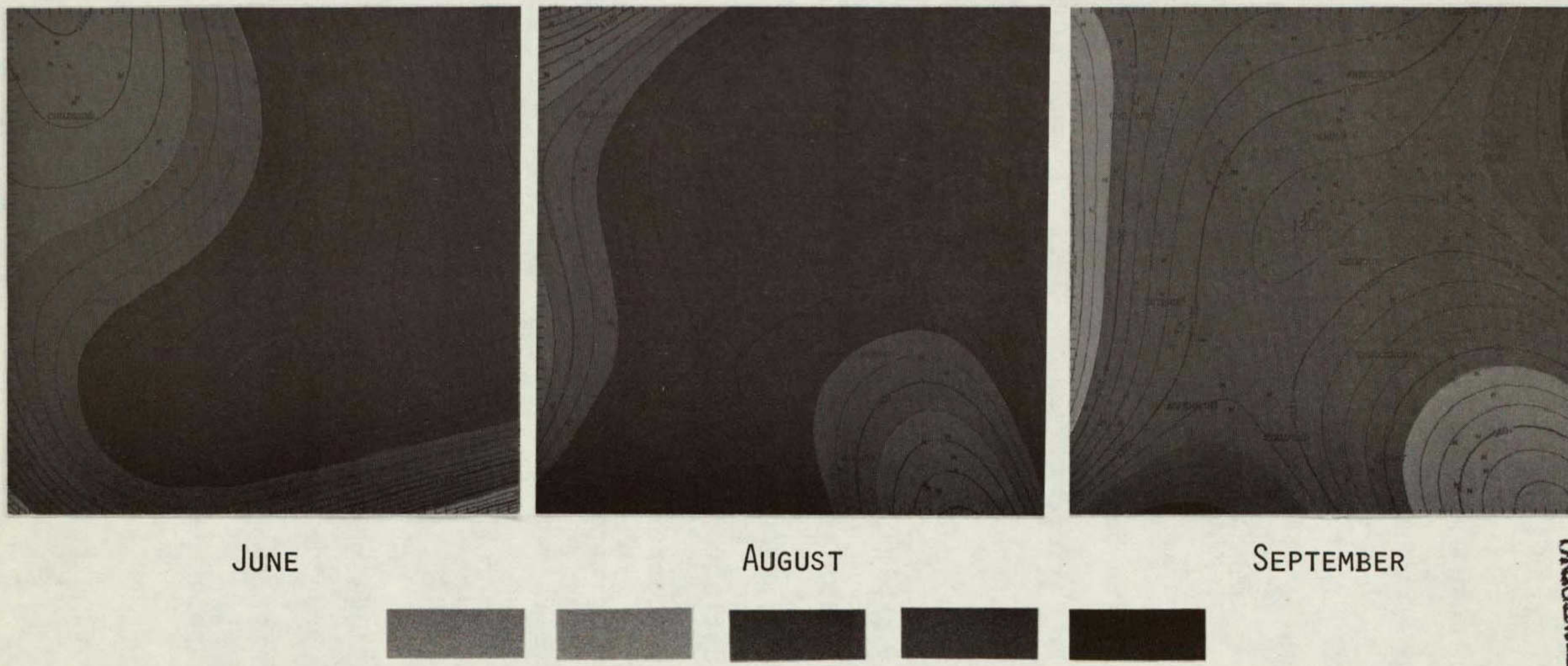


Figure 4-18. Range feed conditions within the ETSA in June, August and September 1975 determined from the Throckmorton green biomass estimation model. The five vegetation condition classes (severe, very poor, fair to poor, good to excellent and excellent) are represented as increments of green biomass.

Throckmorton model green biomass maps show the areas of very poor vegetation conditions to be less extensive than indicated on the TVI6 maps. Also, the western edge of the ETSA is shown to be in only good to excellent condition rather than excellent, and the fair to poor condition class covers more area in the southeastern and western portions of the ETSA. The September map of green biomass (Figure 4-18) is distinctly different from the TVI6 map in Figure 4-17. It appears that the green biomass estimation model under-estimated range feed conditions in September. This can partially be explained by the large amounts of perennial broomweed present on this date (see Section 4.2.2 and 4.3.2). Good to excellent conditions are indicated in only the east-northeast and south-southeast corners of the ETSA. The southeast corner shows a larger area of very poor vegetation conditions. Most of the remaining ETSA is shown to have fair to poor vegetation conditions as compared to the corresponding TVI6 map which shows most of the region to be in good to excellent condition.

The principal function of the primary site ground data was to provide a record of vegetation conditions within the ETSA to evaluate the success of the vegetation condition mapping from secondary site Landsat data. The ground measurements of total green biomass (grasses plus forbs) was graphically presented in Figure 4-5 and is represented as vegetation condition class equivalents of green biomass (see Section 4.3.3) in Figure 4-19.

From the ground truth data, it can be seen that in June most of the Extended Test Site Area had green biomass greater than 1500 kg/ha and, consequently, was classified as excellent vegetation conditions. The primary exceptions to this were in the southeast, southwest and northwest corners where green biomass was generally between 750 and 1300 kg/ha indicating only fair to poor vegetation conditions. Figures 4-20 and 4-21 illustrate that forbs were an important component of green biomass in the south central portion of the ETSA as early as June, while the northeast quadrant and southeast corner supported good stands of green grass at this time. Percentage vegetation moisture content measurements illustrated in Figure 4-22 provide convincing evidence that the June Throckmorton model Range Feed Condition Map (Figure 4-18) accurately depicts the vegetation conditions. Plant moisture content in the areas of the ETSA classified as having good to excellent range feed conditions is shown to be generally greater than 45% and, in some cases, greater than 55%. Plant moisture in the south and southeast was less than 45%, and in the southwest and northwest corners was less than 35%. The vegetation conditions that were mapped using the Throckmorton model green biomass estimates would be expected after observing the rain fall amount

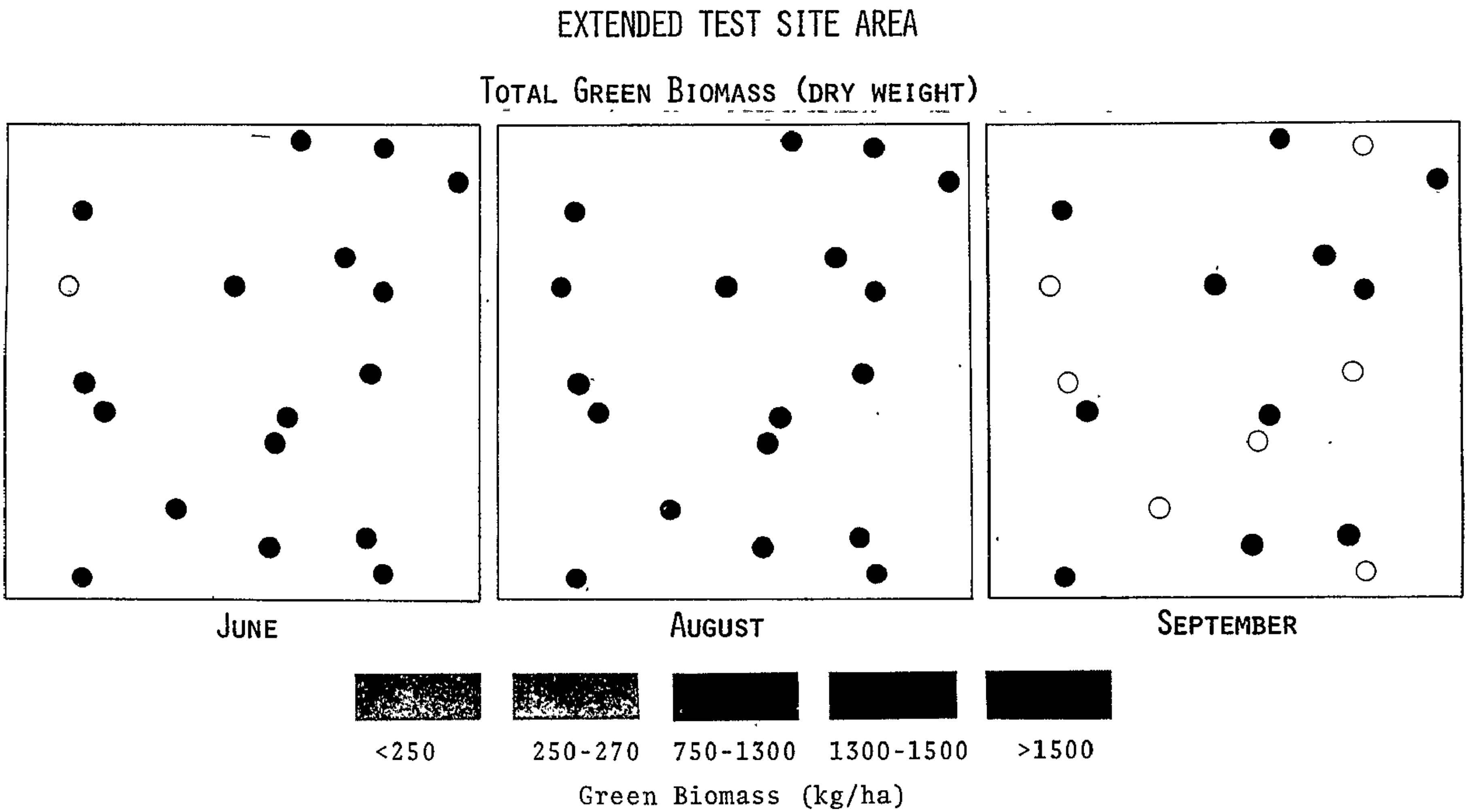


Figure 4-19. Green biomass measured at the ETSA primary sites colored to represent the vegetation condition class equivalents for comparison with the maps in Figures 4-17 and 4-18 (see also Figure 4-5).

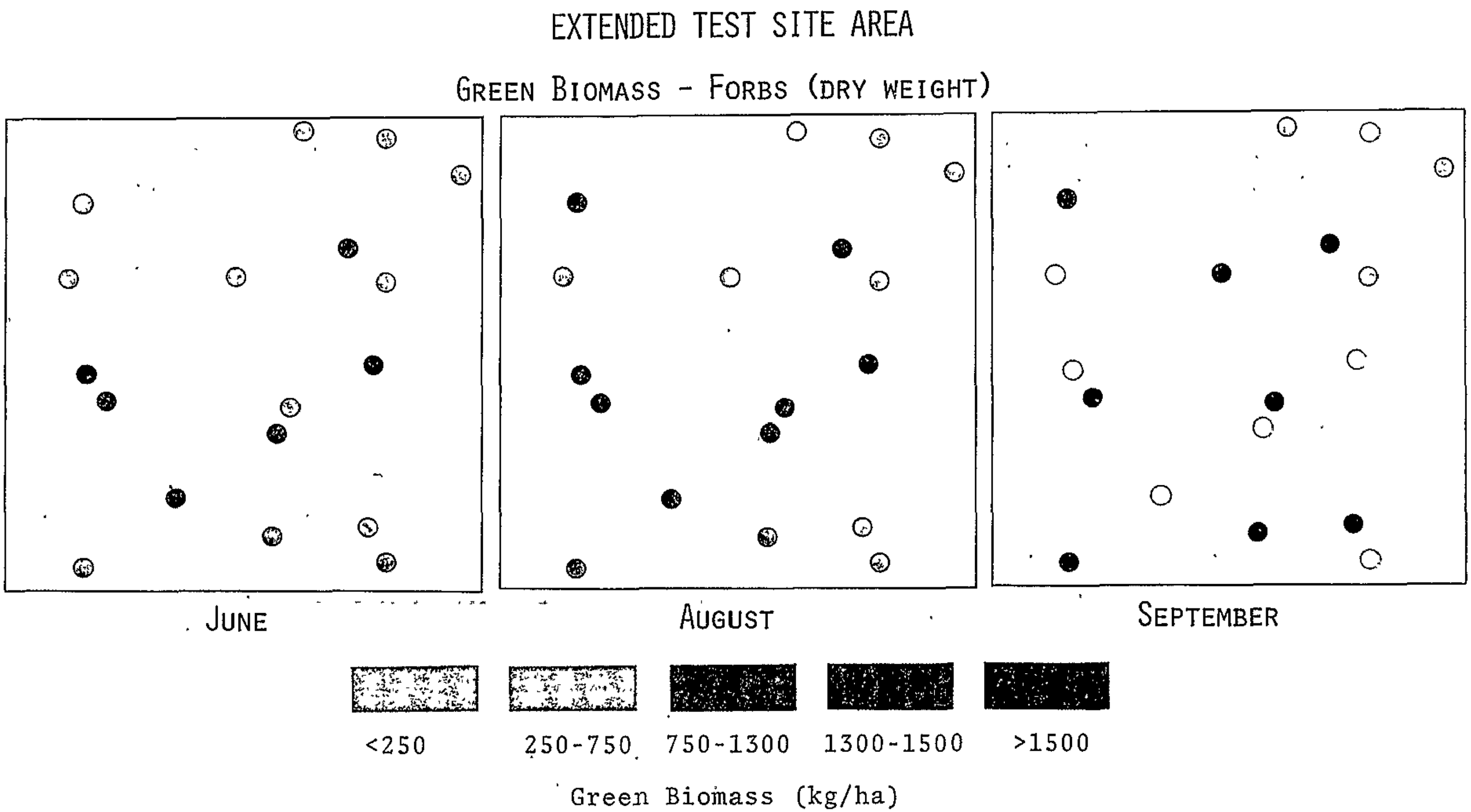


Figure 4-20. Forb component of green biomass measured at the ETSA primary sites colored to represent the vegetation condition class equivalents for comparison with the maps in Figures 4-17 and 4-18 (see also Figure 4-5).

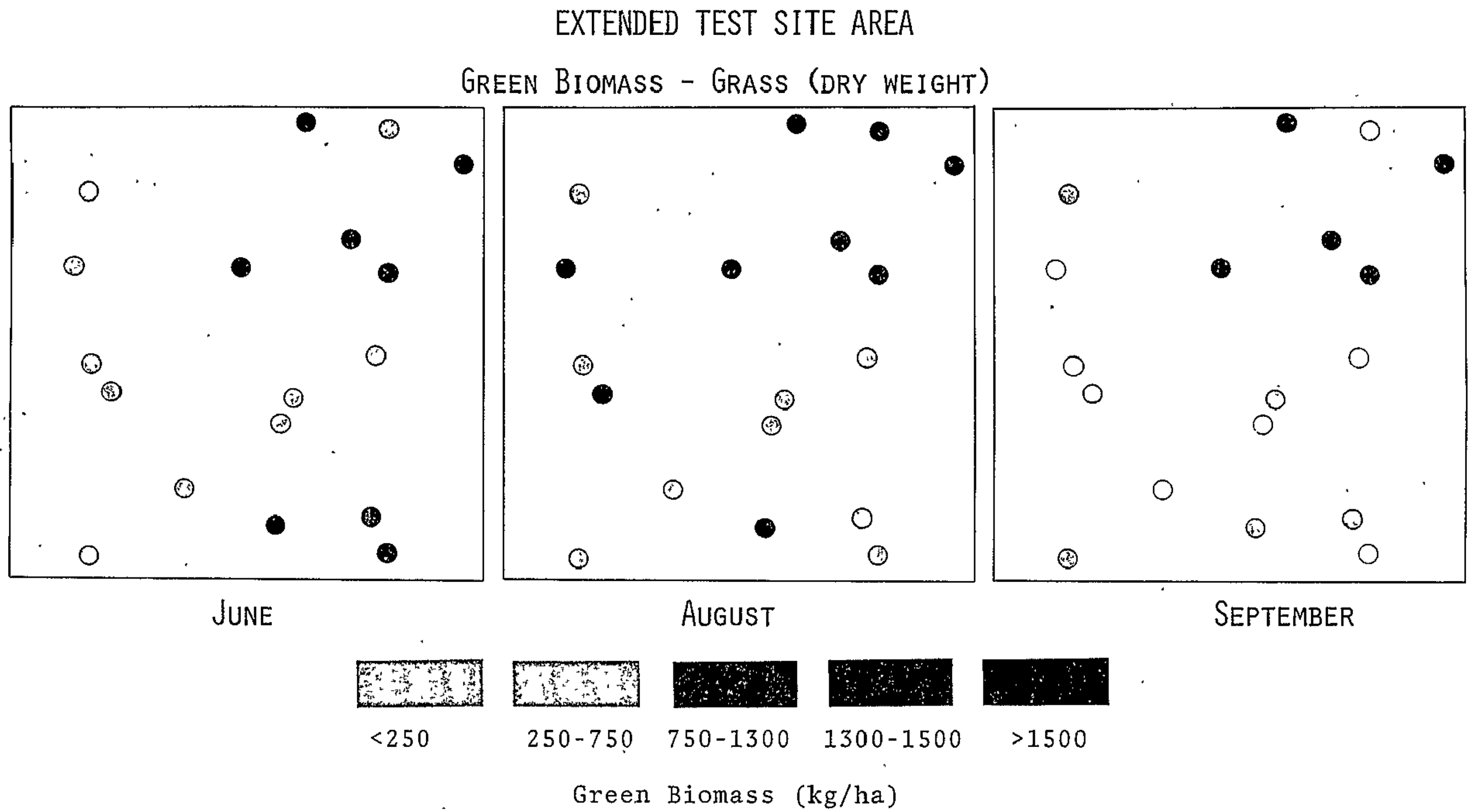


Figure 4-21. Grass component of green biomass measured at the ETSA primary sites colored to represent the vegetation condition class equivalents for comparison with the maps in Figures 4-17 and 4-18 (see also Figure 4-5).

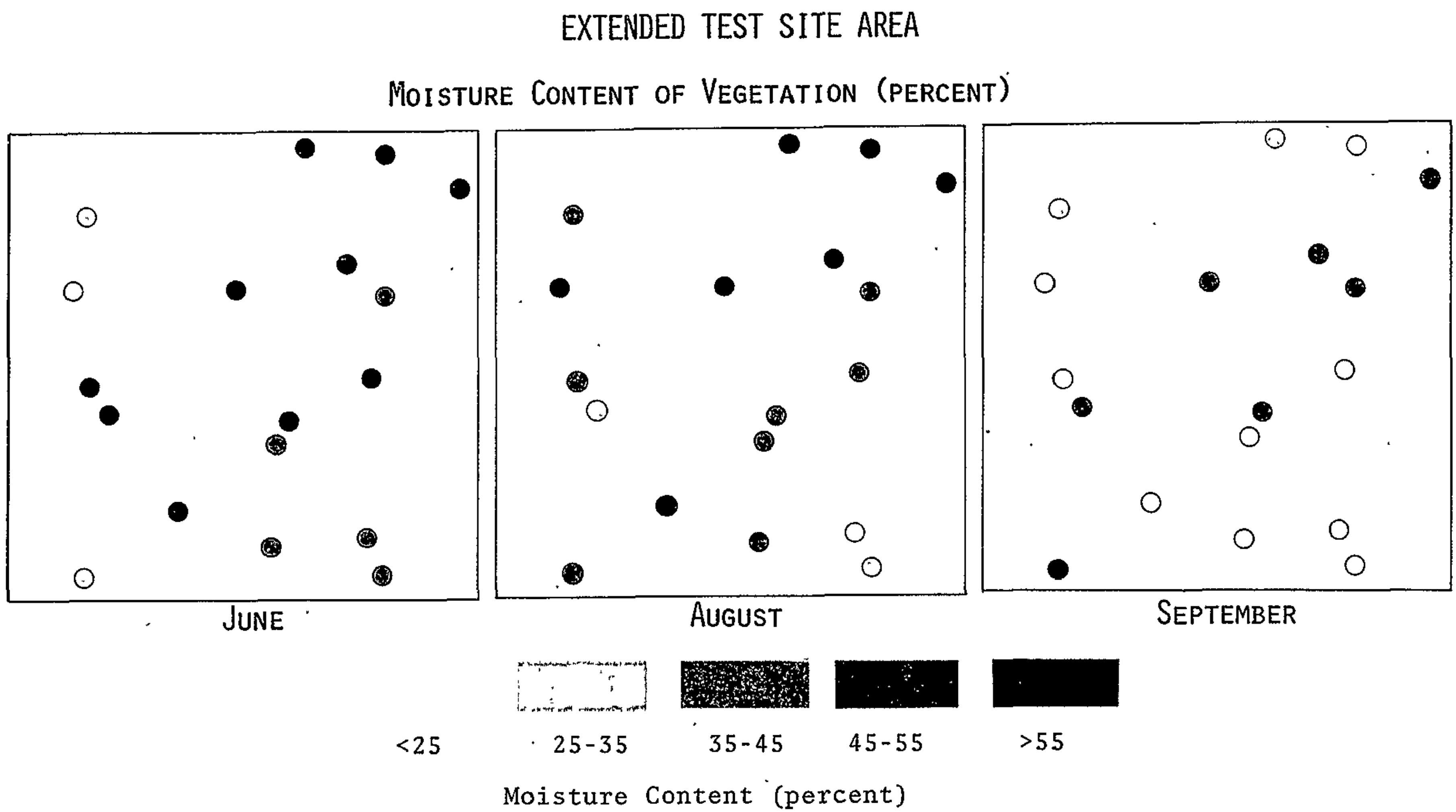


Figure 4-22. Moisture content of the herbaceous vegetation measured at the ETSA primary sites.

distribution that occurred within the ETSA during the 18-day period prior to the June Landsat overpasses (Figure 4-9).

The ground truth data for the August sampling period indicated that the most significant changes in vegetation condition occurred in the northwest and the southeast corners of the ETSA. Total green biomass and vegetation moisture content increases appreciably in the northwest quadrant (Figures 4-19 and 4-22). In the south-east quadrant, the opposite trend occurred in that vegeta-tion moisture content was decreased considerably. The green biomass was also reduced, particularly that of the grass component (Figures 4-22 and 4-21). A small change was also detected in the southwest corner where a slight increase in plant moisture content was detected. These ground measured changes in vegetation conditions within the ETSA are evidenced in the Throckmorton model Range Feed Condition Map for August in Figure 4-18. The comparable TVI6 map for August in Figure 4-17 also shows these general trends.

Total green biomass measured in September was greater than 1500 kg/ha at eight of the eleven primary sites sampled (Figure 4-19). At seven of these eight, however, the forb component alone accounted for greater than 1500 kg/ha (Figure 4-20). The grass component of green biomass was less than 750 kg/ha in the southwestern half of the ETSA and 750-1300 kg/ha in the northeastern half (Figure 4-21). Vegetation moisture content was very high in the southwest corner at 45-55% and was determined to be 35-45% along a diagonal from the southwest corner to northeast corner. The northwestern corner was somewhat dryer at 25-35% moisture in the vegetation and the southeast corner was the driest area at less than 25% (Figure 4-22). The TVI6 parameter Range Feed Condition Map (Figure 4-17) probably provides a slightly more accurate representation of the vegetation conditions with the ETSA than the Throckmorton model Range Feed Condition Map for September, shown in Figure 4-18. The rainfall data for September presented in Figure 4-9 provide evidence that the vegetation condition should be good along a diagonal from the southwest to the northeast corners of the ETSA, and the driest area should be in the southeast corner. Ground truth measurements of vegetation moisture content confirm that these observations are correct. The Throckmorton model map for September properly portrayed the central area of the ETSA as having the greatest amount of green biomass but probably underestimated the amount of green biomass greatly. Since perennial broomweed was the dominant vegetation throughout the ETSA in September, and because of the poor relationship of TVI6 to broomweed biomass in September (Table 4-1, dry green forb biomass), the low TVI6 values were further degraded by the input of weather data into the estimation model.

4.3.5 ETSA Regional Maps Compared With SRS Reports

The USDA Statistical Reporting Service (SRS) publishes "Pasture and Range Feed Condition" maps for the continental U. S. on a monthly basis from April through December in "Crop Production" and the National Weather Service's (NOAA) "Weekly Weather and Crop Bulletin".

The pasture and range feed conditions in Texas and Oklahoma on June 1, August 1 and October 1, 1975 as reported by the Statistical Reporting Service are presented in Figures 4-23, 4-24 and 4-25, respectively. The SRS reported that in June, the pasture and range feed conditions were good to excellent across the entire ETSA. By August 1, the SRS maps indicated that a broad region of poor to fair pasture and range feed conditions had developed in the north central Texas area, which encompassed the southeast corner of the ETSA. Throughout September, conditions had generally worsened across Oklahoma and Texas rangelands. By October 1, the SRS reported that poor to fair range feed conditions had encroached into the northwest corner of the ETSA, and these conditions still prevailed in the southeastern quadrant.

The Throckmorton model green biomass map of range feed conditions and the TVI6 Range Feed Condition Maps

PASTURE AND RANGE FEED CONDITIONS

June 1, 1975

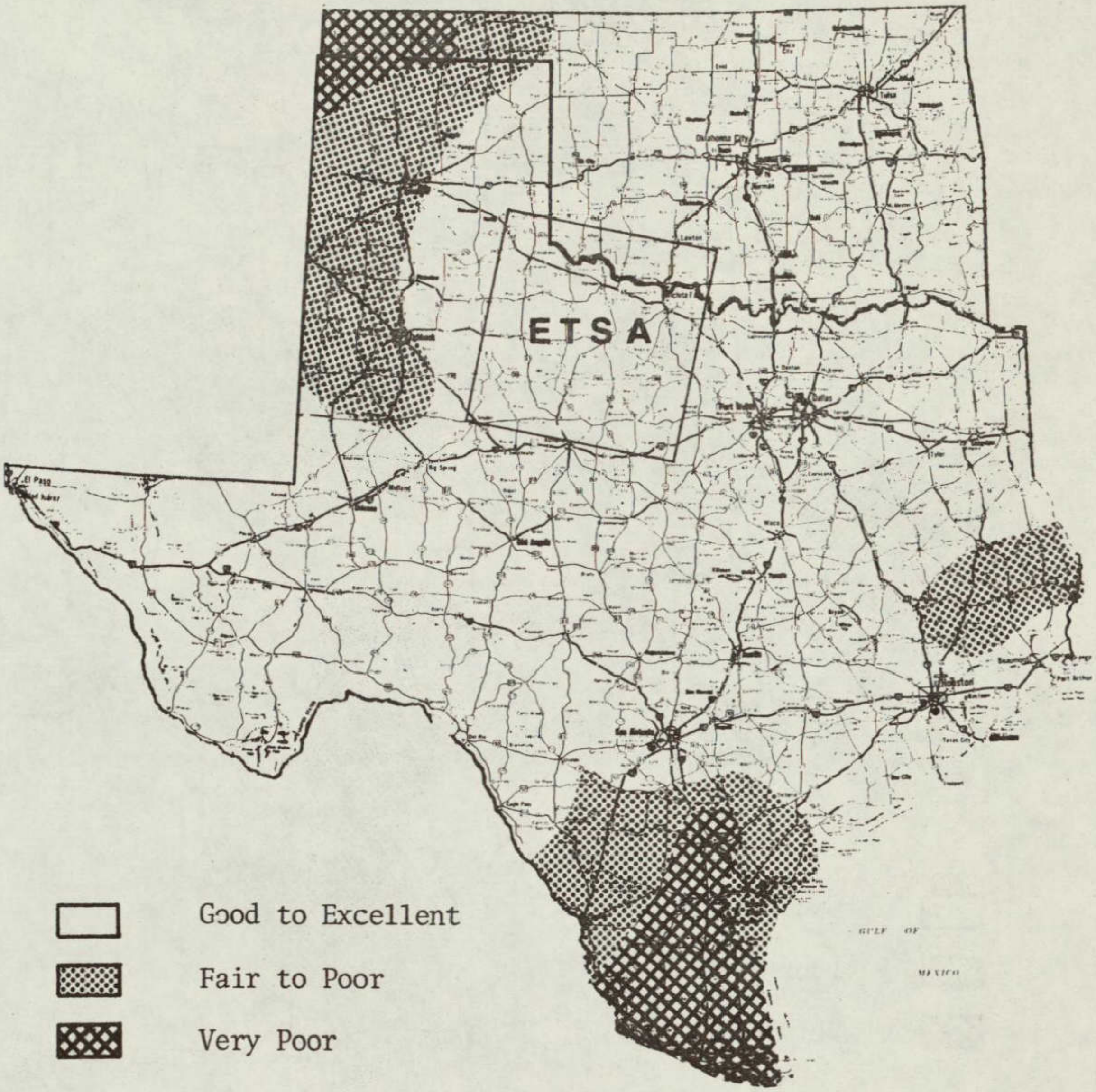


Figure 4-23. Pasture and range feed conditions in Texas and Oklahoma on June 1, 1975 as reported by the USDA Statistical Reporting Service (adapted from SRS Map 334-75-6).

PASTURE AND RANGE FEED CONDITIONS

August 1, 1975

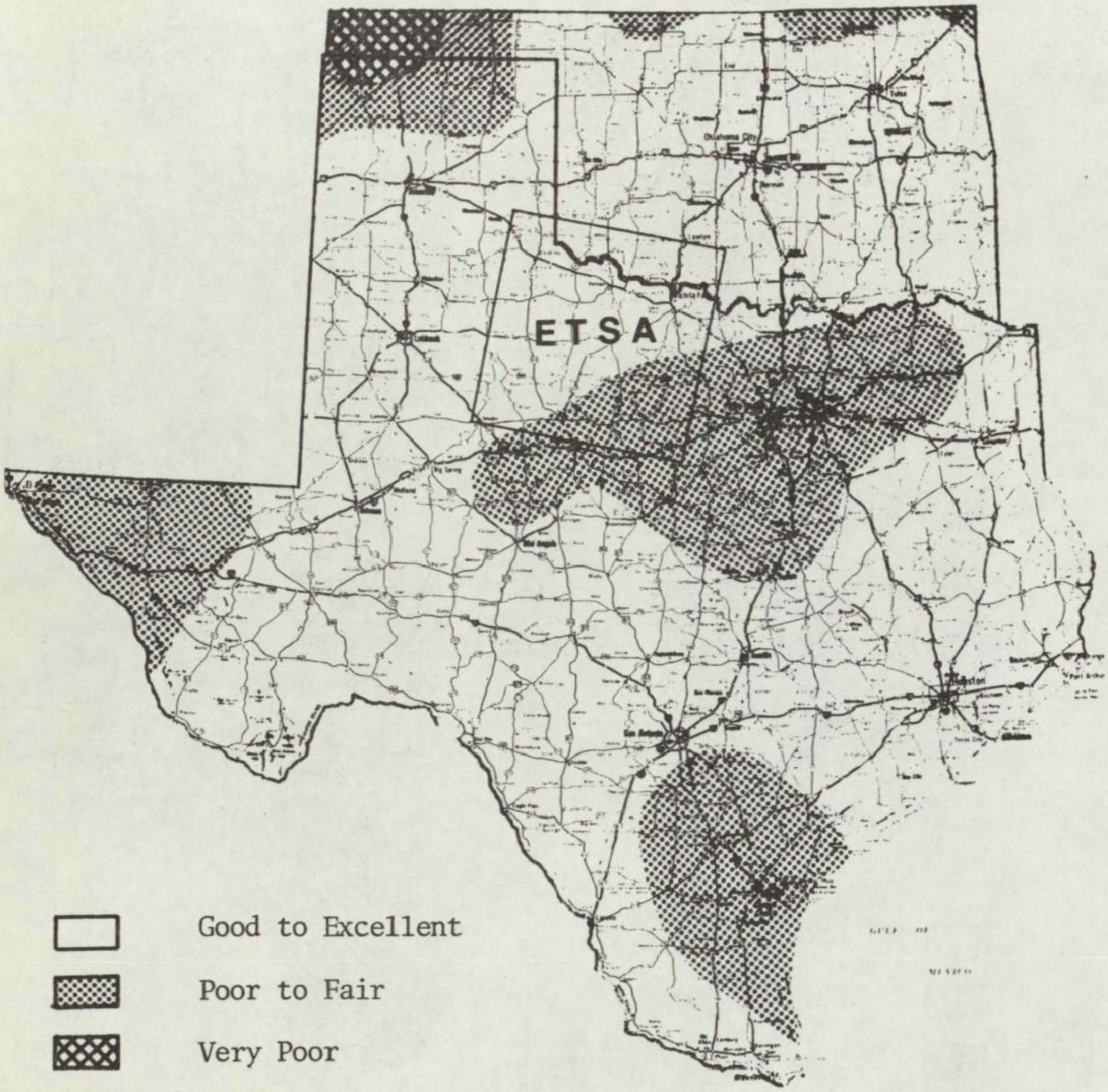


Figure 4-24. Pasture and range feed conditions in Texas and Oklahoma on August 1, 1975 as reported by the USDA Statistical Reporting Service (adapted from SRS Map 337-75-8).

PASTURE AND RANGE FEED CONDITIONS

October 1, 1975

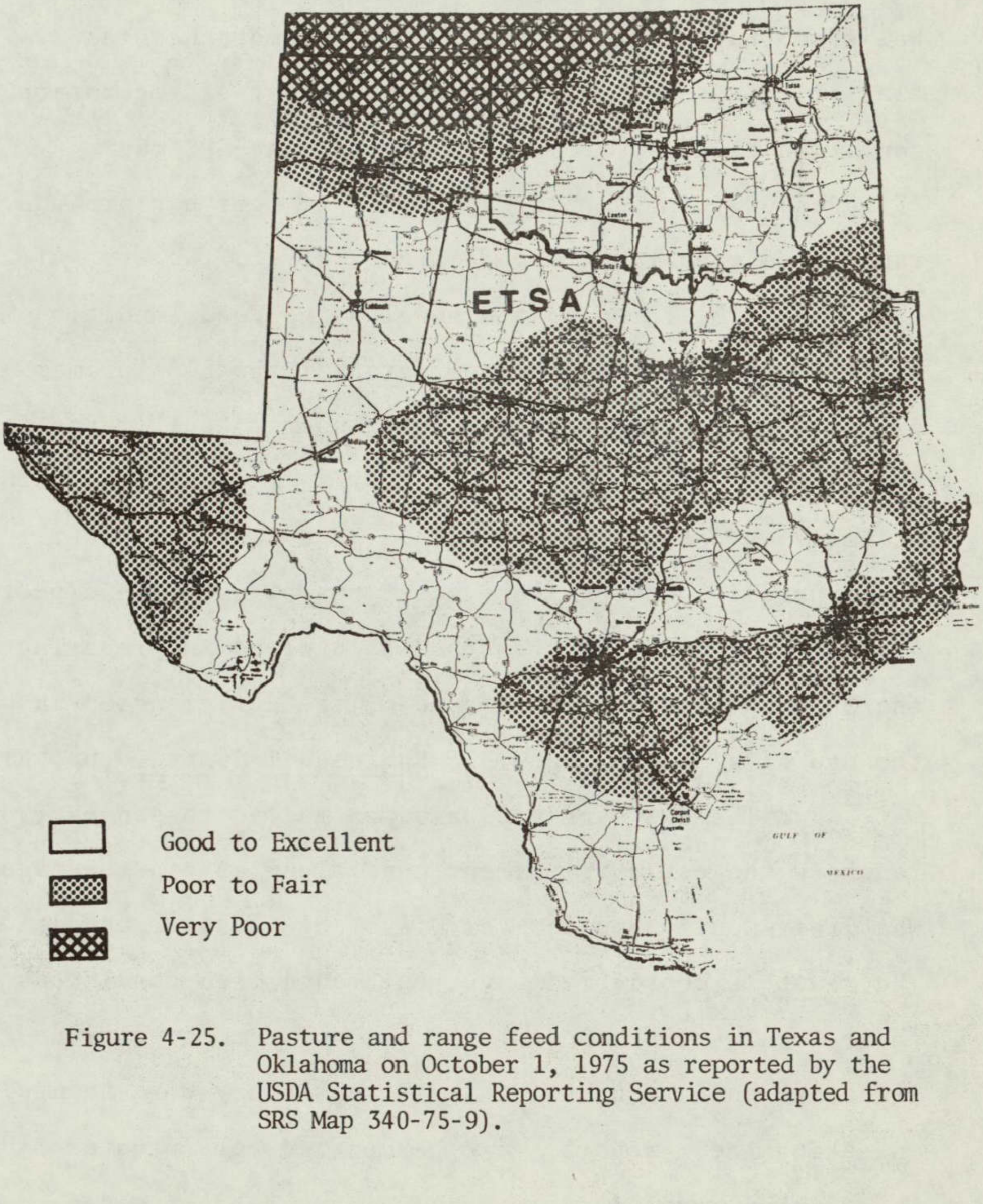


Figure 4-25. Pasture and range feed conditions in Texas and Oklahoma on October 1, 1975 as reported by the USDA Statistical Reporting Service (adapted from SRS Map 340-75-9).

(Figures 4-18 and 4-17, respectively) show general agreement with the SRS maps concerning the areas of drought stress and good to excellent forage conditions. However, it is believed that the Landsat-derived maps more accurately classified and portrayed the areal extent of vegetation condition classes. For example, the June SRS map (Figure 4-23) shows an area of poor to fair pasture and range feed conditions lying immediately to the west of the ETSA. The Throckmorton model Range Feed Condition Map and the ground truth data collected at the ETSA primary sites indicate that this region of poor to fair range feed conditions probably extends farther to the east and actually encompasses the western portion of the ETSA. However, discrepancies between these two types of maps are expected. J. R. Gray summarized the process involved in preparing the SRS maps and described some of the deficiencies in the map data in the June 1975 Rangeman's Journal (pp. 81-82).

The SRS maps are based on mailed responses from ranchers who estimate current conditions as a percentage of what they would be under very favorable weather conditions. The ranchers consider the current range feed conditions in their local areas, feed prospects, moisture conditions, livestock conditions and whatever else they wish to include in making their report. The percentages are plotted by location on state maps, and the areas are delineated according to condition categories. According to Gray, delineating these areas is similar to meteorologists drawing lines of equal pressure on a weather map.

Gray listed the following deficiencies that exist in the pasture and range feed condition reports:

- The report is based on opinion. Opinions may be influenced by a variety of unrelated situations.
- The report is generalized for broad areas. Individual ranches may be experiencing extreme drought even through the general area (which may be an entire state) is reported as good to excellent. The report is based on averages.
- A condition considered and reported as severe drought in one area...may be considered and reported as good to excellent in another.
- The exact boundaries, particularly near state boundaries, of the condition classes are usually based on compromises.
- In some areas, sampling problems persist with large areas not being represented by reports from local respondents.
- Current conditions may change more rapidly than the monthly interval of the report.

Despite these deficiencies, however, Gray relates that a report such as this is useful to ranchers in deciding about feed purchases, culling and livestock buying and selling. More accurate, unbiased and timely reports such as might be produced from Landsat MSS data (e.g., TVI6 index to range feed conditions or Throckmorton model green biomass index to range feed conditions) should be more readily accepted and certainly more useful to the rancher and others in agribusiness.

4.4 Regional Vegetation Condition Mapping from Landsat Applied to the Great Plains Corridor

Techniques to measure and monitor vegetation conditions from Landsat on a regional basis were developed, applied and evaluated, as presented earlier in the report, for the Extended Test Site Area in north central Texas and south central Oklahoma. Ground truth measurements taken at primary sites which formed a well distributed network of checkpoints were used for evaluating the vegetation condition maps produced for three Landsat overpass periods. The results from the ETSA study indicate that vegetation conditions can be mapped on a regional basis using the Landsat-derived TVI6 parameter as an estimator of green biomass which is then used as an index to vegetation conditions. In this section of the report, an application of the regional range feed condition mapping technique in the central and northern Great Plains for one Landsat cycle is described, and an evaluation of the map is presented.

4.4.1 Contour Mapping Procedures Applied to GPC Test Areas

The computer mapping techniques developed for producing contours of selected parameters were originally developed for the square Extended Test Site Area but the capability for expanding to almost any size area was also included. The distribution of data points across an area to be mapped is extremely important for accuracy. Consequently, the original computer maps generated from the Landsat data for the selected Great Plains Corridor test areas were generated as two separate print-outs. One rectangular print-out area was defined to include the southern test areas, and the second print-out included the northern test areas. The Oklahoma-Texas border formed the south end of the test areas mapped for the October 1-6, 1975 Landsat overpass cicle.

The density of secondary sites used for Landsat data extraction and parameter mapping was not as great in the GPC test areas as in the ETSA, especially in the northern half of the GPC. In the southern GPC test area which encompassed five Landsat frames, 138 secondary sites were established. The northern GPC test area encompassed six Landsat frames and contained 78 secondary sites.

For mapping vegetation conditions in the GPC test area, green biomass estimates were calculated from TVI6 (based on the regression between TVI6 and green biomass at the Throckmorton test site) without including the weather parameters in the calculations. Vegetation conditions were classified according to green biomass levels in the same manner as for the ETSA, as described in Section 4.3.3.

4.4.2 Range Feed Conditions in the GPC Test Areas

Four of the six original GPC test sites provided ground truth data applicable to the October 1-6, 1975 Landsat overpass period used for the regional vegetation condition mapping activity (Table 3-2). At the Woodward and Chickasha, Oklahoma test sites, ground truth data were collected on the day of the Landsat overpass. The last ground data taken in 1975 at the Hays, Kansas test site were acquired on September 24 and the last Sand Hills, Nebraska test site data were acquired on September 17. No ground truth data were collected beyond August 29 at either of the two northernmost test sites. Although only these four ground checkpoints were available for evaluating the accuracy of the vegetation condition map, these locations did provide quantitative measurements of ground conditions not available from any other source.

The Chickasha, Oklahoma test site had high biomass production in 1975. Although only 35-50% of the total herbaceous biomass was green, more than 1850 kg/ha of green biomass was measured. On most of the clipped plots, 0% exposed bare ground was recorded. At the Woodward, Oklahoma test site, only 140 miles northwest of the Chickasha site, the situation was considerably different. The amount of bare ground exposed when viewed from the vertical averaged almost 45%, ranging from 10% up to 75% bare ground. Only 10% of the herbaceous vegetation was green plant material and green biomass was measured at less than 200 kg/ha.

The Range Feed Condition Map in Figure 4-26 was produced from the Landsat data and depicts these observed conditions in Oklahoma quite accurately. The Chickasha site,

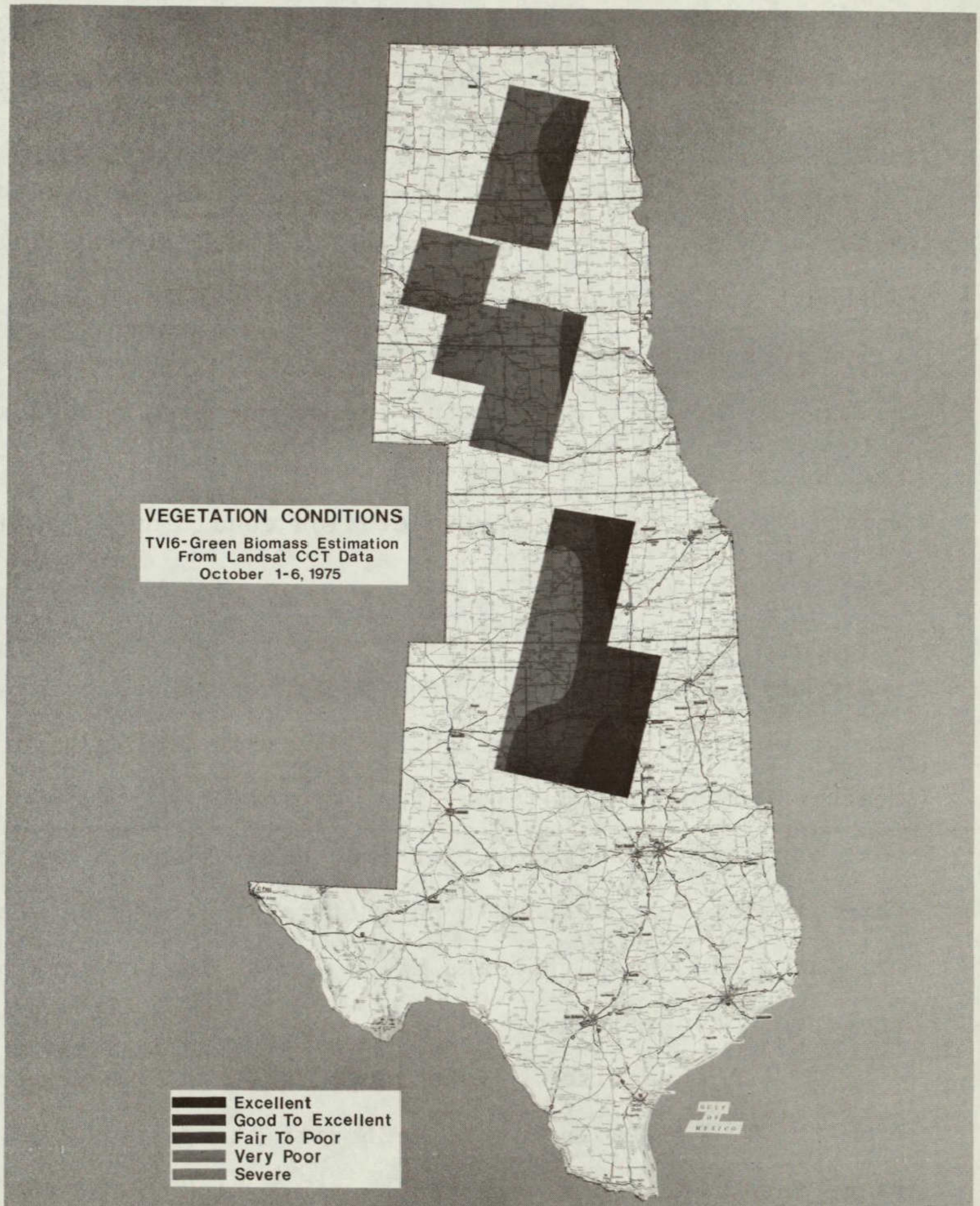


Figure 4-26. Range feed conditions within the GPC test areas for October 1-6, 1975 determined from TVI6 estimation of green biomass.

which recorded greater than 1500 kg/ha of green biomass, lies well within the dark green area classified as having excellent vegetation conditions. The Woodward test site is centrally located within the area mapped as having very poor vegetation conditions.

The Hays, Kansas test site recorded low green biomass in late September at slightly less than 500 kg/ha, although the green biomass component of the vegetation constituted more than 80% of the total aboveground herbaceous biomass. Typically, less than 15% of the bare ground was exposed. The Hays test site is shown to border on the fair to poor and very poor vegetation condition areas in Figure 4-26.

At the Sand Hills, Nebraska test site in mid-September, just over 50% of the total herbaceous biomass was green, resulting in slightly less than 750 kg/ha of green biomass. In addition, the vegetation moisture content was considerably lower at Sand Hills than at the other three test sites. The TVI6 parameter map shows the whole region within which the Sand Hills lie as having very poor range feed conditions.

A comparison of the range feed conditions plotted from the TVI6 data in Figure 4-26 with the pasture and range feed conditions reported by the USDA Statistical

Reporting Service in Figure 4-27 shows that the two maps report vegetation conditions the same for the four GPC test sites. It is quite apparent, however, that all of the GPC test areas are not mapped the same way by both techniques. The major discrepancies lie in the northern half of the GPC.

Without having an intensive ground sample network to verify the vegetation conditions throughout this region, it is very difficult to evaluate the accuracy of either map. Although the limitations and bias of interpreting the vegetation conditions from the October 1-6, 1975 Landsat composite imagery are recognized, it is useful to inspect a few of these images. The Landsat false color composite image containing the Chickasha test site (Figure 4-28, D) displays a very red to dark pink color over most of the scene, particularly the southeastern two-thirds of the image. This, of course, indicates very lush vegetation conditions and large quantities of green biomass. The rangelands in the scene containing the Hays, Kansas test site (Figure 4-28, C) display a pale-brown to reddish-brown color in the southwestern two-thirds of the image and are brownish-red to red in the remaining northeastern one-third of the image. These conditions appear to correspond more closely with the TVI6 map (Figure 4-26) than the SRS map (Figure 4-27). There are

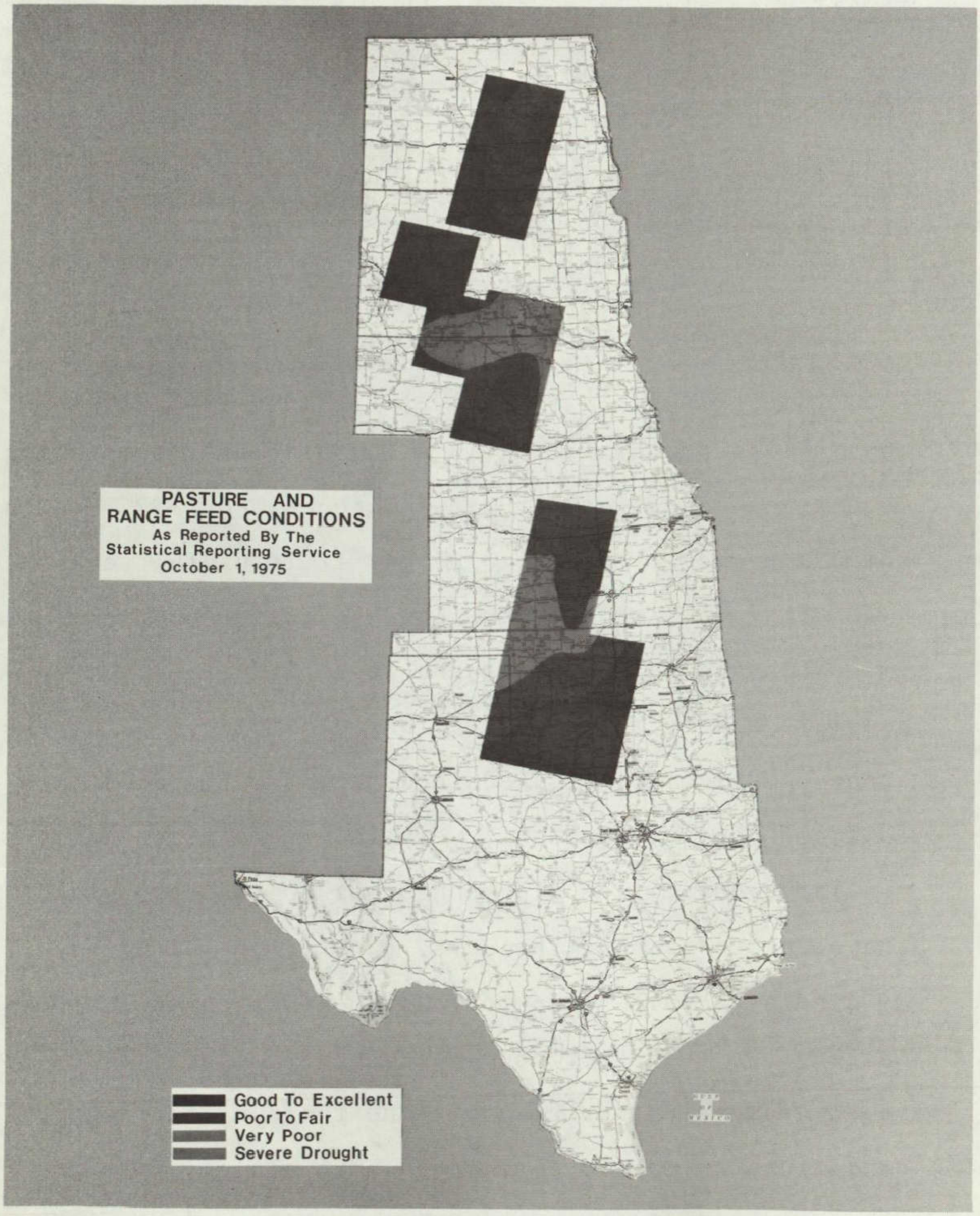


Figure 4-27. Pasture and range feed conditions within the GPC test areas on October 1, 1975 as reported by the USDA Statistical Reporting Service (adapted from SRS Map 341-75-10).

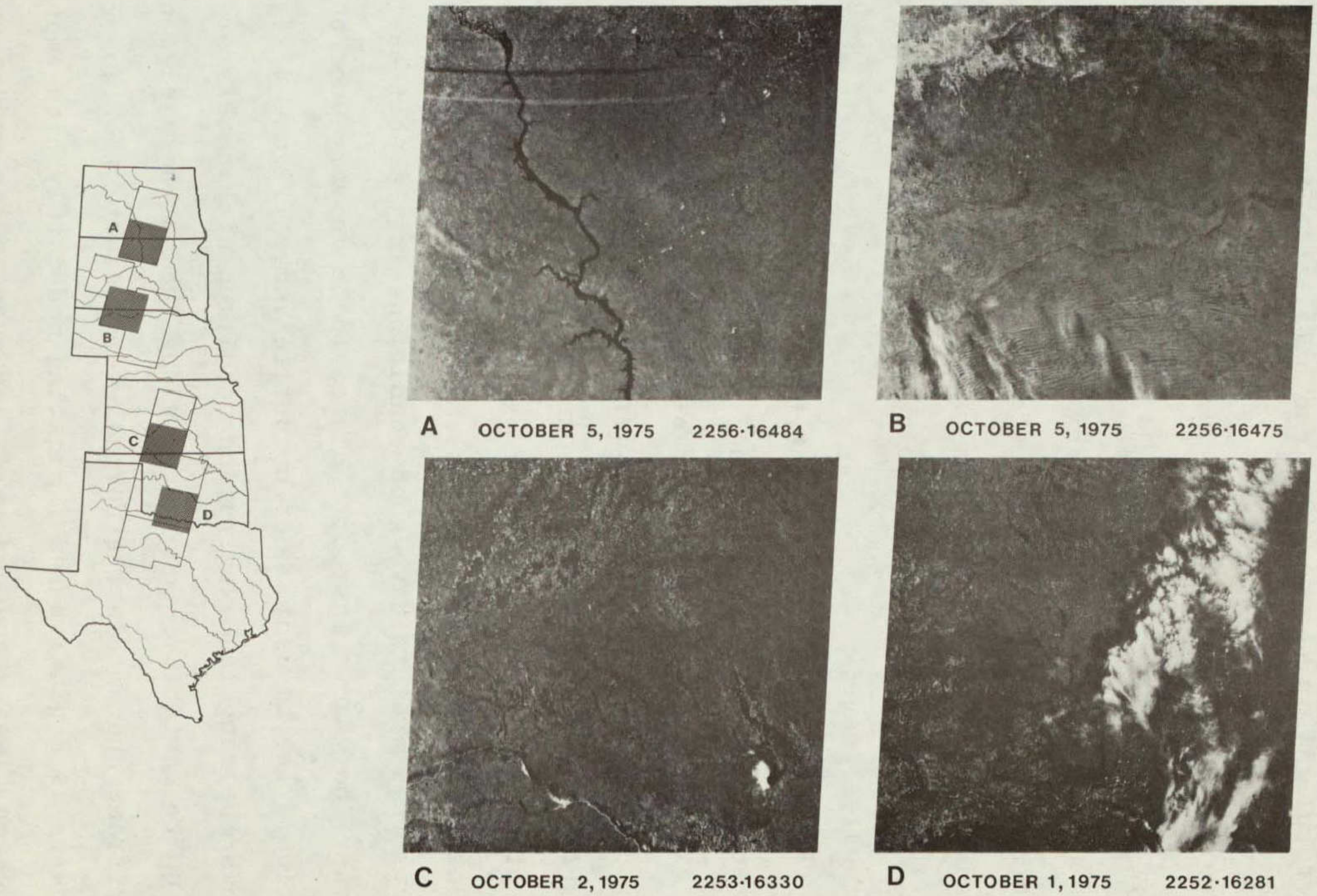


Figure 4-28. Selected false color composite Landsat images (Bands 4,5,7) showing vegetation conditions within the GPC test areas in October 1975.

numerous irrigated crops scattered throughout this image, particularly in the northern one-half, that are a bright red color.

Landsat image B of Figure 4-28 on the South Dakota-Nebraska border clearly indicates that, except for the natural subirrigated meadows in the Sand Hills of Nebraska and occasional irrigated cropland, the range feed conditions are very poor. Most of the rangelands across this whole scene are pale-brown to bluish-green on the color composite image.

The Statistical Reporting Service indicated that on October 1, pasture and range feed conditions were good to excellent in the western two-thirds of the area on the North Dakota-South Dakota border encompassed by image A of Figure 4-28. The eastern one-third of this image is reported to have poor to fair pasture and range feed conditions. The TVI6/green biomass map of range feed conditions shows this area to have good conditions in the northeast corner, but shows most of the area to be in very poor condition. The Landsat color composite image (Figure 4-28, A) shows the rangeland vegetation condition within this area to be quite variable. Generally, along the northern edge of the frame and within the northeastern corner, the rangelands show up as a pinkish-red indicating moderately high amounts of green biomass and generally good vegetation conditions.

Similar conditions are also indicated near the center of the image. Most of the remaining area, however, ranges from a pale brown to a bluish-green color indicating fair to poor range feed conditions.

In general, then, it appears that the TVI6 regional range feed condition mapping technique did an adequate job of detecting and delineating the vegetation conditions within the GPC test areas. In the northern half of the GPC where the distribution of secondary sites was very sparse, the smaller inclusions of different vegetation conditions were not detected. However, the evidence indicates that vegetation conditions for the region were properly classified. A more dense, uniformly distributed network of secondary sites would be used for operational monitoring of regional vegetation conditions.

4.5 Analysis Summary

The ground truth data from the Throckmorton test site in the 1975 growing season provided an opportunity to further evaluate the relationships between ground parameters and Landsat-measured spectral data. The 1975 growing season provided vegetation conditions considerably different than those encountered in the three previous growing seasons during which the Landsat and ground data from the initial study had been acquired and analyzed. Linear regression analysis of the 1972-75 data set (22 dates) reveals that the herbaceous dry green biomass measurement paremeter accounts for more than 90% of the variation observed in the Landsat-derived TVI6. The TVI6 parameter was also found to be well correlated (R^2 = .780) with vegetation moisture content at the Throckmorton test site.

Similar regression analyses were performed to assess the degree of association between the TVI6 parameter and ground measurements taken at each of the ETSA primary sites. The sample sites represented a wide variety of vegetation and soil types that occur within the Rolling Red Plains and Prairies of north central Texas and southwestern Oklahoma. Although the TVI6/ground parameter relationships for the ETSA primary test site were not as well correlated, they were statistically significant and consistent with those documented for the Throckmorton test site. Inadequacies in the ground data are most likely responsible for the lower correlations, particularly between green biomass and TVI6. The higher and more consistent correlations between vegetation moisture content and TVI6 supports this contention. Since moisture content and amount of green biomass can be used as indices of vegetation conditions, both the Throckmorton test site data and the ETSA primary site data provided convincing evidence that the TVI6 parameter could be used to monitor vegetation conditions within the ETSA using 1975 Landsat MSS digital data.

A computer mapping technique was developed and implemented to produce isoline maps of given parameters for a network of secondary sites. Range feed condition maps were generated for the ETSA for three Landsat overpass periods using the TVI6 parameter. In addition, green biomass estimates were calculated for the secondary sites with the Throckmorton green biomass estimation model which used TVI6 and three weather parameters. These estimates were then mapped for the ETSA and used as an index to vegetation conditions.

The range feed condition maps were compared with primary site ground truth data, weather station weather records and Statistical Reporting Service Pasture and Range Feed Condition maps. These evaluations indicate that regional range feed condition mapping techniques are adequate to detect and map the areal extent of at least five levels of vegetative conditions. The Throckmorton model green biomass maps of range feed conditions and the TVI6 range feed condition maps showed general agreement with the SRS maps concerning the areas of drought stress and good to excellent forage conditions. There is considerable evidence that the Landsat-derived maps more accurately classified and portrayed the areal extent of the vegetation condition than the SRS maps.

Following successful vegetation condition mapping within the ETSA, the techniques were applied to the preselected Great Plains Corridor test areas using October 1975 Landsat data. The TVI6 parameter was used to estimate green biomass as an index to vegetation conditions. The TVI6 Regional Range Feed Condition map was compared with Great Plains Corridor test site ground data, color composite imagery and the SRS Pasture and Range Feed Condition map. It was concluded that the mapping technique did an adequate job of detecting and delineating vegetation conditions within the GPC test areas. However, in the northern half of the GPC where the distribution of secondary sites was very sparse, small inclusions of different vegetation conditions were not detected. This occurred even though the overall vegetation conditions for the region were properly classified. It was recognized that the network of secondary sites would need to be more dense for reliable operational monitoring of regional vegetation conditions within the GPC.

In summary, the TVI6 parameter provides a measure of vegetation conditions as they exist at the time of the Landsat overpass. TVI6 can be used to estimate the quantity of herbaceous green biomass present on a site, although certain ground conditions must be met before reliable estimates can be assured. Certain weather factors are known to influence the TVI6 measurement parameter and can be used as correction factors to improve the accuracy of the green biomass estimates. The moisture content of the vegetation also influences the TVI6 parameter and as such enhances the ability of TVI6 to monitor vegetation conditions.

When TVI6 is obtained for a network of well distributed sites with adequate ground cover and limited brush cover, the regional parameter mapping technique can be used to generate maps of range feed conditions. At least five levels of range feed conditions can be mapped using the TVI6 data.

Interpretation of TVI6-derived vegetation condition maps must consider the season of the year for which the data were acquired. For example, in early spring, low TVI6 values (indicating low green biomass) will not necessarily mean that an area is experiencing drought. It may indeed indicate the degree of range readiness. Poor conditions may result from a late growing season (cold temperatures) or very dry winter conditions. Ancillary information, such as the time of the last killing frost, mean temperature for the previous 18-day period, etc., may prove helpful for proper interpretation of maps during the spring green-up period.

5.0 Summary and Conclusions

The purpose of this project has been to define the capabilities and limitations of Landsat MSS data for determining vegetation conditions on a regional basis. The approach has been to apply the models and techniques developed during the Landsat-1 study for quantitative assessment of herbaceous green biomass and vegetation condition. It was anticipated that the study would result in the development of data processing and analysis techniques suitable for the regional application of Landsat data for monitoring "Range Feed Conditions" in the Great Plains Corridor. Assessment of regional drought on rangelands was among the priority applications to be explored during the investigation.

The Landsat-1 investigation identified a Landsat-derived parameter, TVI6 (the sun-angle corrected, transformed, normalized difference of Bands 5 and 6), for statistical estimation of the amount and seasonal condition of rangeland vegetation. The Landsat-2 follow-on investigation has shown that the Landsat digital data can be effectively employed on a regional basis to monitor changes in vegetation conditions. A green biomass estimation model has been applied to a relatively intensive extended test site in north central Texas and southern Oklahoma and a less intensive test site that spans the Great Plains Region from southern

Oklahoma to North Dakota. The study has demonstrated the capability for using TVI6 as an estimator of green forage biomass on rangelands and as an index to vegetation conditions which can be applied regionally. The results of the study revealed the potential for numerous applications in agriculture and particularly for range management.

5.1 Project Accomplishments

Specific accomplishments achieved toward developing and expanding the use of Landsat MSS data for regional monitoring of vegetation conditions are as follows:

A system was developed for regional contour mapping of parameters derived from Landsat MSS data. The success of any effort to provide information to users on a regional basis from satellite remote sensing will depend not only on the accuracy of the information but on the ability to provide a product which is easily interpreted by the users. Contour maps of data which have been statistically defined and computer plotted provide this kind of product. The regional parameter mapping technique developed on this project meets the requirements for displaying Landsat-derived parameters in a meaningful format.

It was clearly demonstrated that even with much better than normal summer precipitation in the ETSA, differences in growing conditions were reflected in the amount and quality of vegetation and that these conditions were measured by the Landsat-derived parameter TVI6.

TVI6 is sensitive to relatively small changes in the amount of green biomass and the water content of herbaceous vegetation. Both of these parameters are valid indicators of the vigor of range vegetation. Consequently, changes in vegetation conditions are readily detectable with Landsat MSS digital data in the form of the TVI6 parameter.

The Throckmorton model was further evaluated for quantitative estimation of green biomass. The addition of four dates from the 1975 growing season did not significantly influence the relationship previously established between TVI6 and green biomass. The addition of the 1975 data did enhance the statistical correlation and extended the upper range of the data by more than 600 kg/ha.

Weather factors are recognized as being important in changing the scene reflectance and, as shown in the initial study, more important for accurate quantitative estimates of green biomass from Landsat MSS data. However, spectral changes and scene reflectance resulting from heavy infestations of mature common broomweed caused the model to under estimate green biomass in the ETSA in September. Consequently, until further investigation can be made of the impact of several important site-related variables on the scene reflectance recorded by Landsat, the TVI6 values, unadjusted for weather factors, should be used as indices for delineating the biomass and vegetation condition classes.

The regional parameter mapping techniques developed for the ETSA were shown to be adaptable and applicable for monitoring vegetation conditions using TVI6 over much larger areas, such as the Great Plains Corridor. Range feed conditions were mapped within test areas spanning much of the Great Plains Corridor from north Texas through North Dakota. The techniques developed for the ETSA were easily adapted for mapping this much larger region. The vegetation condition classes mapped agree with ground truth data collected at isolated locations throughout the Great Plains Corridor and was found to compare favorably with the Statistical Reporting Service map of pasture and range feed conditions.

The TVI6 maps were found to have certain advantages over the SRS Pasture and Range Feed Condition maps. Rather than being based on opinion, TVI6 is a quantitative measurement of the vegetation unaffected by human bias. Whereas the SRS maps are generalized for broad areas, localized differences can be detected by Landsat with the proper sampling density. Continuity for mapping vegetation conditions with the same standards is maintained over large areas with Landsat regardless of political boundaries. With Landsat, information can be obtained readily with the detail required on a "need-to-know" basis such as for areas experiencing drought.

Based on the results of the Great Plains Corridor investigations, strategies were proposed for the operational use of TVI6 for forage evaluation on an individual ranch basis and a regional basis. The operational procedures proposed were based on the capabilities of the current Landsat sensor systems with the anticipation that more timely product turnaround could be achieved, as would be required for user-oriented operational satellite systems.

As anticipated, the investigation established priorities on the needs for additional research to quantify green biomass estimation from Landsat MSS data. These needs are: 1) to evaluate the impact of site-related factors (such as ground cover, standing brown vegetation and species composition) on rangeland scene reflectance; 2) to determine thresholds of green biomass detection on different range sites; 3) to evaluate temporal influences (such as plant maturation, litter accumulation, sun angle, etc.) on rangeland scene reflectance; 4) to evaluate other spectral regions to determine the capability for measuring range scene components other than green biomass, such as total biomass and ground cover; and 5) to evaluate pixel-to-pixel variations in Landsat data as a source of information about rangeland.

5.2 Applications for Range Management

A number of potential applications in the field of agriculture for the green biomass and vegetation conditions measurement and monitoring techniques that were developed and tested during this study were discussed in Section 5.2 of Final Report RSC 1978-4. This study provides additional support for the proposed applications in the field of agriculture. Section 4.6 of Final Report RSC 1978-4 included a discussion of ranch management systems, described the place of entry of remote sensing information into these systems and discussed possible uses of remote sensing for ranch management. In this seciton of the current report, several suggestions are made for using the Landsat-based green biomass and vegetation condition monitoring techniques for forage evaluation and monitoring on an individual ranch basis and for operational forage condition monitoring on a regional basis.

The most obvious application of green biomass estimates obtained from Landsat is to measure current production and monitor changes in green biomass for accumulating or estimating seasonal yield. Such an approach could be implemented for the forages on native rangelands and tame pastures, and possibly for supplemental feeds used for livestock production. In the past, there have been no economically feasible means of timely monitoring vegetation conditions on a regional basis. Consequently, it has not been possible to estimate the amount of forage available for livestock production. The findings of this study, as complimented by the findings of the initial Landsat GPC investigation, indicate that it is possible to monitor range forage available. This can be accomplished on an individual ranch or management unit basis, or on a regional basis through a selected-site sampling procedure.

These studies have shown that it is feasible to monitor both "range readiness" and "range feed condition" for native rangelands and tame pastures meeting certain criteria for continuity of the herbaceous canopy. The potential for monitoring the amount and status of supplemental feeds (i.e., hay crop, small grains and other crops used as livestock feeds) is also supported by the results of this Landsat investigation. Therefore, it should be possible to use the Landsat data to estimate the amount of feed available by seasons on a regional basis and to establish the proper carrying capacity of the rangeland resource on a management unit basis.

Periodic monitoring of green biomass on rangeland with Landsat data has the potential for providing much more information about the range resource than just the amount of forage available for livestock consumption. The ability to <u>monitor</u> green biomass with remote sensor systems, such as Landsat or Landsat follow-on satellites, is a key element of many of these applications.

An assessment of range condition or trend seems feasible, although certain ancillary information will be required. Observation of the phenological development throughout the year should reveal rates of development other than that expected for climax vegetation. Animal distribution and forage utilization patterns within a pasture could be determined through change detection evaluation of the amount of biomass in different parts of a pasture. Areas of over grazing should be easily detected, and critical areas determined from low biomass detected in normally higher producing areas. The detection and mapping of range fires, monitoring of subsequent regrowth and determination of readiness for grazing following the burn should be easily accomplished using biomass detection techniques.

By understanding the phenological development of range plants, it is possible to selectively map the distribution and density of certain species using the green biomass measurement parameter. For example, by selecting a time during the year when most of the range vegetation other than the species of interest is dormant or browned-out, the green plant is greatly contrasted and its contribution to scene reflectance is measured. On many Texas rangelands, mesquite, a noxious woody plant, remains quite green and vigorous during the seasonal summer drought that is normally experienced in July and August. In contrast, the herbaceous vegetation contains very little or no green plant material.

Likewise, in many areas where evergreen brush species occur, the winter dormant period provides a similar contrast between the evergreens and the herbaceous understory and/or deciduous woody species. An evaluation of the amount of green biomass within a scene during one of these critical seasons yields an evaluation of the brush density for the species of concern. Landsat's capability for temporal reassessment of noxious brush infestations makes it a potent tool for determining the spread of a species or the reduction due to the application of brush control treatments. Grass response following removal of brush can also be monitored, as well as the longevity of the brush control treatment.

5.2.1 Strategies for Forage Evaluation and Monitoring on an Individual Ranch Basis

Operational forage evaluation and monitoring from Landsat on an individual ranch basis may only be economically practical (with current costs) for large ranch operations where quantitative information could be supplied on a subscription basis. The information would have to be specific for individual management units (e.g., pastures) containing 50 to 100 hectares or more. A highly automated system for locating the Landsat pixels associated with the specific management units and for generating forage reports (with useful increments of production) for the rancher would have to be developed. In order for decisions to be implemented based on information that would be provided, the turnaround time from data acquisition to delivery to the rancher would generally have to be one week or less. Cloud cover at the time of overpass could present a serious problem, particularly with a satellite overpass cycle of 18 days or greater. Nevertheless, with current Landsat capabilities, the potential does exist for performing forage evaluations on certain types of rangeland on an individual ranch basis.

Several different approaches could be taken for measuring the production for individual grazing units. The higher the level of sophistication, the more accurate the information is likely to be. For example, the simplest and possibly least desirable approach would begin by developing a base map of the ranch on which individual grazing units are delineated along with ground features that are easily recognizable on the Landsat data. The base map would serve as an overlay for locating Landsat pixels corresponding with each grazing unit. The mean TVI6 value for each grazing unit could then be calculated from the Landsat data, and a simple one-variable model could be used to convert TVI6 values to green biomass estimates in terms of kg/ha or lb/acre. Using this average green biomass per unit area value, the estimate of total green biomass for the grazing unit could easily be calculated.

If it is assumed that in the early spring following winter dormancy (with herbage consumption, trampling, disappearance, nutrient leaching, etc.), the total green biomass is approximately equivalent to the forage available, the initial stocking rate could be set on the basis of feed currently available. By periodically monitoring the green biomass and making adjustments for livestock utilization and disappearance, the stocking rate can be adjusted periodically.

A second, more intensive scheme for using the Landsat data for forage evaluation on an individual ranch would probably include the following alternative approach. The base map overlay, as described above, would not only show the boundaries of the grazing units or pastures and certain easily recognizable ground features, but would also show range site boundaries and "excludable areas" (e.g., stock watering tanks, buildings, oil and gas well development scars, roads, etc.). A base map overlay such as this could be entered into an interactive display, minicomputer processing system for registration with the Landsat CCT data. This would enable automated extraction of MSS data for pre-selected strata (i.e., range sites, pastures, etc.).

Landsat spectral data for each of the different forage producing areas within each grazing unit would be extracted independently and a green biomass estimation model applied for each site. Based on the estimates obtained by range site, estimates of production per unit area could then by obtained by calculating the total amount of forage per management area.

Through future research, it is hoped that more accurate estimates of green biomass can be made for low producing sites or for sites having different species composition, soil texture, etc. Perhaps all that will be required is applying different adjustment coefficients in the TVI6 green biomass estimation model.

It will be very important to frequently monitor the status of the green biomass throughout the growing season to account for the addition of forage to the total standing biomass. By knowing the stocking rate on a given grazing unit, an estimate of the forage removal by the livestock can be made for a specified period. Additional herbage removal through "disappearance" will also have to be accounted for in determining the total forage available at any given time. Through adequate and periodic monitoring of green biomass for each grazing unit, it should be possible to determine the accumulated yearly production. Therefore, at the end of the growing season, the amount of forage available for the dormant period should be known.

5.2.2 Strategies for Operational Regional Forage Condition Monitoring

A logical approach for providing ranchers and other managers with information for management decisions would utilize the techniques developed and tested during this study for regional rangeland vegetation monitoring. A reliable information system would involve the development of a pre-selected sample site network for the region to be monitored from which the Landsat data would be extracted and the TVI6 parameter or model estimate of green biomass calculated. These data would then be used to generate maps of forage production or vegetation conditions within the region of concern. The maps would be distributed through normal information channels in a timely manner.

The development of an intensive sample site network is critical for assuring an accurate information system. Although the sample site selection is a relatively detailed procedure, it would essentially be a one-time operation for a given region. The selection procedure would optimally be a multi-stage remote sensing/ground reconnaissance procedure. Selected temporal Landsat imagery would be used to stratify the region into uniform vegetation/soil landscapes. Within each of the major landscape types, high altitude, color-infrared aerial photography would be acquired on sample basis during a season when the maximum vegetation differentiation and productivity differences would be revealed. Potential sample sites would be selected on the highflight aerial photography and, using signature extension techniques, additional sites would be selected on the Landsat imagery. The selected sites would provide a well distributed network of primary and alternate rangeland sites which meet selection criteria for ground cover and brush canopy cover as discussed earlier in this report.

Each tract of rangeland should be at least 50-100 hectares in size to facilitate the extraction of a sufficient number of pixels to provide a reliable signature. Field reconnaissance checking of a subset of the total selected sample site should be accomplished to verify their adequacy for the intended purpose.

Following the final site selection, the sites would be plotted on topographic maps to determine their UTM or latitude-longitude coordinates. A computer file of the sample sites would then be established by coordinate values. The Landsat data that are ultimately extracted for each of these sample sites would be plotted by coordinate location on the final maps. If weather data are to be used in model estimation of green biomass, weather reporting stations near each sample site that will provide representative rainfall and temperature measurements must be identified and associated with the appropriate sample sites in the computer file.

After the sample site network has been established and individual sample sites have been identified by coordinate location, the Landsat data extraction procedure would logically be automated. The automated procedure would locate the sample site, correct the spectral data for sun angle and other effects and calculate the TVI6 parameter. The TVI6 parameter would then be plotted as isoline contour maps of vegetation conditions; or by merging weather data with TVI6, the green biomass model estimates could be calculated. Isoline contour maps of this parameter would then be generated for the region.

In an operational, long-term regional monitoring system, a small ground data network probably should be established to provide checkpoints for periodically testing the system and for anomaly identification. The ground information network might be set up as a cooperative effort with established range research field stations or other similar organizations.

For an operational regional information system to be effective, products must be generated and distributed on a timely basis. A product turnaround of not more than 7-10 days from data acquisition to product distribution would be required. It is anticipated that information in the form of range feed condition maps or the data in other formats would be published by most local newspapers or farm journals. Other communications media such as extension service outlets and possibly radio and television could be used in disseminating this information. As indicated earlier in this report, the vegetation condition maps should also find broad applications to many situations found in dryland agriculture.

The most devastating factor in dryland agriculture within the Great Plains Region is the recurrence of short- and long-term droughts. Seasonal droughts often severely affect crop yield and cause rangelands to be abusively grazed. Long periods of below normal precipitation can cause serious regional economic consequences. Currently, water budget models are used to chart drought stricken areas from weather data. Landsat type data appear to offer a more direct and accurate approach to regional monitoring of drought effects.

The concept of utilizing rangeland as a phenological indicator for crops on a regional basis has a potential for wide applications in much of the United States and in vast regions of the world where native rangeland and dryland farming co-exist. The usefulness of native grasslands as integraters of environmental conditions is enhanced by the fact that, in general, fertilization and irrigation are not used. Consequently, little confusion should arise due to imposed cultural practices if cropland conditions are inferred from satellite measurements of rangeland vegetation.

5.3 New Technology Statement

In accordance with the New Technology Clause of Contract NAS5-20796, it is noted that no developments during the period of this report are considered applicable to the reporting requirements.

6.0 Publications and Presentations

Several documents have been written and presentations given during the period of the follow-on project. These have resulted from work done under the Landsat-1 Great Plains Corridor project as well as the Follow-On Regional Application project.

D. W. Deering presented the unpublished paper "Satellite Monitoring of Rangeland Resources in the Great Plains Region" to the 28th Annual Convention of the Society for Range Management. This was a semi-technical paper and was presented on February 13, 1975 in Mexico City.

In April 1975, R. H. Haas and D. W. Deering co-authored a two page article for the Texas Agricultural Experiment Station Information Report 75-1, Grazing Management, Beef Cattle Production and Brush Control. This article was entitled "Satellite Measurement of Range Forage Condition".

D. W. Deering gave a semi-technical presentation concerning the techniques and results of the Landsat-1 contract work. The talk was given on May 2, 1975 to the Southwest Chapter of the American Right of Way Association's land use planning seminar in Midland, Texas.

J. W. Rouse, Jr. presented a paper in June 1975 co-authored by R. H. Haas, D. W. Deering, J. W. Rouse, Jr. and J. A. Schell entitled "Monitoring Vegetation Conditions for Use in Range Management" at the Earth Resources Survey Symposium. The paper presented results of the Landsat-1 Great Plains Corridor rangeland study and described the approach being taken under the present Landsat Follow-On contract. This paper was published in the proceedings (NASA TM X-58168; JSC-09930).

D. W. Deering presented "Measuring 'Forage Production' of Grazing Units from Landsat MSS Data" at the Tenth International Symposium on Remote Sensing of Environment in Ann Arbor, Michigan in October 1975. The paper, Texas Agricultural Experiment Station contribution TA12-188, was published in the symposium proceedings. The paper was co-authored by D. W. Deering, J. W. Rouse, Jr., R. H. Haas and J. A. Schell.

R. H. Haas presented a paper entitled "Mapping Rangeland Vegetation in North Central Texas from Landsat Space Imagery" at the annual meeting of the Society for Range Management in Omaha, Nebraska on February 18, 1976. The paper was co-authored by K. C. McDaniel and D. W. Deering.

On April 22, 1976, J. C. Harlan and D. W. Deering gave a presentation to NASA administrators in Washington, D. C. The presentation summarized the accomplishments of the rangeland Landsat investigations at TAMU and the rangeland management uses of Landsat data that are being developed.

On October 20, 1976, D. W. Deering presented the final results of the Landsat Great Plains Corridor follow-on investigation to the Landsat Agricultural Review Panel at Goddard Space Flight Center, Maryland.

APPENDIX A

Weather data for the 61 weather stations used in the ETSA

Table A-1. Monthly summaries of precipitation (inches) at the 61 ETSA weather stations for January-September 1975.

WEATHER STATION	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.
TEXAS:									
Albany	0.00	0.00	0.00	0.00	4.15	1.13	2.54	2.55	1.99
Anson	0.88	2.03	0.41	1.28	3.80	0.47	4.45	3.44	4.22
Antelope	1.24	3.33	1.09	1.45	8.96	3.18	5.41	2.36	2.65
Archer City	0.94	2.40	2.74	2.01	11.73	2.09	4.96	1.88	3.84
Aspermont 2 SSW	0.73	2.53	0.52	0.81	4.62	0.55	5.32	1.41	5.71
Bateman Ranch	1.58	1.80	0.00	0.00	8.32	1.75	6.54	1.71	4.02
Benjamin 4 SSE	0.79	1.83	0.94	1.73	5.31	0.00	0.00	0.00	0.00
Breckenridge 2NNW	1.43	2.39	1.59	0.00	3.27	2.48	1.61	2.25	1.93
Childress FAA AP	1.36	2.14	0.97	1.05	2.00	2.37	3.01	2.85	2.20
Chillicothe 2 NE	1.67	2.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crowell	1.54	2.76	1.13	0.63	6.19	1.51	7.60	1.14	3.64
Dumont	0.88	2.50	0.36	0.63	2.76	5.10	1.31	3.19	0.00
Dundee 6 NW	1.39	2.11	1.25	1.66	9.33	3.15	5.04	2.35	3.90
Eastland	1.48	2.25	0.94	3.24	5.18	1.36	3.40	1.14	1.70
Electra	2.01	3.23	1.51	2.57	10.60	2.52	7.42	1.59	3.27
Graham	1.28	2.67	1.30	1.65	7.66	5.07	2.03	1.46	1.47
Guthrie	0.98	2.19	0.64	0.83	8.04	1.87	3.52	1.24	4.49

Table A-1. Monthly summaries of precipitation (inches) at the 61 ETSA weather stations for January-September 1975. (continued)

WEATHER STATION	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.
Hackberry	0.00	2.13	0.10	0.50	2.50	7.50	0.00	2.85	5.50
Hamlin	1.03	1.61	7.71	0.90	5.66	0.25	4.32	1.77	3.78
Haskell	0.65	1.61	0.58	1.03	7.35	1.36	5.12	1.93	3.55
Henrietta	1.26	3.15	2.24	2.48	10.86	2.85	4.85	2.18	3.88
Jayton	0.00	1.48	0.10	0.80	4.00	1.30	4.74	2.45	5.00
Latimer Ranch	0.00	0.00	0.52	0.32	5.50	0.84	6.13	5.33	3.55
Memphis	0.00	1.45	0.00	1.25	1.90	2.90	3.40	1.00	2.18
Munday	0.77	2.01	1.05	1.01	5.79	2.57	0.00	1.46	1.84
Olney	0.71	2.55	1.58	1.29	8.95	3.05	2.19	2.44	0.00
Olney 5 NNW	1.25	1.45	1.14	1.08	11.18	3.42	4.80	1.56	2.85
Paducah	0.94	2.16	0.76	0.59	3.11	2.14	0.00	4.19	3.01
Paducah 17 SSE	1.42	2.29	0.56	0.87	5.23	2.21	6.64	1.79	3.80
Pitchfork Ranch	0.85	2.12	0.25	0.23	0.00	0.00	0.00	0.00	5.00
Possum Kingdom Dam	1.24	3.69	1.60	1.67	0.00	0.00	0.00	0.00	0.00
Quanah 5 SE	1.41	0.00	0.85	0.43	3.53	2.67	10.22	4.19	3.11
Ranger 1 W	1.54	1.89	0.83	2.55	3.08	1.53	3.05	0.26	1.40
Roby	0.95	1.80	0.16	0.00	3.15	1.28	0.00	0.00	0.00
Ross Ranch	0.95	2.37	0.58	1.40	7.34	2.40	4.58	1.92	6.25

Table A-1. Monthly summaries of precipitation (inches) at the 61 ETSA weather stations for January-September 1975. (continued)

WEATHER STATION	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.
Rotan	0.54	2.14	0.28	1.02	2.57	1.55	5.78	2.63	4.14
Seymour	1.32	2.23	0.83	1.73	5.18	2.18	4.35	2.47	4.22
Snyder	0.33	2.04	0.15	0.31	3.33	1.14	6.24	2.43	5.38
South Camp (6666)	0.75	0.00	0.00	1.06	0.00	0.00	0.00	0.00	4.72
Stamford 1	0.00	1.11	0.47	1.53	3.38	0.47	0.00	2.16	0.00
Strawn 8 NNE	0.93	2.19	0.85	2.06	5.74	3.53	1.68	2.10	1.64
Throckmorton 2 W	0.66	2.11	0.79	1.35	4.95	1.22	1.53	3.07	3.01
Texas Experimental Ranch	0.75	2.48	0.90	1.24	6.48	2.02	3.33	2.89	4.84
Truscott	1.17	2.06	0.83	0.99	5.55	1.88	4.89	4.04	5.48
Vernon	1.76	2.01	0.61	1.05	7.49	4.41	0.00	4.47	3.23
Wellington 1 NNW	0.72	2.38	1.25	1.47	3.09	3.36	4.35	3.17	0.00
Wichita Falls WSO AP R	0.91	1.71	1.57	2.94	9.66	1.69	3.41	3.46	3.65
OKLAHOMA:									
Altus Irr. Res. Station	1.58	2.06	0.90	1.28	4.61	5.18	7.13	1.96	2.22
Baird 4N	1.44	2.64	1.77	2.26	10.02	4.04	5.01	1.66	3.20
Chattanooga 3NE	1.15	3.90	1.76	1.50	6.43	4.17	4.10	2.74	3.59

Table A-1. Monthly summaries of precipitation (inches) at the 61 ETSA weather stations for January-September 1975. (continued)

WEATHER STATION	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUG.	SEPT.
Comanche	1.53	2.66	3.52	2.10	9.31	4.40	4.51	3.53	4.16
Duncan	1.94	2.49	3.64	1.38	0.00	2.58	6.82	1.12	2.92
ElDorado	0.84	2.81	1.04	0.94	4.17	5.44	9.19	0.00	0.00
Frederick	1.89	2.02	1.04	0.86	8.29	8.62	4.44	1.29	3.42
Grandfield	2.21	2.92	1.86	1.76	8.24	10.17	6.02	1.67	3.30
Hollis	1.40	2.74	0.95	2.60	3.87	6.98	2.54	1.83	2.26
Lawton	2.35	0.00	1.25	1.65	11.42	4.27	4.73	0.53	3.34
Snyder	1.70	1.89	1.13	0.00	5.78	3.66	4.77	2.46	2.41
Tipton 4 S	1.59	1.91	1.42	0.68	6.09	7.37	4.79	2.33	3.86
Walters 1 W	2.47	2.66	1.50	2.13	10.58	2.50	3.98	2.44	5.08
Waurika 2 NNW	1.80	2.40	2.37	3.57	8.57	3.93	3.33	3.28	4.09

Table A-2. Long-term weather record summary and locations of the 61 weather stations used in the ETSA.

WEATHER STATION	COUNTY	LATITUDE	LONGITUDE	ELEVATION (ft.)	ANNUAL AVERAGE TEMP. (°F)	ANNUAL AVERAGE PRECIP. (in.)	FROST-FREE DAYS
TEXAS:							
Albany	Shackelford	32° 44'	99° 18'	1438	64.7	26.57	234
Anson	Jones	32° 45'	99° 54'	1700	66.5	23.67	234
Antelope	Jack	33° 26'	98° 22'	1077		28.00	
Archer City	Archer	33° 36'	98° 38'	1030	63.6	27.81	239
Aspermont 2 SSW	Stonewall	33° 06'	100° 14'	1750	63.0	22.36	234
Bateman Ranch	King	33° 35'	100° 09'	1810		28.36	
Benjamin 4 SSE	Knox	33° 32'	99° 46'	1403		22.82	
Breckenridge 2NNW	Stephens	32° 46'	98° 54'	1185	64.4	32.45	244
Childress FAA AP	Childress	34° 26'	100° 17'	1951	61.9	20.67	232
Chillicothe 2 NE	Hardeman	34° 15'	99° 31'	1400		24.67	
Crowell	Foard	33° 59'	99° 43'	1451		23.93	
Dumont	King	33° 48'	100° 31'	2010		25.09	
Dundee 6 NNW	Archer	33° 49'	98° 56'	1051		25.82	
Eastland	Eastland	32° 24'	98° 49'	1450	63.8	27.09	244
Electra	Wichita	34° 02'	98° 55'	1216		22.89	

Table A-2. Long-term weather record summary and locations of the 61 weather stations used in the ETSA. (continued)

WEATHER STATION	COUNTY	LATITUDE	LONGITUDE	ELEVATION (ft.)	ANNUAL AVERAGE TEMP. (°F)	ANNUAL AVERAGE PRECIP. (in.)	FROST-FREE DAYS
Graham	Young	33° 06'	98° 35'	1045	64.0	28.03	223
Guthrie	King	33° 37'	100° 19'	1740	63.5	24.11	219
Hackberry	Cottle	33° 54'	100° 09'	1680		29.71	
Hamlin	Jones	32° 53'	100° 08'	1720		21.47	
Haskell	Haskell	33° 10'	99° 44'	1605	63.1	24.14	234
Henrietta	Clay	33° 49'	98° 12'	900	64.1	31.40	234
Jayton	Kent	33° 15'	100° 34'	2010	62.5	22.17	222
Latimer Ranch	Cottle	33° 53'	100° 23'	1950		25.43	
Memphis	Hall	34° 44'	100° 33'	2100	61.1	20.53	244
Munday	Knox	33° 27'	99° 38'	1460	64.8	24.64	233
Olney	Young	33° 22'	98° 46'	1197	65.6	25.19	245
Olney 5 NNW	Archer	33° 26'	98° 47'	1184		28.14	
Paducah	Cottle	34° 01'	100° 18'	1900	61.7	22.12	234
Paducah 17 SSE	King	33° 47'	100° 12'	1810		21.79	
Pitchfork Ranch	Dickens	33° 36'	100° 32'	1920		21.96	
Possum Kingdom Dam	Palo Pinto	32° 52'	98° 26'	900		25.84	
Quanah 5 SE	Hardeman	34° 15'	99° 41'	1495	62.7	24.32	224

Table A-2. Long-term weather record summary and locations of the 61 weather stations used in the ETSA. (continued)

WEATHER STATION	COUNTY	LATITUDE	LONGITUDE	ELEVATION (ft.)	ANNUAL AVERAGE TEMP. (°F)	ANNUAL AVERAGE PRECIP. (in.)	FROST-FREE DAYS
Ranger 1 W	Eastland	32° 28'	98° 42'	1540	65.1	26.93	235
Roby	Fisher	32° 44'	100° 23'	1980		20.87	
Ross Ranch	King	33° 35'	100° 01'	1660		24.03	
Rotan	Fisher	32° 52'	100° 28'	1925	65.3	21.21	223
Seymour	Baylor	33° 36'	99° 15'	1294	63.0	26.36	220
Snyder	Scurry	32° 43'	100° 55'	2325	62.4	19.32	224
South Camp (6666)	King	33° 30'	100° 27'	1870		24.84	
Stamford 1	Jones	32° 56'	99° 47'	1630		23.39	
Strawn 8 NNE	Palo Pinto	32° 40'	98° 28'	1177		32.96	
Throckmorton 2 W	Throckmorton	33° 11'	99° 12'	1400	64.3	25.82	223
Texas Experimental Ranch	Throckmorton	33° 17'	99° 13'	1400		27.10	
Truscott	Knox	33° 45'	99° 49'	1529	63.3	22.80	234
Vernon	Wilbarger	34° 10'	99° 18'	1212	64.3	25.65	225
Wellington 1 NNW	Collinsworth	34° 52'	100° 13'	2030		28.07	226
Wichita Falls WSO AP R	Wichita	33° 58'	98° 29'	994	64.1	27.22	246

Table A-2. Long-term weather record summary and locations of the 61 weather stations used in the ETSA. (continued)

WEATHER STATION	COUNTY	LATITUDE	LONGITUDE	ELEVATION (ft.)	ANNUAL AVERAGE		FROST-FREE DAYS
					TEMP. (°F)	PRECIP. (in.)	
OKLAHOMA:							
Altus Irr. Res. Station	Jackson	34° 35'	99° 20'	1380	62.8	24.23	230
Baird 4N	Comanche	34° 32'	98° 10'	1080		32.64	
Chattanooga 3NE	Comanche	34° 27'	98° 37'	1154	62.5	28.48	224
Comanche	Stephens	34° 22'	97° 58'	1015		33.65	
Duncan	Stephens	34° 30'	97° 58'	1125	62.8	32.44	224
ElDorado	Jackson	34° 28'	99° 39'	1455		27.90	
Frederick	Tillman	34° 24'	99° 01'	1300	64.0	26.45	234
Grandfield	Tillman	34° 14'	98° 41'	1135		29.70	
Hollis	Harmon	34° 41'	99° 55'	1615	62.7	22.25	221
Lawton	Comanche	34° 37'	98° 27'	1150		30.18	
Snyder	Kiowa	34° 39'	98° 57'	1350		22.18	
Tipton 4 S	Tillman	34° 26'	99° 08'	1355	62.3	25.25	234
Walters 1 W	Cotton	34° 21'	98° 19'	990	63.4	31.44	224
Waurika 2 NNW	Jefferson	34° 12'	98° 01'	935	63.9	31.56	236

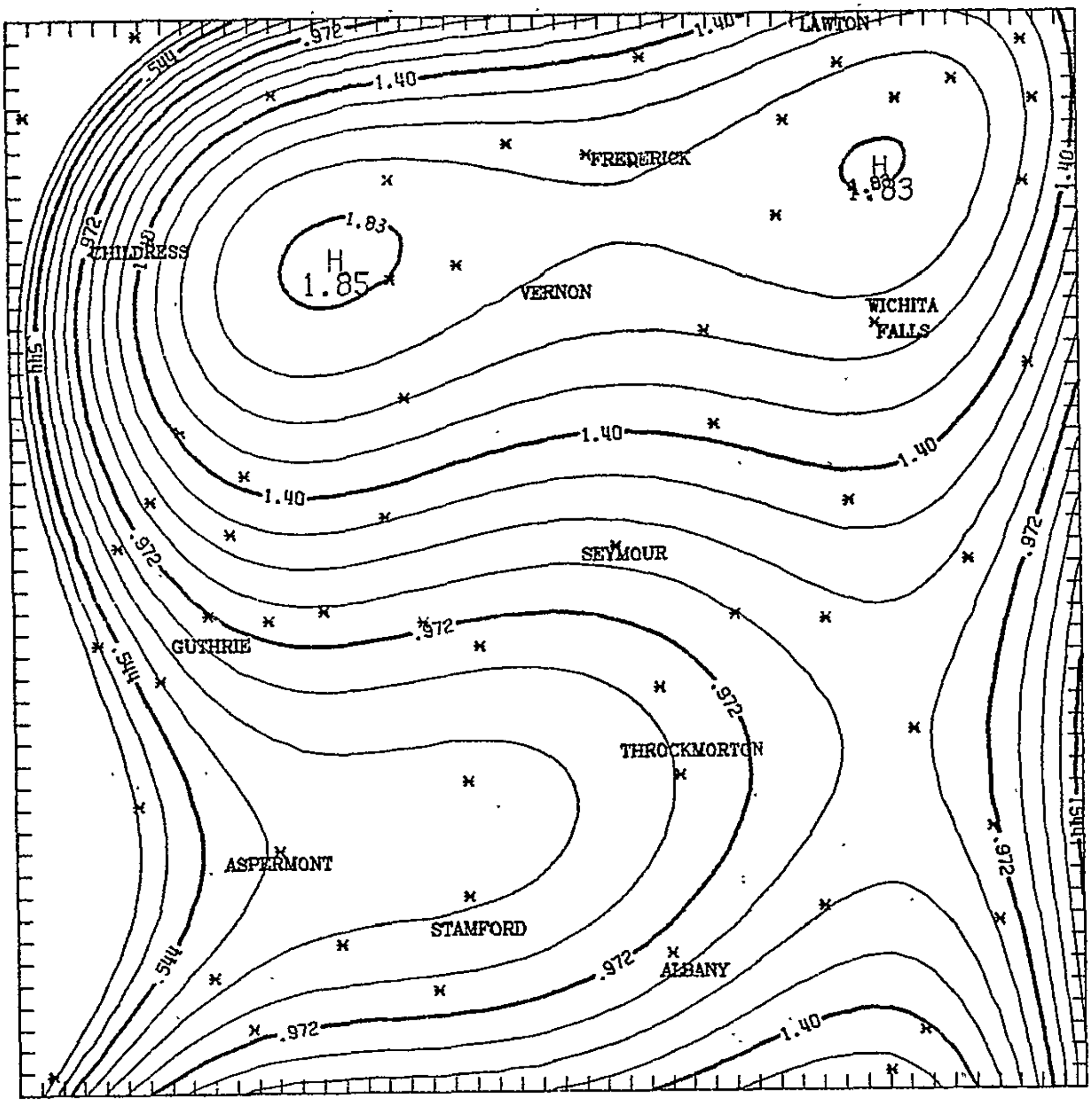
APPENDIX B

Isoline maps of monthly precipitation
and 18-day accumulations for the ETSA

EXTENDED TEST SITE AREA

JANUARY

MONTHLY RAINFALL

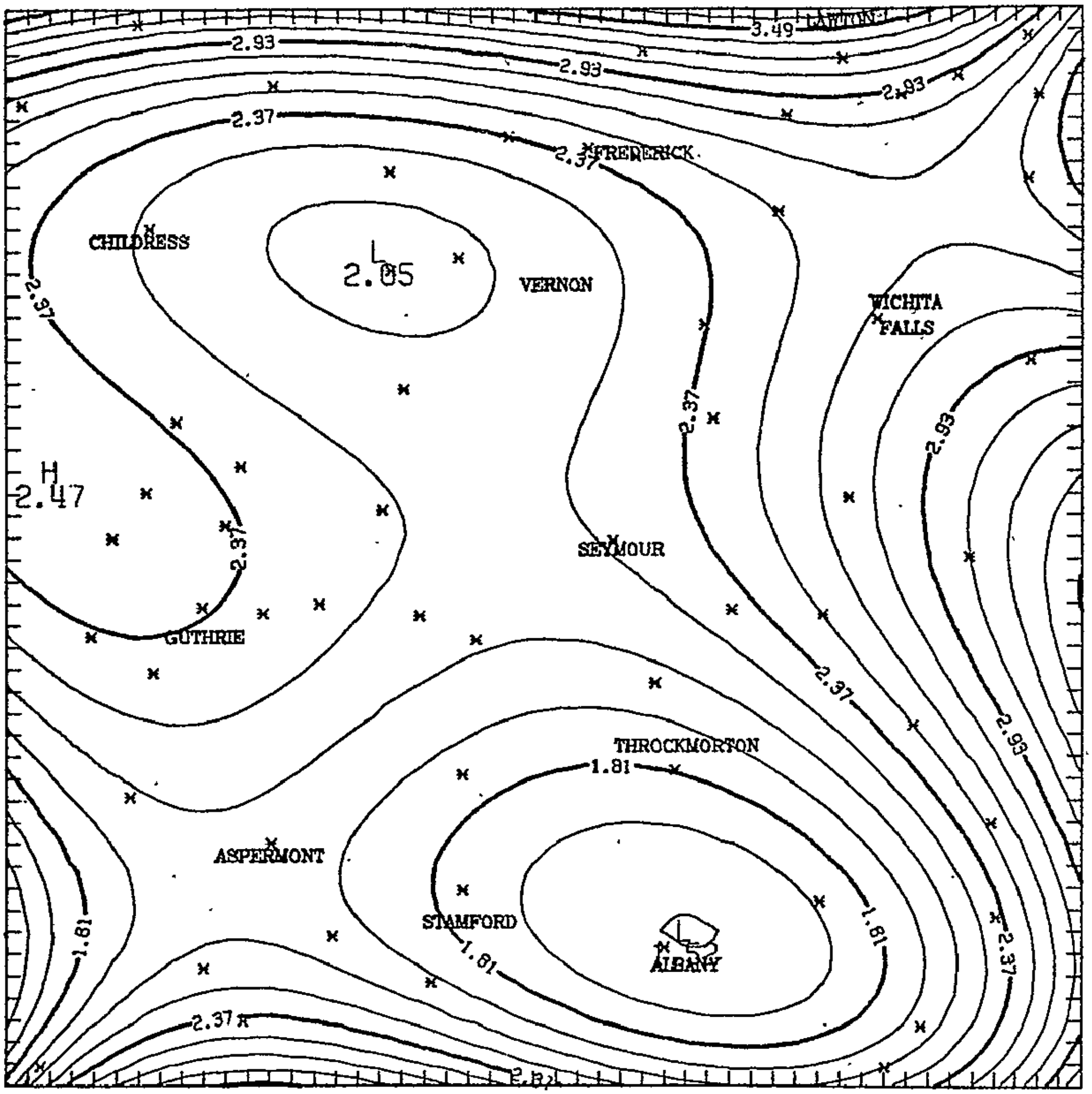


Precipitation in Inches

EXTENDED TEST SITE AREA

FEBRUARY

MONTHLY RAINFALL

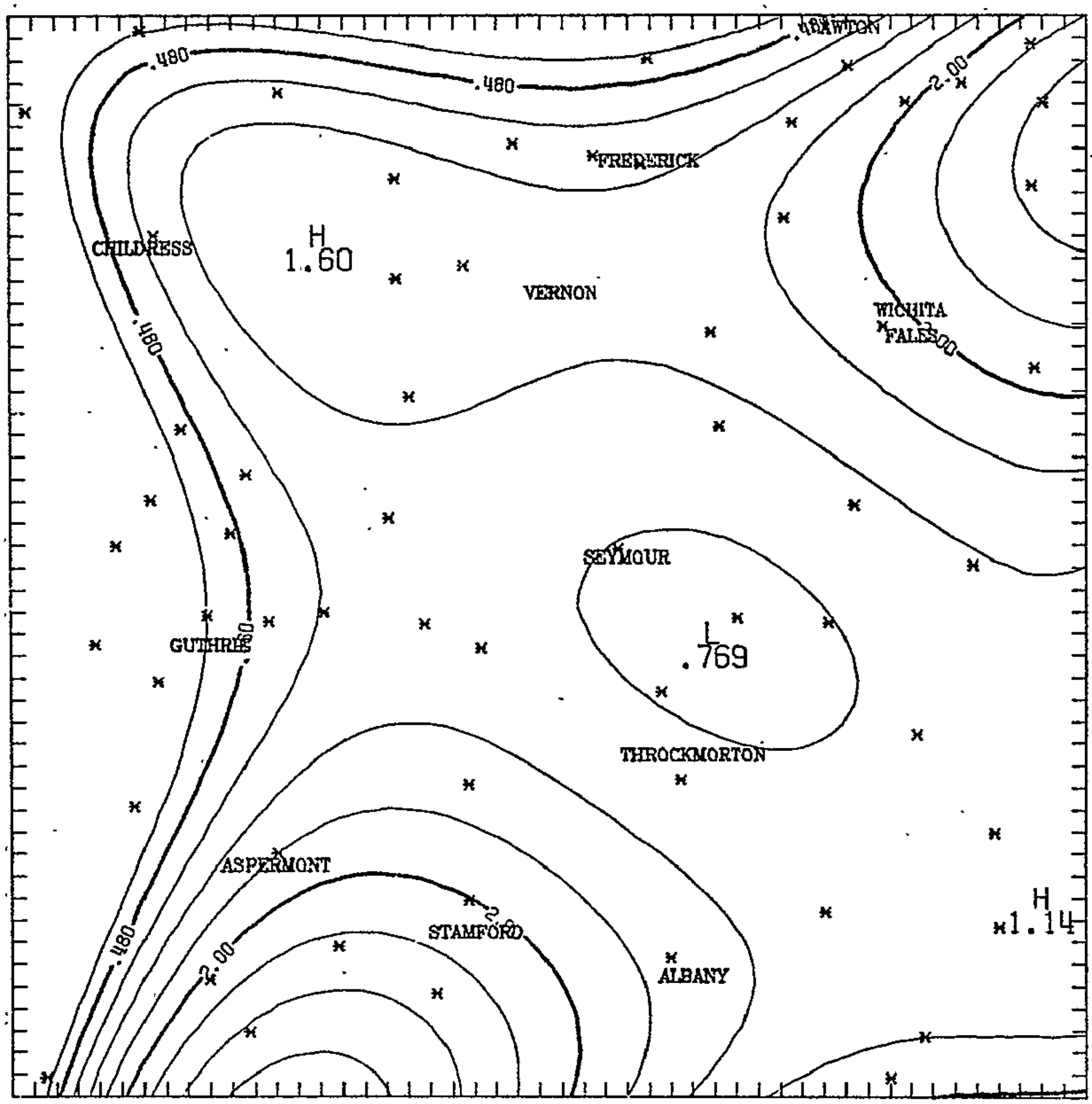


Precipitation in Inches

EXTENDED TEST SITE AREA

MARCH

MONTHLY RAINFALL

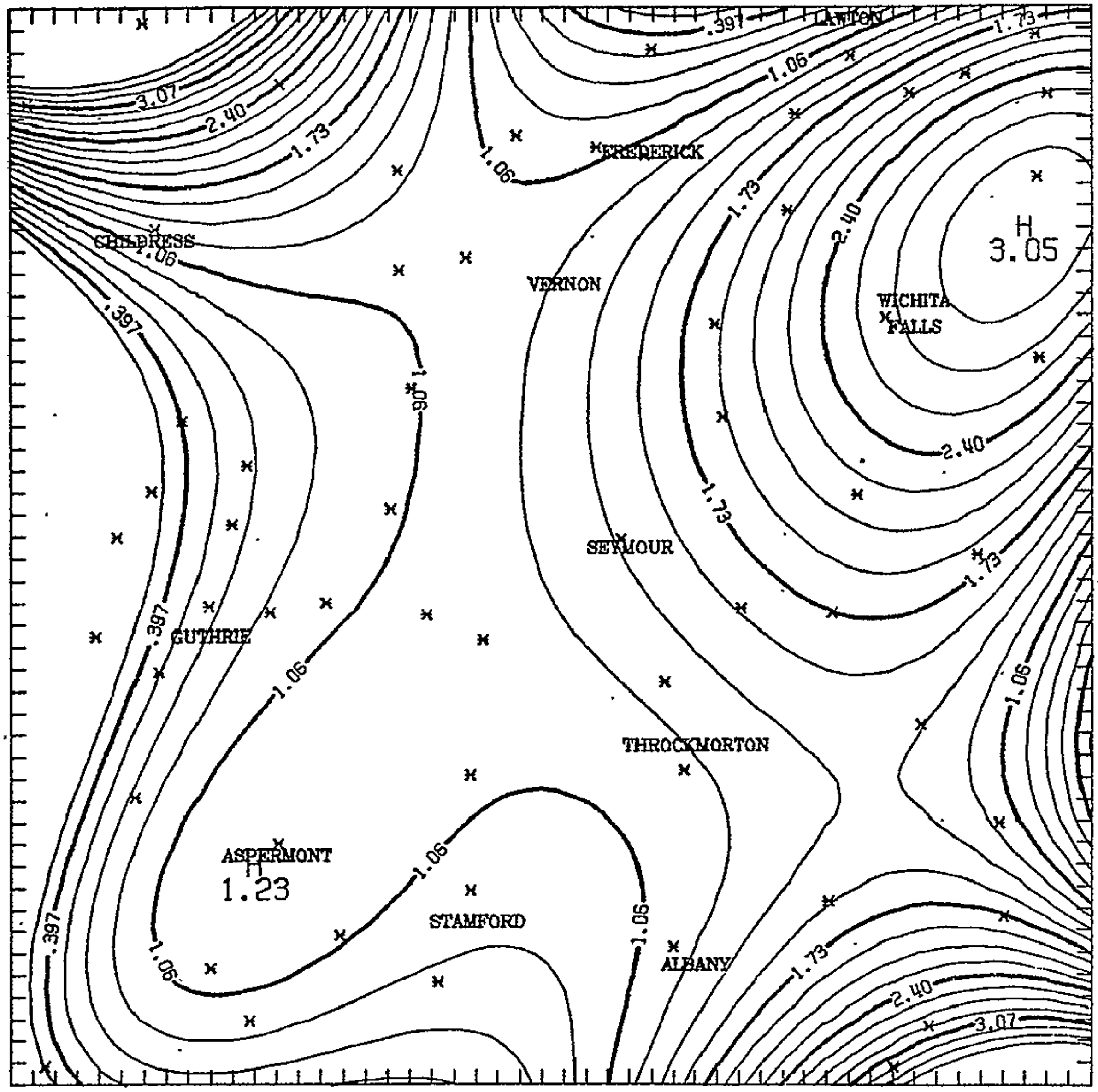


Precipitation in Inches

EXTENDED TEST SITE AREA

APRIL

MONTHLY RAINFALL



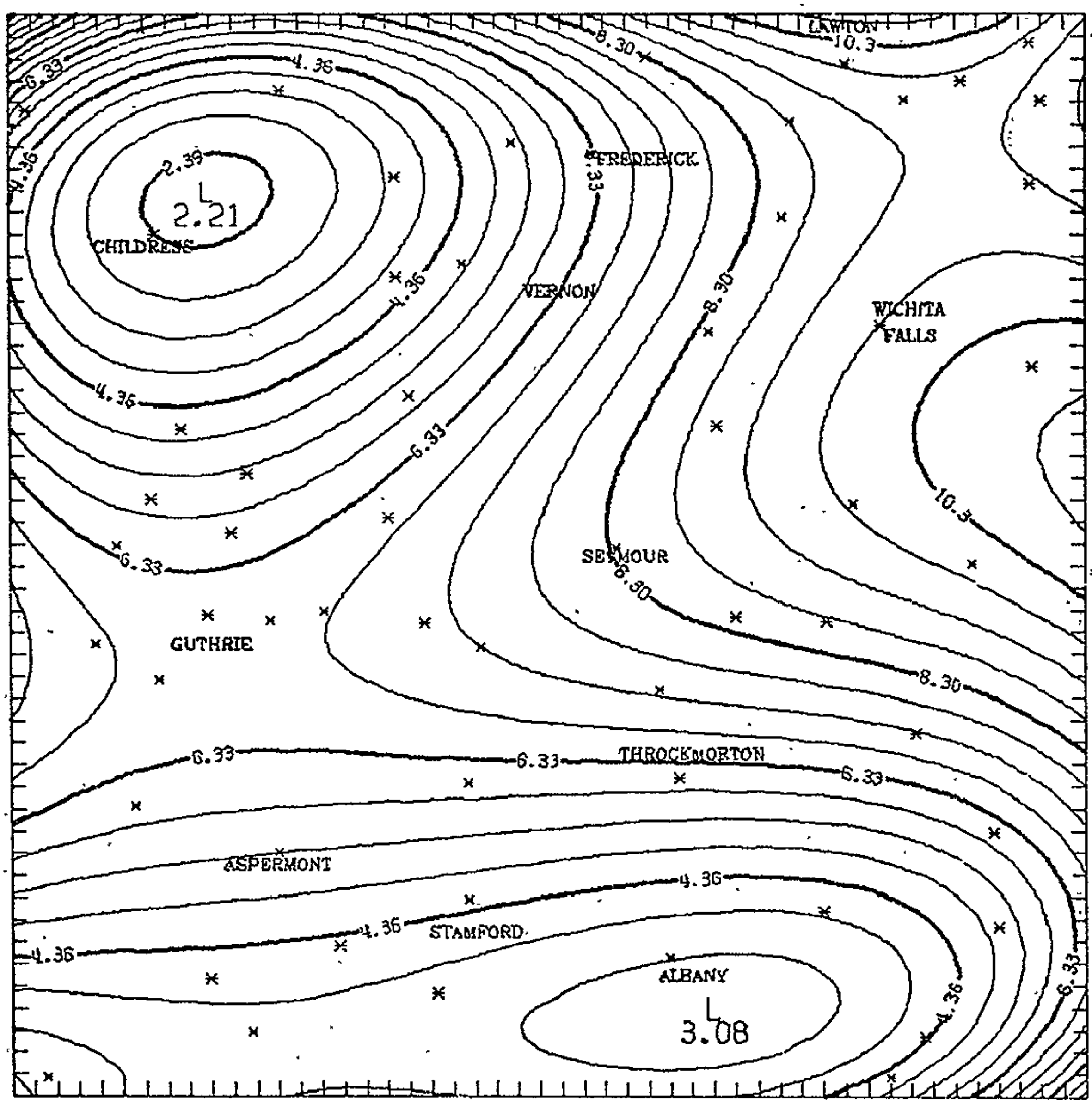
Precipitation in Inches

C-3

Extended Test Site Area

MAY

MONTHLY RAINFALL

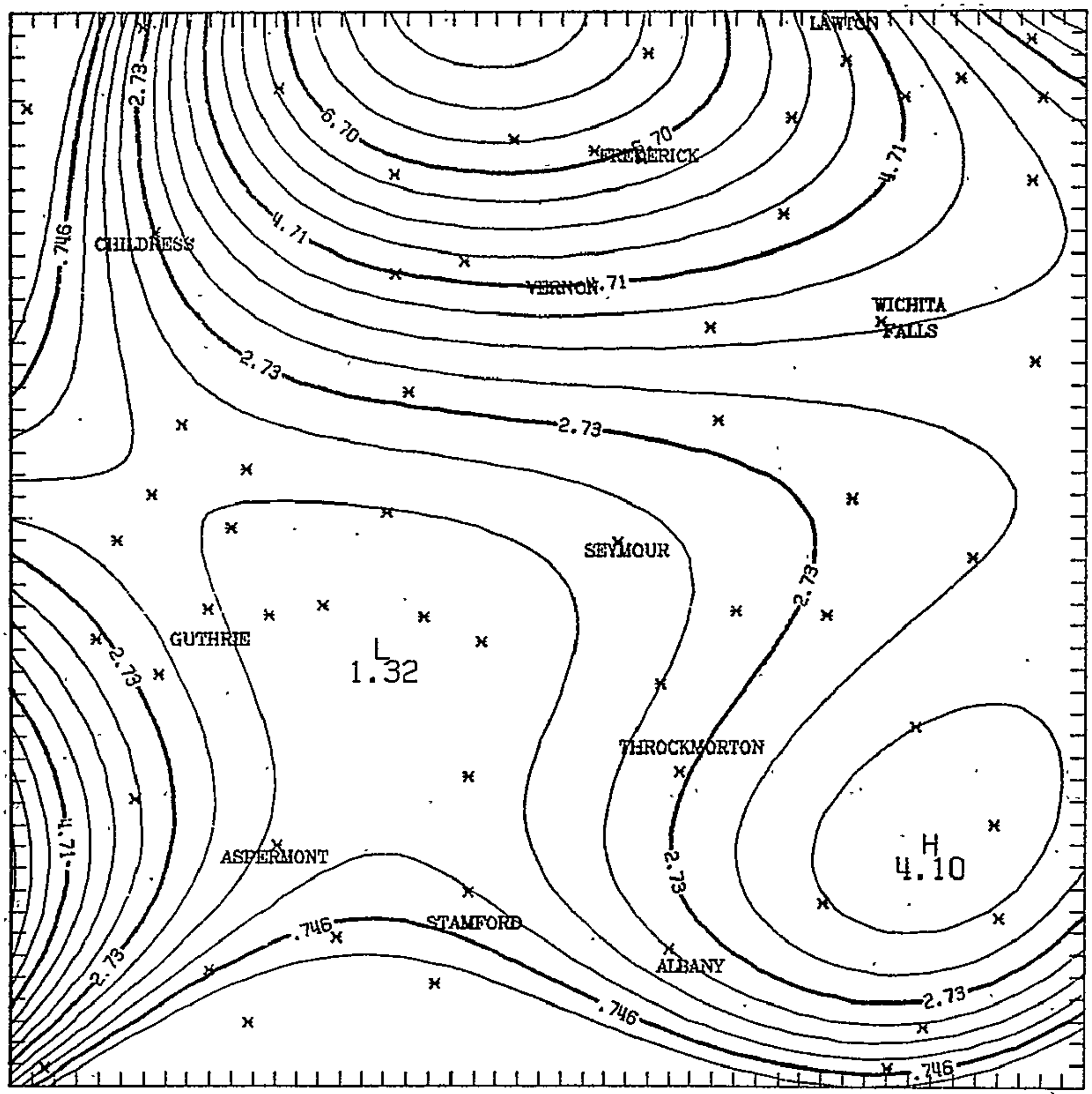


Precipitation in Inches

EXTENDED TEST SITE AREA

JUNE

MONTHLY RAINFALL

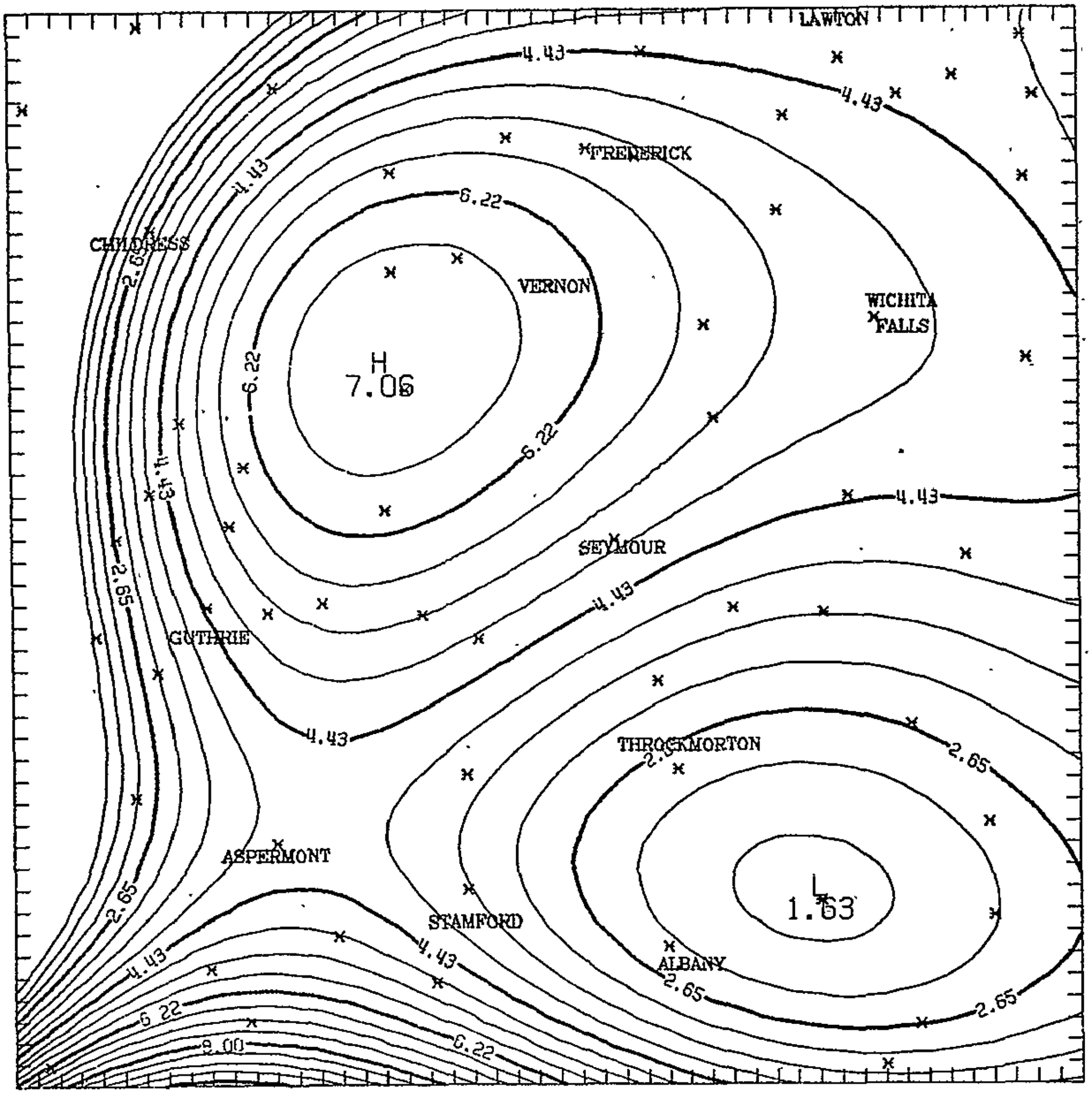


Precipitation in Inches

EXTENDED TEST SITE AREA

JULY

MONTHLY RAINFALL

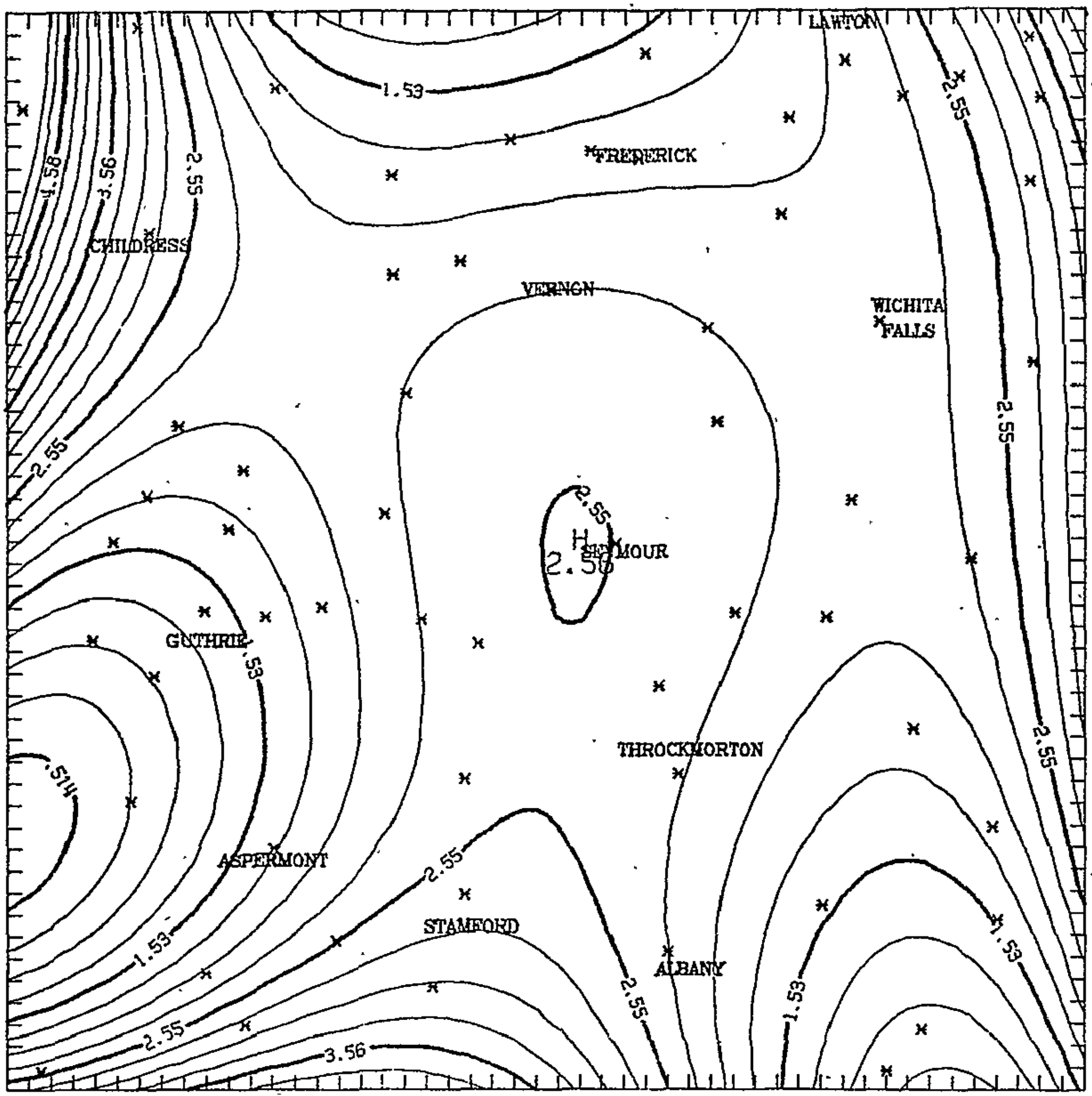


Precipitation in Inches

Extended Test Site Area

AUGUST

MONTHLY RAINFALL

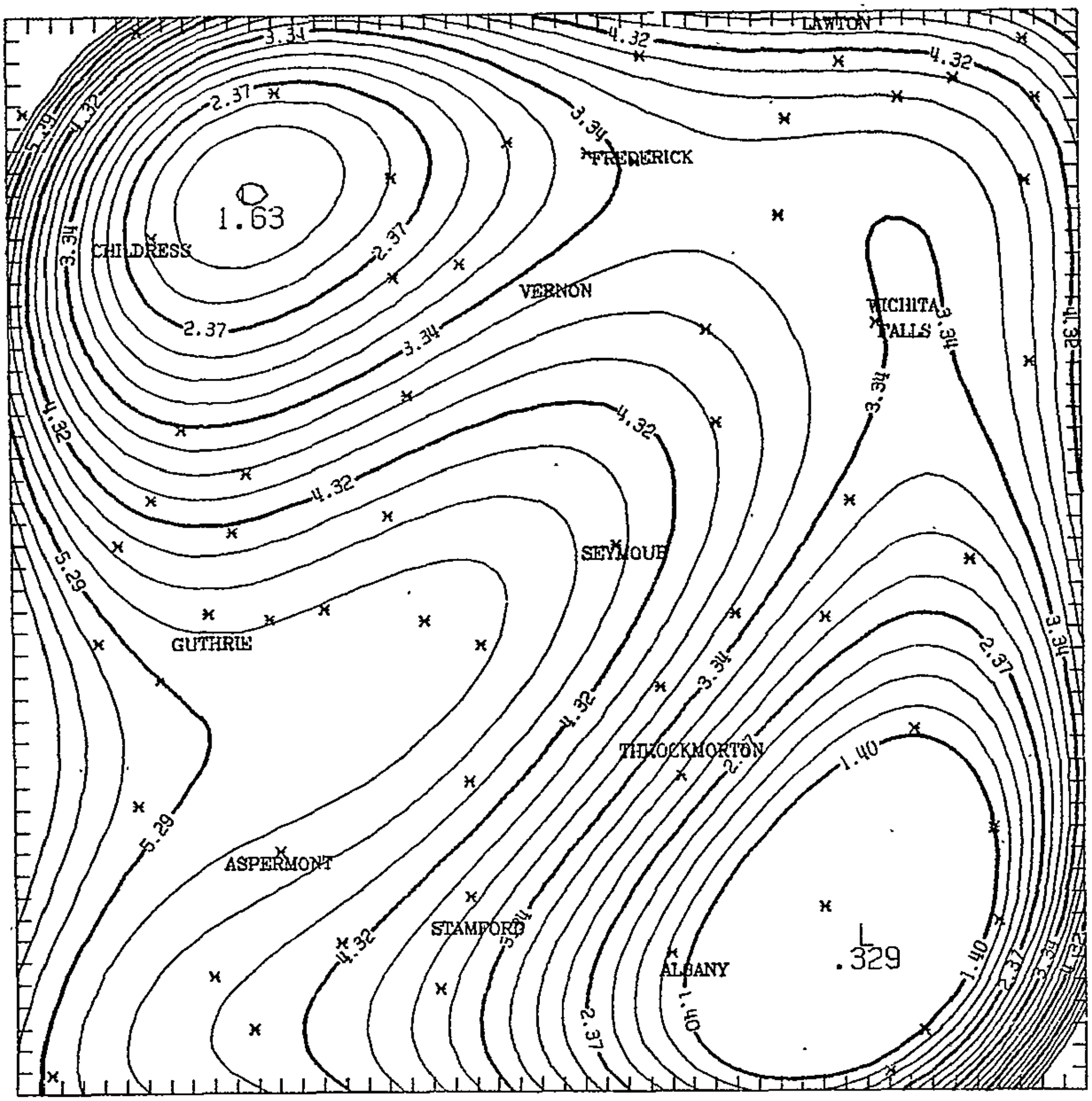


Precipitation in Inches

EXTENDED TEST SITE AREA

SEPTEMBER

MONTHLY RAINFALL

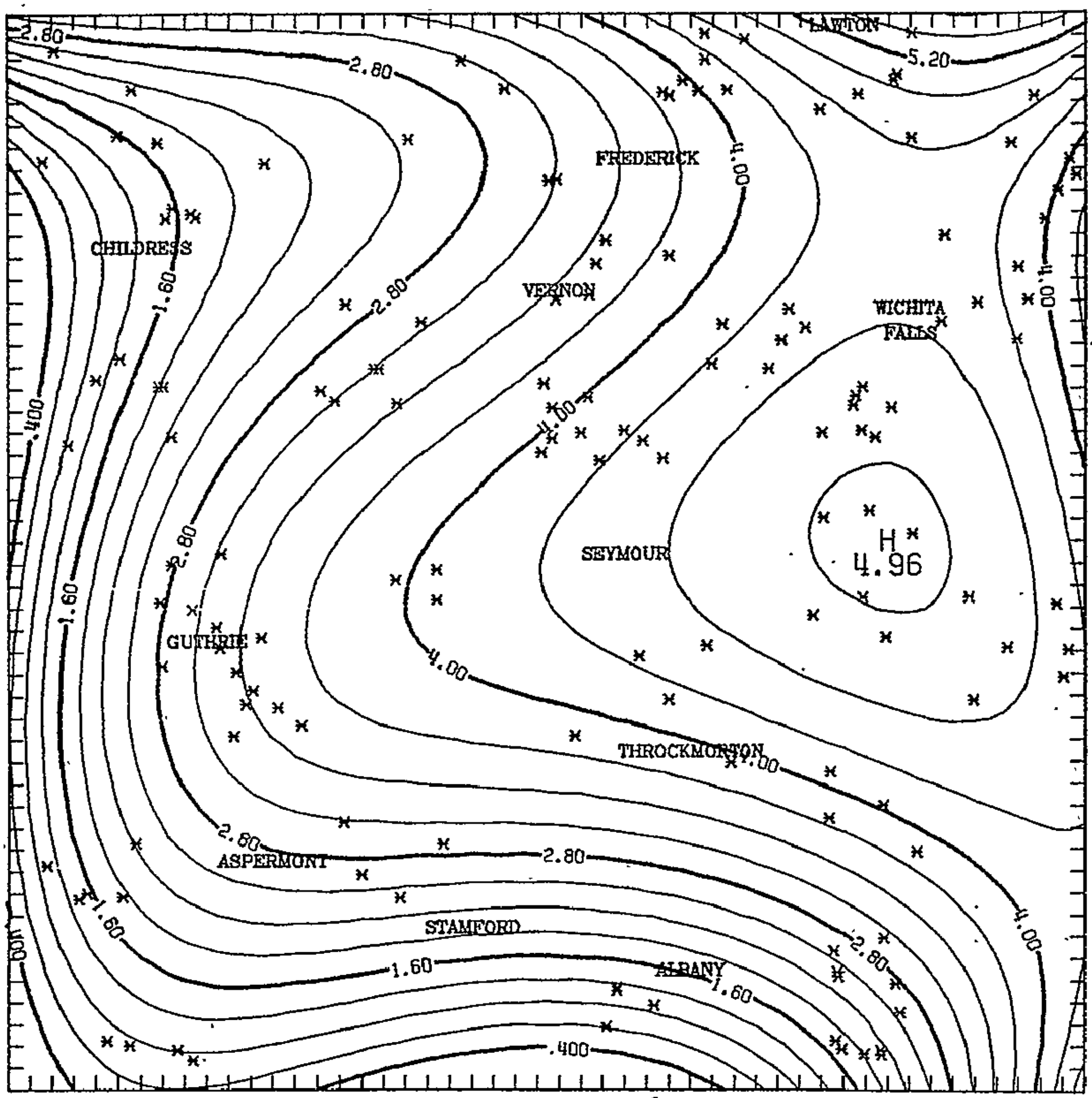


Precipitation in Inches

EXTENDED TEST SITE AREA

JUNE

18-DAY RAINFALL*



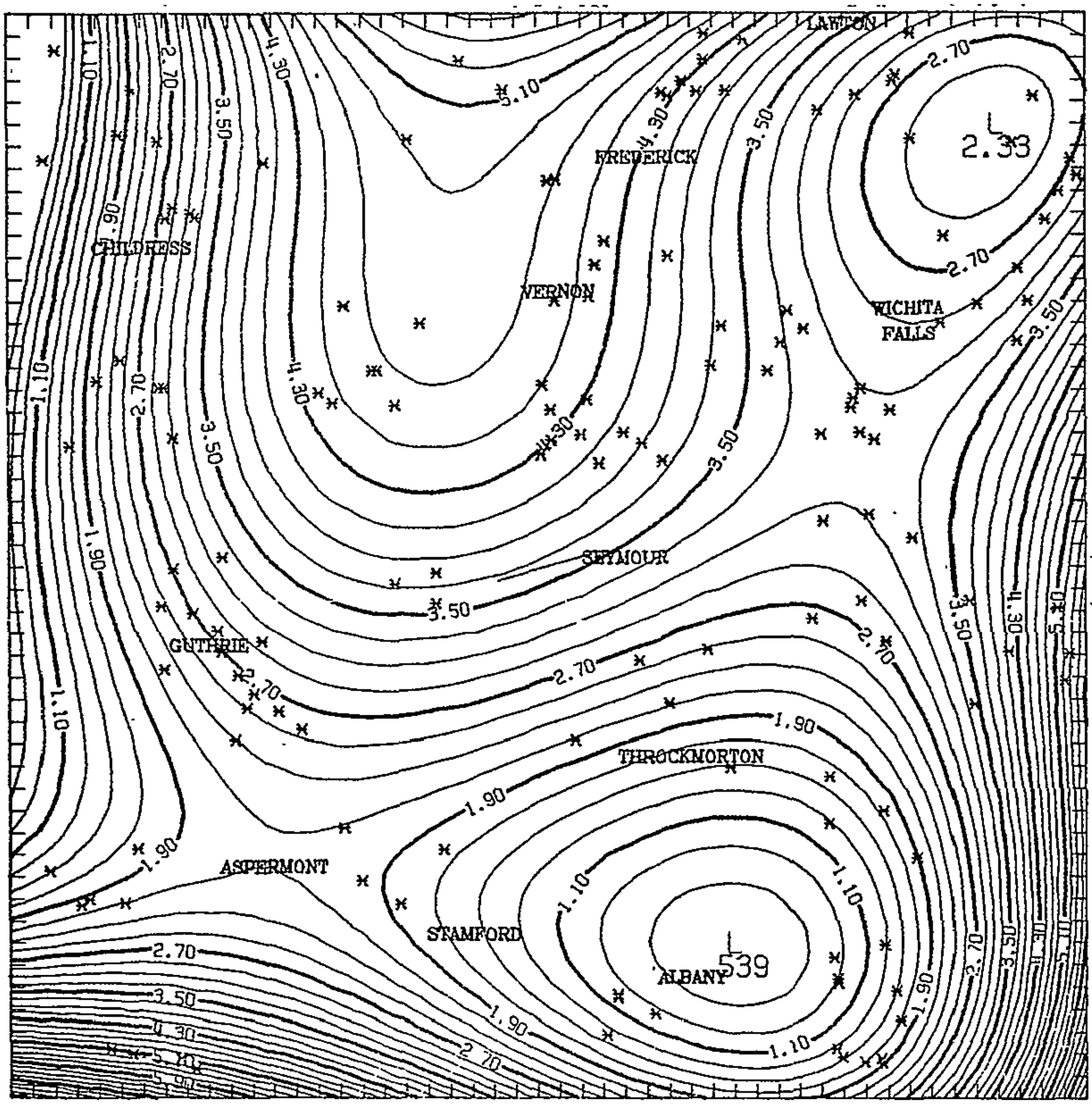
Precipitation in Inches

*Quantity of precipitation accumulated in the 18-day period prior to the satellite overpass for the June sampling period.

Extended Test Site Area

AUGUST

18-DAY RAINFALL*



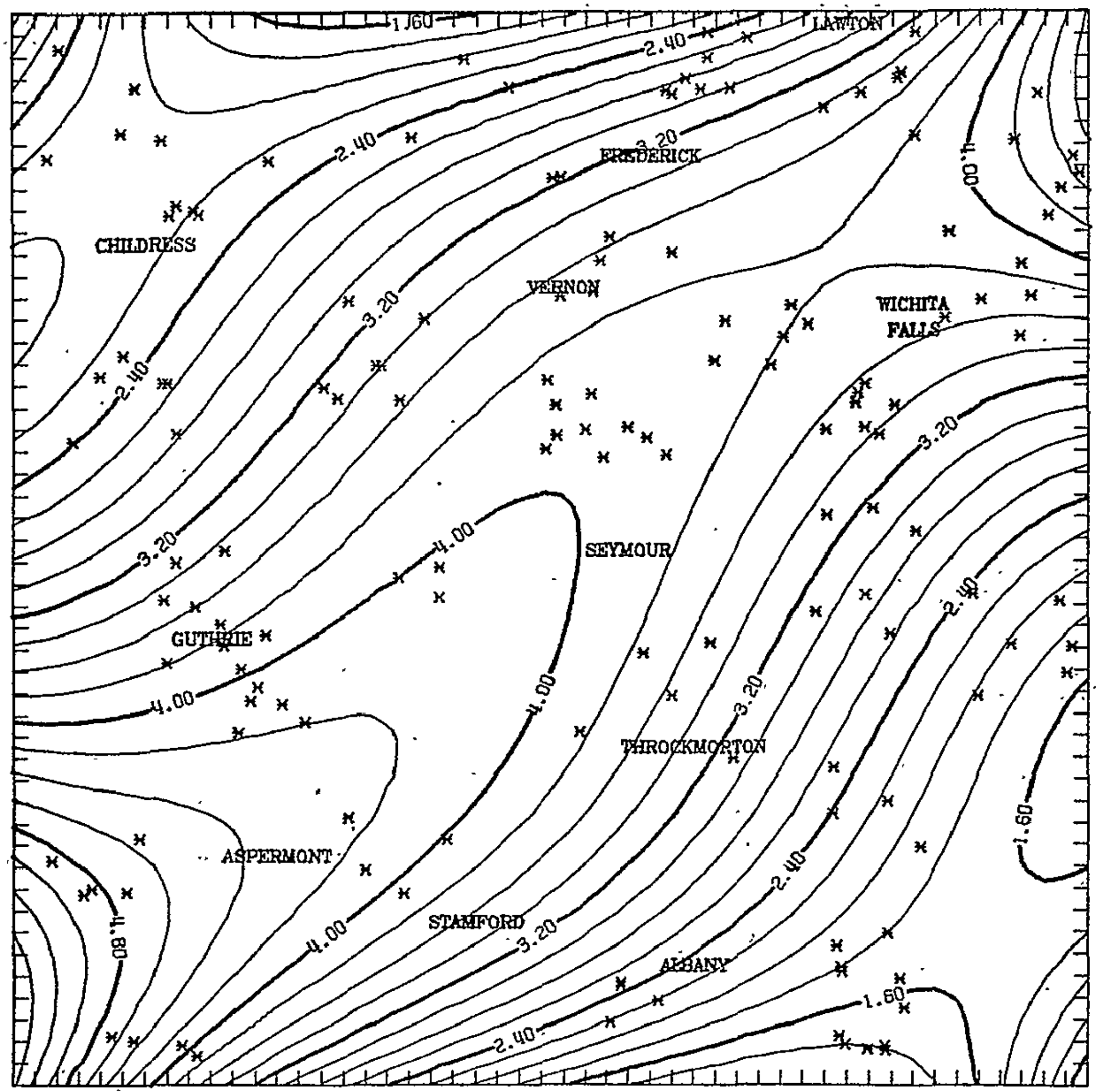
Precipitation in Inches

*Quantity of precipitation accumulated in the 18-day period prior to the satellite overpass for the August sampling period.

EXTENDED TEST SITE AREA

SEPTEMBER

18-DAY RAINFALL*



Precipitation in Inches

*Quantity of precipitation accumulated in the 18-day period prior to the satellite overpass for the September sampling period.

APPENDIX C

Tentative land classification for the ETSA

TENTATIVE LAND CLASSIFICATION OF GPC TEST SITE IN NORTH CENTRAL TEXAS

Symbolic and Technical Legend

10. Urban

20. Agricultural Land

30. Rangeland

  31. Grassland and herbaceous types

    31.1 North central prairie (Little bluestem/Sideoats grama)

    31.2 Mixed grass prairie (Sideoats/Texas wintergrass/Buffaloe grass)

    31.3 Shortgrass prairie (Buffaloe grass)

  32. Shrubland types

    32.1 Mesquite/Little bluestem/Sideoats grama

    32.2 Mesquite/Lotebush/Mixed grass

    32.3 Mesquite/Mixed shrub/Shortgrass

    32.4 Mesquite/Sandsagebrush/Sand dropseed

    32.5 Sand shinnery oak

    32.6 Shallowland, mixed shrub

  33. Savanna-like types

    33.1 Live oak/Mesquite

    33.2 Post oak/Mesquite

    33.3 Juniper breaks

40. Forest and Woodlands

    43. Mixed

        43.1 Oak-Juniper Woodland

        43.2 River bottomland (Phreatophyte and riparian vegetation)

50. Water

    51. Streams and waterways

    52. Lakes and ponds

    53. Reservoirs

60. Barrenlands

Descriptive Legend

1.0 Urban - includes the residential, business, transportation and industrial sectors of cities and towns.

2.0 Agricultural Land - includes field and row type cropland, pasture, orchards, vineyards, etc.

3.0 Rangeland - natural vegetation types other than forest and woodlands

3.1 Grassland and herbaceous types

3.11 Little bluestem/sideoates grama - includes the north central prairie. Found in the northwest portion of the study area.

3.12 Mixed grass prairie - this type occurs primarily as a result of brush control practices aimed at mesquite. Over time, this type will revert to a mesquite/lotebush/ mixed grass type if mesquite is not continually controlled. Common grasses include buffaloe grass, Texas winter-grass, sideoats grama and sand dropseed.

3.13 Shortgrass prairie - buffaloe grass is the prominent grass species. Other grasses include Texas winter grass/sideoats grama and Arizona cottontop.

3.2 Shrubland types

3.21 Mesquite/little bluestem/sideoats grama - essentially north central prairie type with mesquite invasion.

3.22 Mesquite/lotebush/mixed grass - the most extensive type occurring throughout the study area found on primarily four range sites; shallow and deep hardland, shallow upland and rolling dissected hills. Production on this type is effected by two primary factors; past brush control and grazing history and site potential. The M/L/buffaloe grass community with associated grasses such as Texas wintergrass and Arizona cottontop is the dominant vegetation community in this type. Other plant communities include M/L/western wheatgrass found in swales and along waterways, and the M/L/tobosagrass community found in heavy clay lowland sites.

3.23 Mesquite/mixed shrub/shortgrass - similar to M/L/mixed grass type except for increased shrub diversity and increased prominence of buffaloe grass. Additional shrubs include ephedra and wolfberry. This type is found primarily in the southwestern portion of the study area.

3.24 Mesquite/sand sagebrush/sand dropseed - found primarily in the northeastern portion of the study area on sandy soils and slightly rolling hills.

3.25 Sand shinnery oak - found in the northwestern and south central portion of study area. Confined to sandy soils. Grows in association with mesquite and sand sagebrush and sand dropseed.

3.26 Shallowland, mixed shrub - found in north central portion of the study area on shallow, highly erodable soils (Vernon complex). Low production site. Shrub diversity is high including shad scale, four wing salt brush, mesquite, juniper, ephedra, indigobush, wolfberry, etc. There are several distinct communities in this type, but they are small and largely controlled by microrelief and soil conditions.

3.3 Savanna-like types

3.31 Live oak/mesquite - found in the south central to southeastern portion of the study area in valleys and gentle sloping uplands. The relative prominence of live oak diminishes in respect to mesquite as one moves from the southeast to the southwest. In several areas, mesquite has been tree grubbed leaving a live oak grassland type.

3.32 Post oak/mesquite - found along the east central portion of the study area. Cover value ranges from light (<5%) to dense stands (>50%). In association with mesquite in the dense stands, and with elm, chittumwood, greenbriar and blackjack oak in denser stands.

3.33 Juniper breaks - the second most extensive vegetation type in the study area. Found on rough dissected slopes along river drainage and on rough broken land. Juniper is generally confined to sloped off ridges and drainages. It is often found in patches on escarpments or on steep slopes with skunk brush, or in small flats and gentle slopes with mesquite and lotebush. Grasses commonly in association with Juniper include silver bluestem, slim tridents and three awn.

4.0 Forest and Woodlands

4.3 Mixed - mixed evergreen and deciduous tree species.

4.31 Oak-Juniper Woodland - found in southeastern portion of study area around Possum Kingdom Reservoir. Occurs on the slopes and ridges of hilly land. There's a high diversity of oak and other woody species. In general, oak tends to dominate north facing slopes while Juniper dominates south exposed slopes.

4.32 River bottomland - includes phreatophyte and riparian vegetation along streams and waterways. Distinct communities are apparent and include such types as the Elm/Hackberry/ Cottonwood community and salt cedar communities.

5.0 Water

5.1 Stream and waterways

5.2 Lakes and ponds

5.3 Reservoirs

6.0 Barrenlands - no types were delineated as such in the study area. This type includes rocklands, badlands, sand dunes and beaches, etc.

APPENDIX D

ETSA primary site ground data summary and Landsat measurements

Table D-1. Mean values for ground measured parameters at the ETSA sampling locations by site for the three sample periods in 1975 and corresponding Landsat MSS data.

		GROUND MEASUREMENTS						LANDSAT MEASUREMENTS				
								RADIANCE[c]				
Location and Site	Date	Total Biomass[a] (kg/ha)	Green Biomass[b] (kg/ha)	Green Forb Component of Green Biomass (%)	Moisture Content of the Vegetation (%)	Surface Soil Moisture (%)	Soil Moisture at 30 cm. Depth (%)	Band 4	Band 5	Band 6	Band 7	TVI6
A1	June	2310	1306	26	46	5.9	13.4	d				
	Aug.	2278	927	33	30	3.9	10.4	5.87	5.79	7.08	5.53	.775
A2	June	2123	1094	20	42	4.4	13.0					
	Aug.	1596	723	33	29	5.1	11.3	5.90	5.80	6.94	5.02	.768
B1	June	3602	1232	13	37	9.6	16.0	6.69	6.13	8.92	7.09	.828
	Aug.	3449	1055	42	25	7.6	16.7	5.95	5.78	7.44	5.87	.791
	Sept.	5112	2396	83	35	13.0	15.2	7.85	5.20	7.13	6.21	.811
B2	June	2756	1102	22	44	8.5	13.3	6.39	5.82	8.68	6.94	.835
	Aug.	2745	776	50	25	7.4	12.2	5.92	5.73	7.56	5.86	.798
C1	June	5795	2141	15	38	14.9	15.9	5.45	4.62	8.12	6.81	.880
	Aug.	5733	2078	19	35	23.4	17.2	5.49	4.56	8.15	6.78	.885
	Sept.	6527	2224	68	35	25.2	24.2	7.52	4.53	7.04	6.11	.847
C2	June	2778	1354	29	44	7.0	12.8	5.45	4.57	8.45	7.12	.893
	Aug.	3004	1627	68	37	17.9	14.8	5.46	5.08	7.09	5.63	.816
	Sept.	3393	1640	68	35	18.8	19.0	7.44	4.79	6.14	4.97	.790
D	June	3512	1608	74	46	10.1	16.5					
	Aug.	2688	1266	91	37	22.4	16.2	4.81	4.11	7.21	5.78	.880

Table D-1. Mean values for ground measured parameters at the ETSA sampling locations by site for the three sample periods in 1975 and corresponding Landsat MSS data. (continued)

		GROUND MEASUREMENTS						LANDSAT MEASUREMENTS				
								RADIANCE[c]				
Location and Site	Date	Total Biomass[a] (kg/ha)	Green Biomass[b] (kg/ha)	Green Forb Component of Green Biomass (%)	Moisture Content of the Vegetation (%)	Surface Soil Moisture (%)	Soil Moisture at 30 cm. Depth (%)	Band 4	Band 5	Band 6	Band 7	TVI6
E	June	2513	998	49	32	3.6	10.1	6.18	6.81	7.92	5.94	.759
	Aug.	2436	916	44	36	20.7	19.8	5.38	4.92	8.65	7.06	.880
	Sept.	3115	2176	86	46	15.0	19.7	7.19	4.45	8.07	7.42	.888
F1	June	2506	1149	52	31	1.8	6.1	5.84	5.90	7.43	5.45	.784
	Aug.	2838	1151	71	37	4.9	5.6	5.30	5.42	6.57	4.92	.772
	Sept.	2442	1531	69	36	6.2	6.4	7.22	4.96	6.40	5.45	.791
F2	June	3985	1339	27	26	1.5	5.5	5.76	5.89	7.57	5.67	.790
G1	June	2211	790	68	28	2.2	2.8					
G2	June	2426	609	34	27	0.3	2.3					
	Aug.	2380	1376	28	48	4.9	6.4	5.54	5.24	8.05	6.63	.843
H	June	4313	2258	49	47	8.0	10.0					
	Aug.	5609	1966	35	31	9.6	11.8	4.97	4.45	6.92	5.56	.847
	Sept.	4990	2222	72	39	12.9	23.6	7.14	4.37	6.85	5.83	.849
I	June	5339	2271	71	45	6.8	14.4					
	Aug.	3519	1785	77	44	11.2	16.4	4.97	4.49	7.26	6.03	.848
J1	June	2660	1222	24	46	17.9	16.6	5.51	5.08	7.79	6.35	.843

Table D-1. Mean values for ground measured parameters at the ETSA sampling locations by site for the three sample periods in 1975 and corresponding Landsat MSS data. (continued)

Location and Site	Date	GROUND MEASUREMENTS: Total Biomass[a] (kg/ha)	Green Biomass[b] (kg/ha)	Green Forb Component of Green Biomass (%)	Moisture Content of the Vegetation (%)	Surface Soil Moisture (%)	Soil Moisture at 30 cm. Depth (%)	LANDSAT MEASUREMENTS: RADIANCE[c] Band 4	Band 5	Band 6	Band 7	TVI6
	Aug.	3454	1636	20	40	22.7	20.7	5.15	4.25	7.76	6.46	.890
	Sept.	4302	2130	48	41	17.0	18.3	7.66	4.65	7.27	6.24	.848
J2	June	3048	2033	68	56	21.4	17.5	5.44	4.84	8.18	6.79	.870
	Aug.	3648	2191	40	53	13.7	18.4	4.88	3.99	7.79	6.51	.907
	Sept.	5372	4063	91	48	20.5	17.6	7.37	4.26	7.64	6.50	.885
K	June	3183	1464	70	43	13.9	13.9	5.17	4.61	8.12	6.91	.881
	Aug.	3176	1669	66	40	16.0	15.2	5.20	4.41	7.49	6.13	.871
L	June	3737	2066	72	46	19.9	17.3	5.05	4.55	8.00	7.04	.880
	Aug.	3532	1511	78	39	5.6	12.1	5.18	4.59	6.72	5.25	.830
M	June	4983	2201	46	60	26.0	20.5	5.20	4.86	8.37	7.32	.875
	Aug.	6409	2725	55	44	17.3	22.3	5.37	4.45	8.83	7.49	.911
	Sept.	5166	2728	59	41	12.4	18.6	7.53	4.76	6.49	5.46	.809
N	June	2791	1186	15	40	8.0	11.2	6.25	6.42	9.53	7.73	.834
	Aug.	1829	1154	6	35	11.2	14.9	6.47	6.35	9.50	7.55	.836
	Sept.	2742	1123	2	44	12.6	19.9	8.25	5.57	8.29	7.16	.835
O	June	3517	1862	28	40	25.3	21.7	5.34	4.63	9.69	8.26	.924

Table D-1. Mean values for ground measured parameters at the ETSA sampling locations by site for the three sample periods in 1975 and corresponding Landsat MSS data. (continued)

Location and Site	Date	GROUND MEASUREMENTS: Total Biomass[a] (kg/ha)	Green Biomass[b] (kg/ha)	Green Forb Component of Green Biomass (%)	Moisture Content of the Vegetation (%)	Surface Soil Moisture (%)	Soil Moisture at 30 cm. Depth (%)	LANDSAT MEASUREMENTS: RADIANCE[c] Band 4	Band 5	Band 6	Band 7	TVI6
	Aug.	3688	1917	35	54	16.7	14.0	5.45	4.72	8.44	7.17	.885
	Sept.	3674	1693	48	42	14.0	19.7	7.62	5.14	7.94	6.82	.845
P	June	1772	1135	48	56	24.3	21.6	5.56	5.36	8.85	7.13	.869
	Aug.	2636	1684	35	55	16.9	20.4	5.57	5.17	8.70	7.09	.864
Q	June	2897	1615	8	48	24.3	24.9	5.59	5.28	8.56	6.84	.858
	Aug.	3679	1966	11	45	19.7	23.9	5.58	4.91	8.16	6.63	.866
	Sept.	3095	1262	8	35	22.5	21.5					.820

[a]Total aboveground herbaceous biomass (green + brown components) expressed on a dry-weight basis.

[b]Green component of aboveground herbaceous biomass expressed on a dry-weight basis.

[c]Corrected for sun-angle; radiance values in microwatts/sqcm-STR-micrometer.

[d]Missing values indicate clouds or cloud shadow on site.

APPENDIX E

Preliminary TVI6 isoline map of ETSA
from 17 primary site data

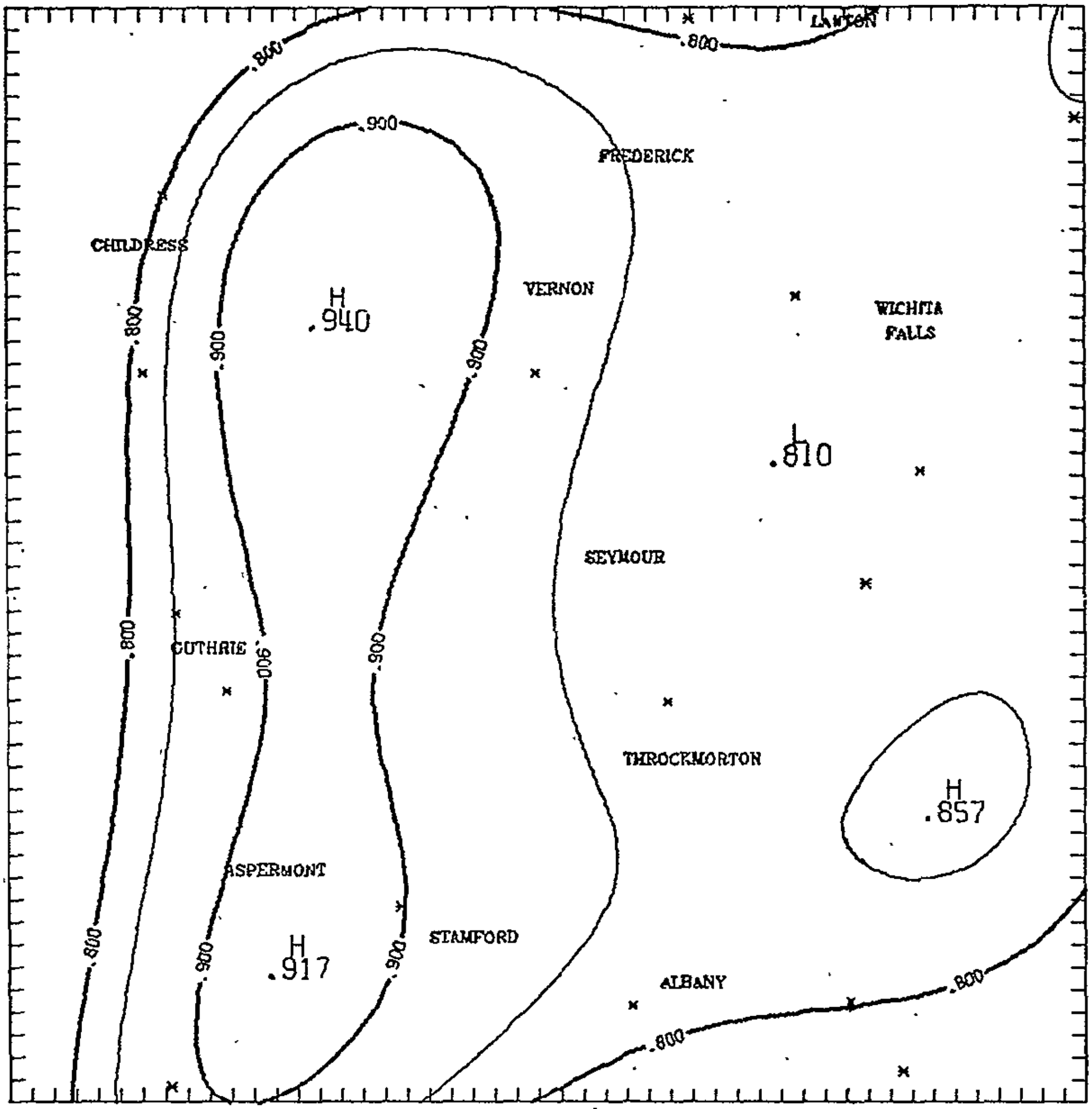


Figure E-1. Isolines of TVI6 for the ETSA from Landsat MSS data obtained on September 22 and 23, 1975. This map was generated using data for the 17 primary sites.

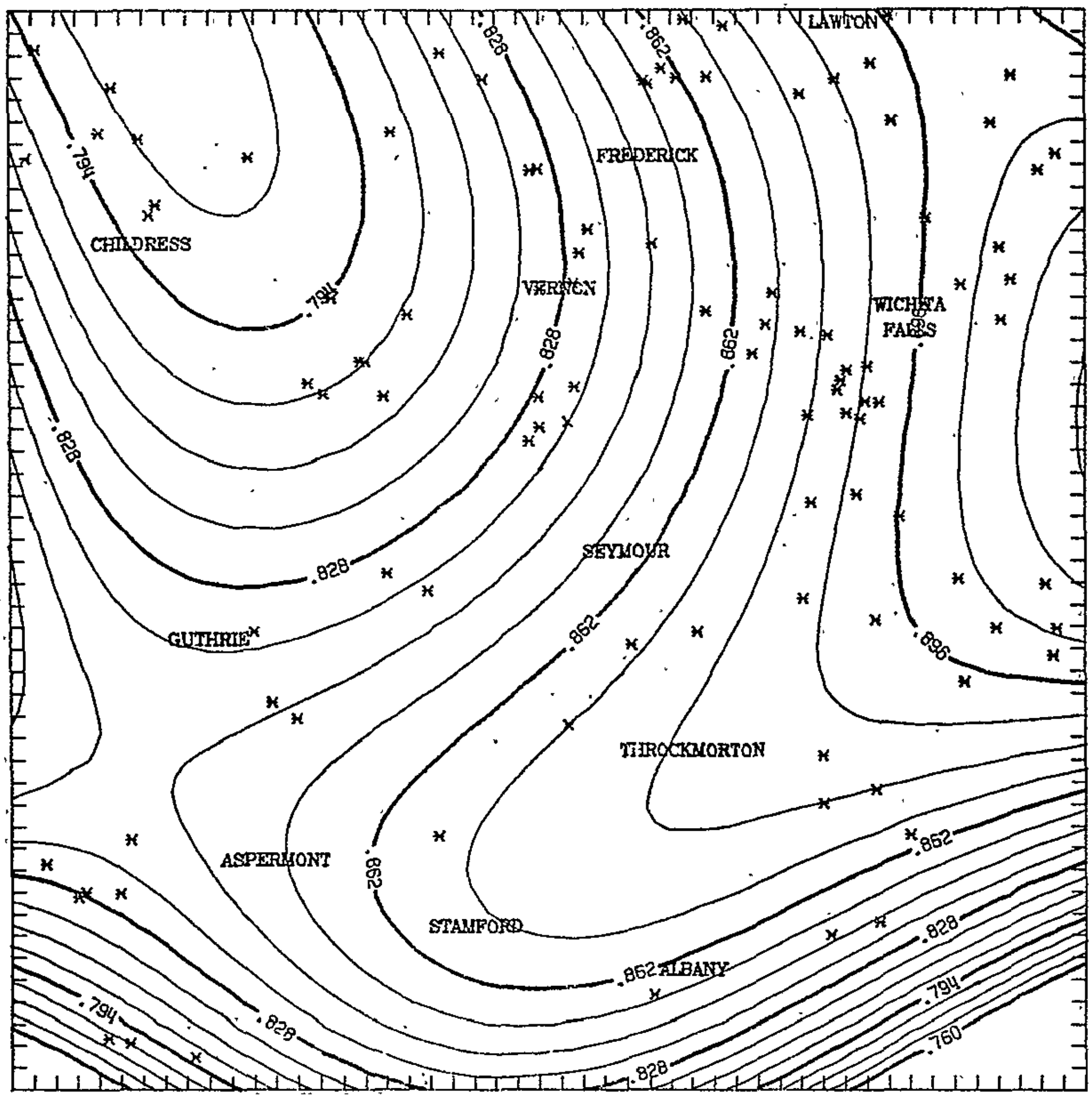
APPENDIX E

Isoline maps of TVI6 and green biomass
from secondary site data

Extended Test Site Area

JUNE

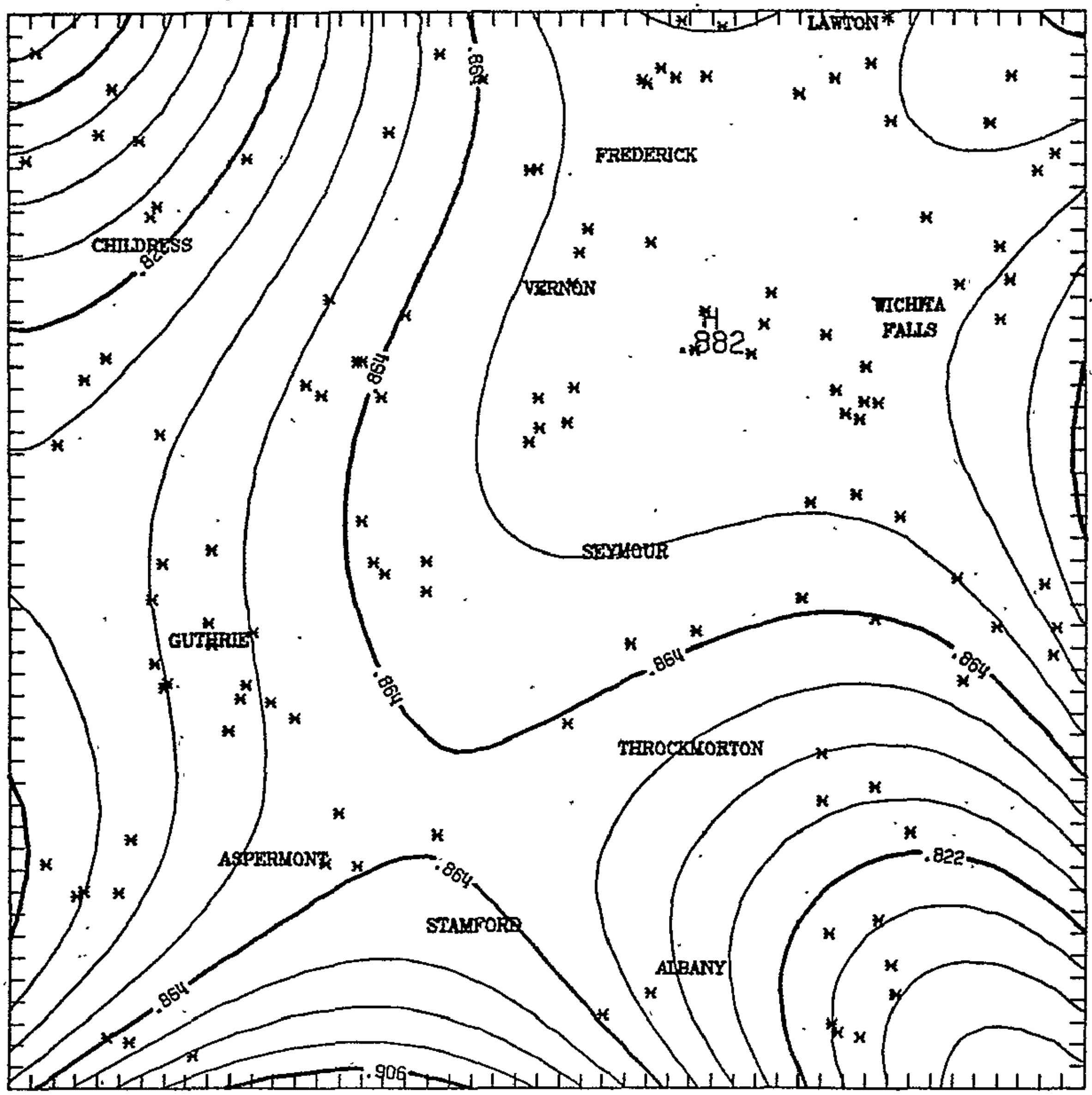
TRANSFORMED VEGETATION INDEX (TVI6)



EXTENDED TEST SITE AREA

AUGUST

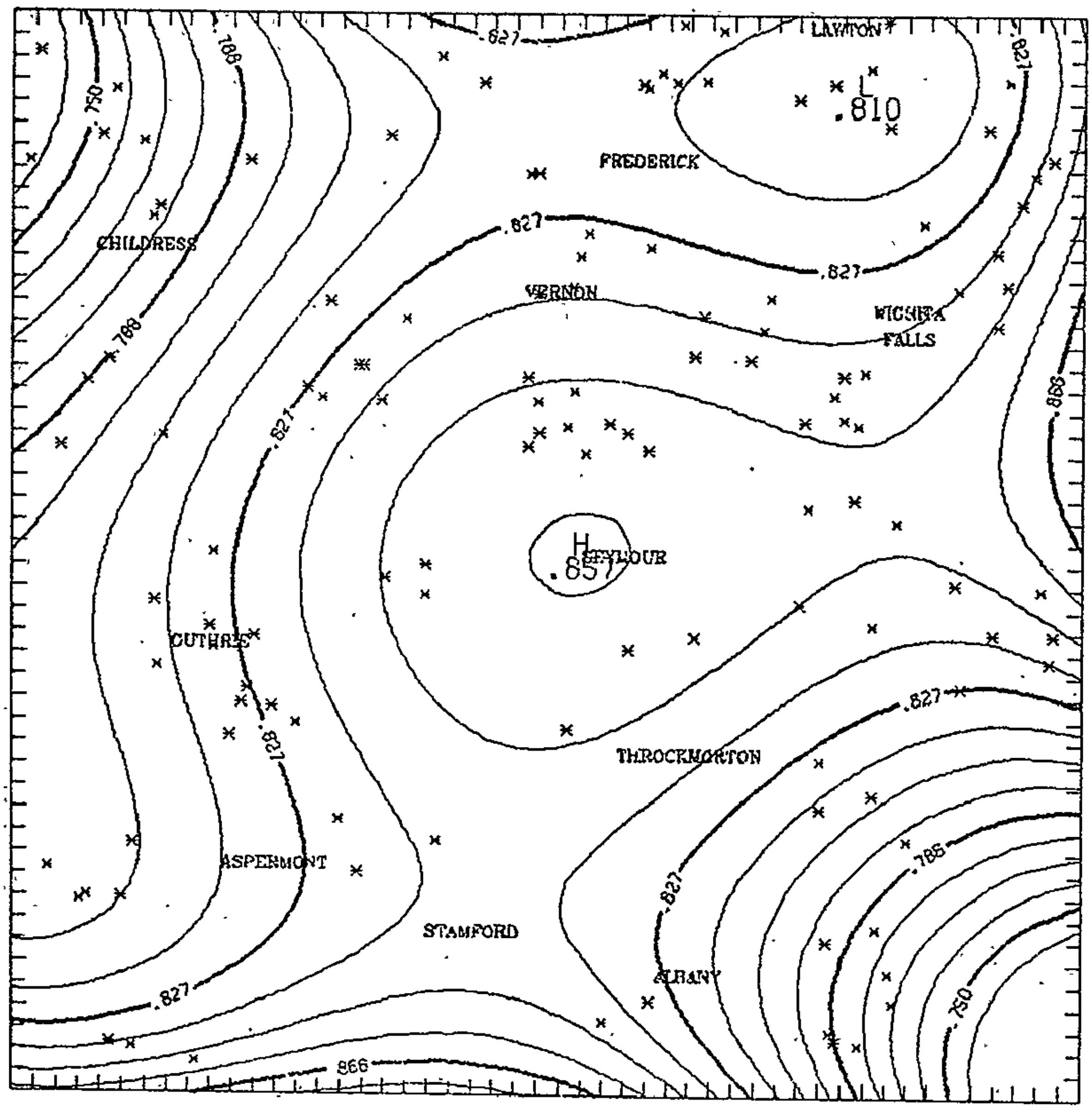
TRANSFORMED VEGETATION INDEX (TVI6)



EXTENDED TEST SITE AREA

SEPTEMBER

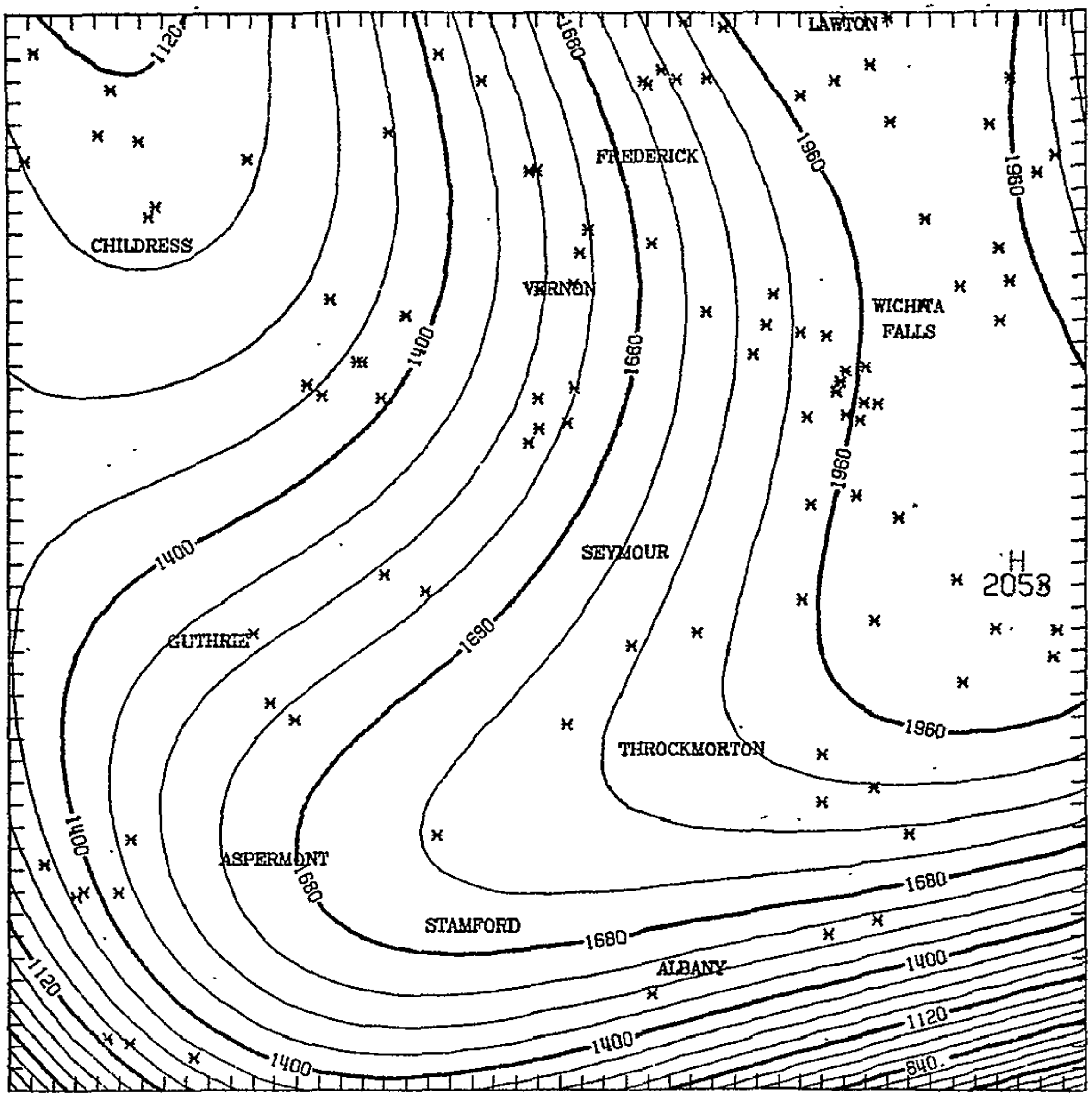
TRANSFORMED VEGETATION INDEX (TVI6)



EXTENDED TEST SITE AREA

JUNE

GREEN BIOMASS - THROCKMORTON MODEL

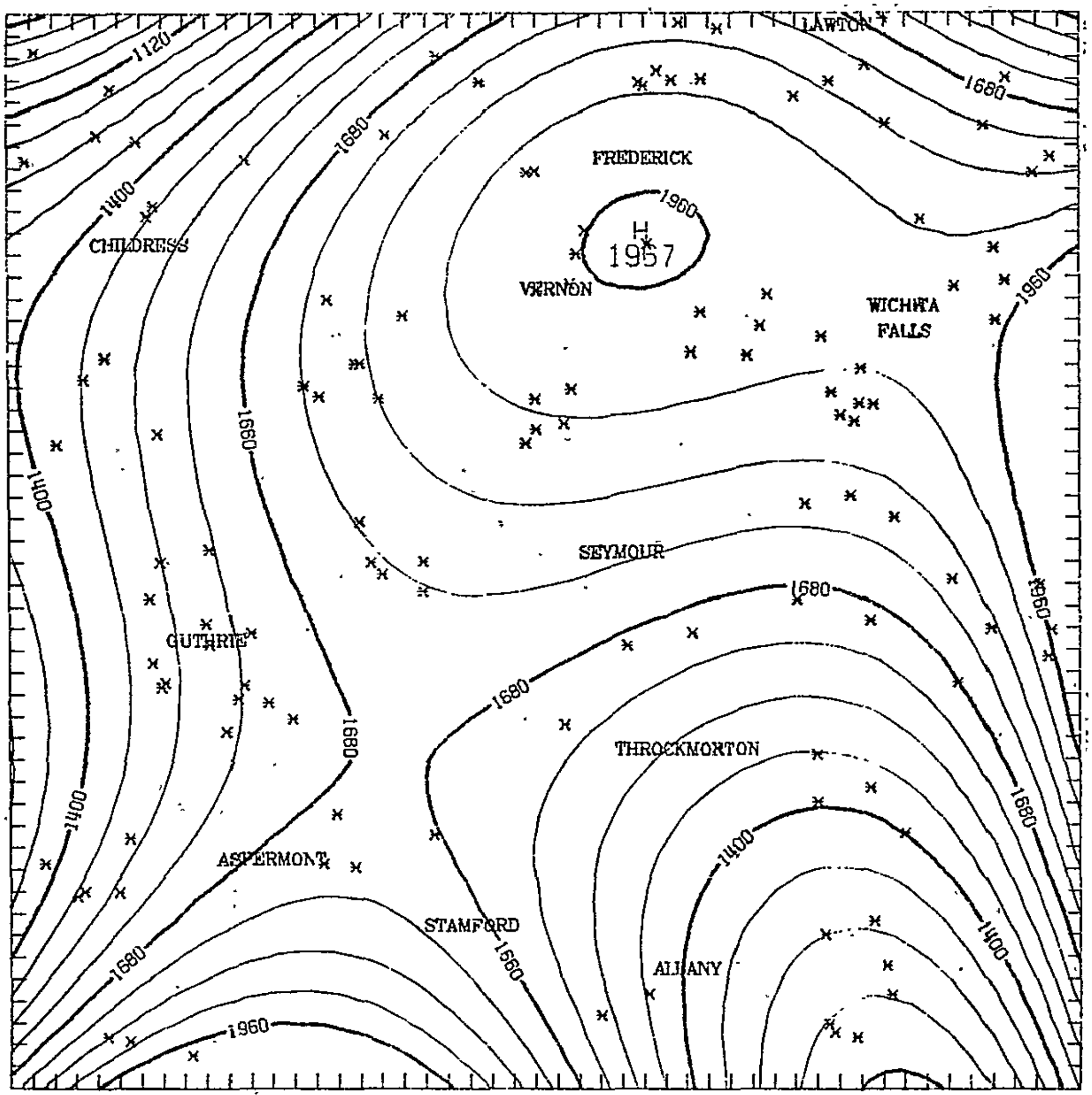


Green Biomass in kg/ha

EXTENDED TEST SITE AREA

AUGUST

GREEN BIOMASS - THROCKMORTON MODEL

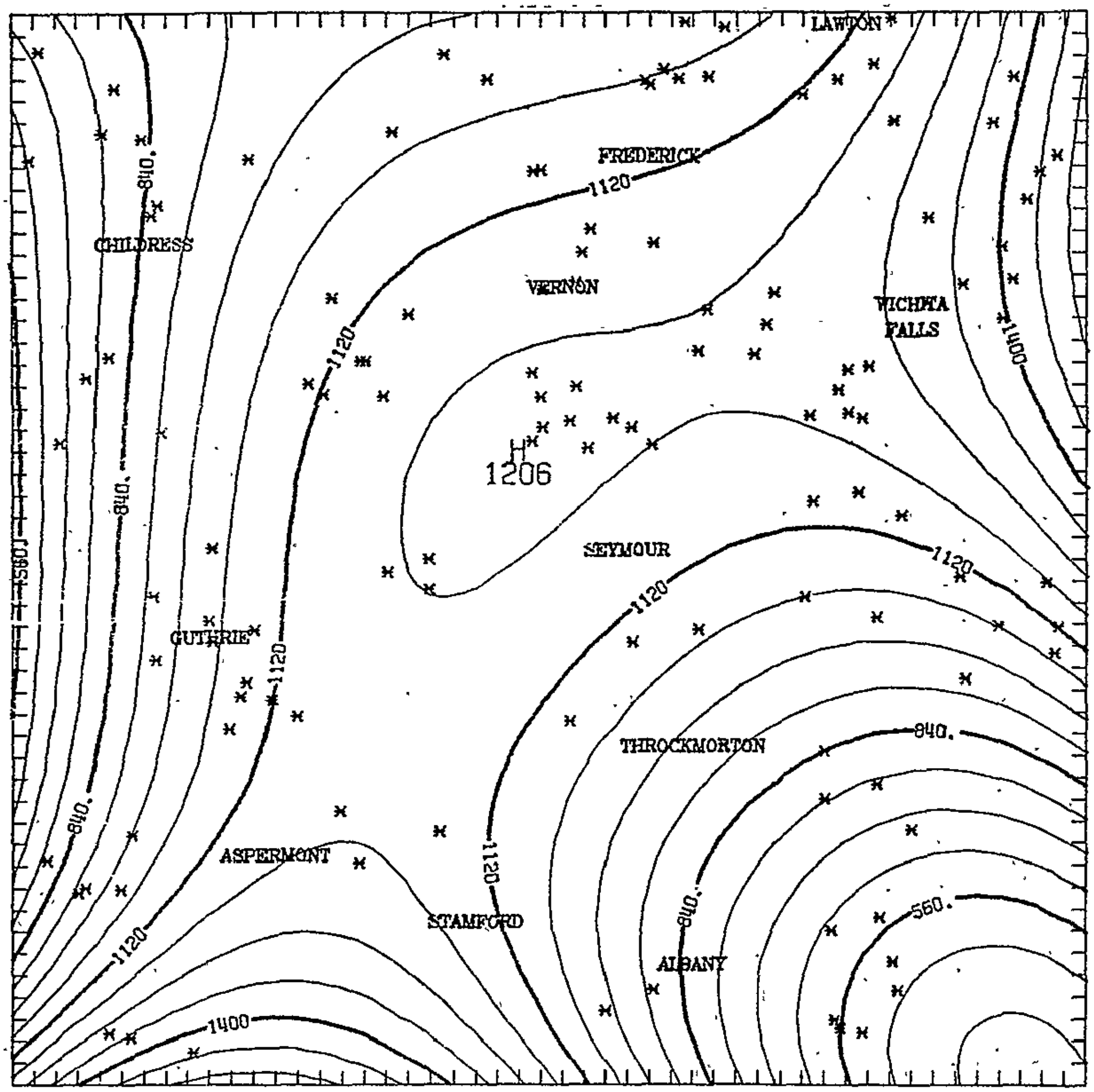


Green Biomass in kg/ha

EXTENDED TEST SITE AREA

SEPTEMBER

GREEN BIOMASS - THROCKMORTON MODEL



Green Biomass in kg/ha

APPENDIX G

Landsat measurements and calculated green biomass for ETSA secondary sites

Table G-1. Landsat MSS data and green biomass (Throckmorton model estimates) for ETSA secondary sites for the June, August and September sampling periods. MSS band radiance values are corrected for sun angle and are given in microwatts/sq cm - steradian - micrometer units.

Site	Radiance Band 4	Band 5	Band 6	Band 7	TVI6	Calculated Green Biomass (kg/ha)
JUNE						
B3	5.93	5.33	8.49	6.80	0.854	1305
B5	6.18	5.80	8.18	6.33	0.818	1278
BB1	5.21	4.81	7.71	6.34	0.855	1701
BB2	5.37	4.86	7.46	5.98	0.844	1571
BB3	5.43	4.83	7.73	6.28	0.854	1661
BB4	5.51	4.81	8.76	7.22	0.889	1929
C3	5.32	4.62	7.76	6.28	0.868	1677
D4	5.79	5.26	8.08	6.40	0.843	1575
E2	6.39	6.53	9.08	7.21	0.815	1077
E3	6.44	7.36	8.59	6.65	0.760	813
E4	6.26	6.88	8.36	6.53	0.773	876
EE1	6.14	6.09	9.52	7.79	0.849	1287
EE2	5.95	5.73	9.31	7.72	0.859	1317
EE3	5.63	5.25	8.26	6.80	0.850	1292
EE4	5.76	5.49	8.49	6.86	0.845	1268
EE5	6.15	6.40	8.55	6.57	0.802	1061
F3	5.77	5.76	7.80	6.04	0.806	1375
F4	6.33	6.46	8.94	7.11	0.813	1409
F5	6.04	5.99	8.19	6.37	0.810	1475
FF1	6.17	6.39	8.01	6.05	0.782	794
FF2	6.39	7.01	8.53	6.39	0.773	751
FF3	6.28	6.32	7.63	5.81	0.771	738
FF4	7.14	7.75	9.55	7.25	0.777	835
FF5	6.20	6.34	8.62	6.58	0.807	936

Table G-1 (cont.)

Site	Band 4	Band 5	Band 6	Band 7	TVI6	Calculated Green Biomass (kg/ha)
GG1	6.10	6.29	7.69	5.84	0.775	1295
GG2	5.91	5.69	7.18	5.38	0.785	1343
GG3	5.72	5.43	7.37	5.73	0.807	1352
GG4	5.91	5.59	7.55	5.77	0.806	1347
GG5	6.24	6.38	8.00	6.03	0.783	1316
GG6	6.44	6.26	8.33	6.29	0.801	1401
GG7	5.80	5.98	8.24	6.37	0.811	1468
H9	6.07	5.28	8.65	6.81	0.861	1926
H10	5.99	5.42	7.88	6.21	0.828	1741
H11	5.78	5.10	7.29	5.71	0.823	1717
HH2	5.79	5.11	7.65	5.81	0.836	1515
HH3	6.19	6.74	9.63	7.18	0.822	1573
JJ1	6.58	6.35	10.53	8.51	0.864	1704
JJ2	6.25	5.63	9.97	8.13	0.882	1791
JJ3	6.13	6.14	8.72	6.83	0.821	1557
JJ4	5.82	5.45	8.39	6.59	0.844	1668
JJ5	5.97	6.05	8.36	6.41	0.813	1579
JJ6	5.59	5.36	8.13	6.40	0.840	1708
JJ7	6.25	6.38	9.42	7.46	0.832	1669
L2	5.04	4.31	8.57	7.35	0.912	2018
L3	4.93	4.23	8.13	7.04	0.903	1974
L4	5.38	5.07	8.73	7.36	0.874	1853
L5	5.18	4.62	8.41	7.15	0.890	2005
L6	5.14	4.52	8.58	7.42	0.900	2018
LL1	5.15	4.50	9.01	7.83	0.913	2037
LL2	5.46	4.85	9.24	7.85	0.901	1974
LL3	4.79	3.97	8.58	7.54	0.931	2145
LL4	5.27	4.84	9.17	7.88	0.900	1983
LL5	5.29	4.76	9.10	7.71	0.902	1978
LL6	5.41	4.94	9.06	7.65	0.891	1929
M2	5.21	5.00	8.05	6.91	0.857	1660
M4	5.39	5.28	8.12	6.89	0.844	1671
M5	5.27	4.78	8.48	7.06	0.883	1815
M6	5.51	4.93	9.05	7.67	0.892	1901
M7	5.47	5.24	8.24	6.94	0.850	1689
N2	5.18	4.59	8.13	7.00	0.882	1764
N3	5.44	5.01	8.45	7.10	0.869	1702
N4	5.28	4.71	8.73	7.39	0.894	1809
N5	5.34	5.05	8.43	7.24	0.867	1605
N6	5.55	5.15	8.93	7.54	0.877	1695
N7	5.20	4.55	9.08	7.75	0.913	1819
N8	5.36	4.94	8.65	7.19	0.879	1656
N9	5. 8	5.14	7.88	6.40	0.843	1492
N10	5.11	4.50	8.62	7.40	0.902	1763
N11	5.37	4.99	8.86	7.55	0.883	1672

Table G-1 (cont.)

Site	Band 4	Band 5	Band 6	Band 7	TVI6	Calculated Green Biomass (kg/ha)
NN1	5.27	4.62	9.44	8.15	0.918	2001
NN2	5.35	4.89	9.09	7.74	0.895	1911
NN3	5.35	4.71	9.36	8.05	0.911	2015
NN4	5.23	4.74	9.04	7.73	0.901	1915
NN5	5.52	5.16	9.06	7.60	0.880	1857
NN5	5.27	4.55	9.52	8.24	0.924	2041
O2	5.40	4.65	9.45	8.10	0.917	1711
O3	5.19	4.93	8.91	7.65	0.887	1644
O4	5.31	4.80	9.82	8.42	0.918	1793
O6	5.25	4.87	9.06	7.52	0.895	1761
P2	5.76	5.19	9.62	8.14	0.894	1523
P3	5.68	5.37	8.95	7.39	0.866	1417
P4	5.21	4.46	9.13	7.79	0.919	1653
P5	5.45	5.07	9.62	8.12	0.900	1542
P6	5.78	5.25	9.61	8.09	0.891	1537
Q2	5.57	5.14	8.76	7.09	0.872	1518
Q3	5.78	5.36	8.85	7.23	0.863	1475
Q4	5.52	4.97	9.04	7.53	0.889	1611
Q5	5.48	4.97	8.55	7.24	0.874	1434
Q6	5.75	5.24	8.60	6.95	0.861	1414
Q7	5.73	5.44	9.04	7.65	0.865	1484
Q8	5.68	5.37	8.47	7.03	0.851	1419
QQ1	6.02	5.95	7.98	6.16	0.804	998
QQ2	5.98	5.77	8.05	6.23	0.816	1056
QQ3	6.36	6.49	8.10	6.17	0.781	823
R2	5.48	4.74	8.65	7.28	0.890	1810
R3	5.22	4.55	7.88	6.67	0.876	1749
R4	5.37	4.88	7.87	6.59	0.857	1725
R5	5.36	4.69	8.62	7.29	0.892	1749
S1	5.42	5.04	7.86	6.45	0.848	1630
S2	5.63	5.32	8.20	6.68	0.844	1585
S3	5.49	5.08	7.64	6.20	0.838	1556
S4	4.16	4.02	5.42	4.43	0.805	1398
S6	5.47	5.09	7.83	6.37	0.844	1585
AUGUST						
A3	5.68	5.36	7.32	5.81	0.809	1143
A4	5.86	5.71	7.87	6.37	0.812	1094
A5	5.63	5.39	6.82	5.23	0.786	1028
A6	5.52	5.06	7.94	6.40	0.849	1321
B3	5.52	4.96	7.64	6.07	0.844	1390
B4	5.87	5.59	7.50	5.93	0.804	1184
B5	6.03	5.96	7.26	5.49	0.774	1043
BB1	5.18	4.75	6.16	4.83	0.793	537
BB2	5.35	4.89	6.80	5.26	0.815	640
BB3	5.48	5.04	7.12	5.65	0.819	648
BB4	5.69	5.30	7.57	6.07	0.822	659

Table G-1 (cont.)

Site	Band 4	Band 5	Band 6	Band 7	TVI6	Calculated Green Biomass (kg/ha)
C3	5.29	4.73	6.66	5.17	0.818	1182
C4	5.55	4.72	7.96	6.52	0.869	1433
D2	5.12	4.84	7.75	6.21	0.855	1497
D3	4.93	3.90	10.75	9.61	0.984	2110
D4	5.11	4.47	8.02	6.61	0.886	1752
D5	4.68	3.97	7.48	6.14	0.898	1708
E2	5.45	5.11	8.50	6.93	0.866	1730
E3	5.82	5.75	9.59	7.87	0.866	1730
E4	5.66	5.38	9.03	7.47	0.868	1740
EE1	5.75	5.57	8.74	7.26	0.850	1547
EE2	5.47	5.46	7.70	6.34	0.819	1412
EE3	5.18	4.98	7.11	5.76	0.822	1413
EE4	5.14	4.83	7.56	6.29	0.849	1542
EE5	5.54	5.22	8.14	6.61	0.847	1533
F3	5.31	5.42	6.80	5.31	0.783	1235
F4	5.68	5.59	7.90	6.59	0.820	1412
F5	5.24	4.96	7.47	6.19	0.837	1516
FF1	5.68	5.99	7.30	5.70	0.773	1199
FF2	5.98	6.70	8.54	6.80	0.788	1271
FF3	5.47	5.30	7.46	6.00	0.818	1277
FF4	6.24	6.97	8.69	6.82	0.781	1033
FF5	5.87	6.40	7.96	6.21	0.780	1138
G3	5.16	4.98	8.24	6.84	0.864	1767
G4	5.39	5.09	10.32	9.11	0.916	1838
G5	5.36	4.97	7.70	6.41	0.846	1502
G6	5.69	5.52	7.34	5.99	0.801	1372
GG1	5.52	5.07	7.90	6.53	0.847	1836
GG2	5.20	4.51	7.53	6.21	0.866	1927
GG3	5.18	4.70	7.68	6.39	0.860	2022
GG4	5.24	4.57	8.42	7.19	0.892	2176
GG5	5.40	4.93	8.28	6.91	0.868	1908
GG6	5.41	4.95	7.43	6.05	0.837	1760
GG7	5.46	5.28	8.18	6.71	0.846	1831
H2	5.15	4.63	6.81	5.52	0.831	1490
H3	5.21	4.72	6.70	5.30	0.821	1575
H4	5.09	4.96	7.08	5.76	0.823	1548
H5	5.05	4.99	6.65	5.31	0.802	1423
H6	4.96	4.68	7.28	6.06	0.847	1639
H7	4.69	4.23	6.12	4.71	0.826	1466
H8	4.79	4.31	6.27	4.91	0.828	1475
H9	4.63	3.90	7.65	6.44	0.908	1860
H10	5.26	4.77	7.44	6.03	0.848	1581
H11	4.86	4.24	6.61	5.28	0.847	1577
HH1	5.19	4.40	8.16	6.71	0.894	1403
HH2	5.06	4.51	7.25	5.97	0.856	1221

Table G-1 (cont.)

Site	Band 4	Band 5	Band 6	Band 7	TVI6	Calculated Green Biomass (kg/ha)
HH3	5.39	5.57	8.07	6.23	0.827	1043
HH4	5.94	5.85	7.86	5.90	0.804	947
HH5	6.14	6.42	8.24	6.16	0.790	880
I2	4.98	4.70	7.40	5.98	0.850	1581
I3	5.40	5.54	7.92	6.48	0.823	1634
I4	5.12	5.20	7.85	6.42	0.839	1528
I5	5.10	4.62	7.66	6.21	0.865	1878
I6	4.83	4.38	6.28	4.91	0.824	1497
JJ1	5.74	5.15	11.03	9.76	0.929	2075
JJ2	4.97	3.96	9.50	8.56	0.955	2199
JJ3	5.21	5.01	7.07	5.70	0.819	1540
JJ4	5.34	4.81	8.08	6.77	0.868	1776
JJ5	5.40	5.11	8.06	6.65	0.851	1694
JJ6	5.23	4.87	7.77	6.42	0.854	1708
JJ7	5.81	5.65	9.03	7.40	0.855	1772
L2	5.12	4.33	8.04	6.65	0.894	1356
L3	4.90	4.08	8.16	6.84	0.913	1447
L5	5.42	4.78	8.45	6.92	0.881	1301
L5	5.26	4.52	8.02	6.69	0.883	1346
L6	5.37	4.53	8.30	6.76	0.891	1379
LL1	5.24	4.19	8.68	7.30	0.921	1594
LL2	5.63	4.79	8.90	7.47	0.895	1587
LL3	5.12	4.53	6.68	5.33	0.832	1121
LL4	5.32	4.72	8.23	6.90	0.878	1313
LL5	5.29	4.47	8.04	6.65	0.886	1544
LL6	5.40	4.69	8.05	6.68	0.874	1378
M2	5.53	4.56	9.11	7.74	0.913	1769
M3	5.60	4.73	9.11	7.71	0.903	1812
M4	5.34	4.33	9.37	8.09	0.932	1952
M6	5.50	4.86	8.33	6.98	0.874	1590
M7	5.56	4.84	8.57	7.14	0.882	1628
N2	5.20	4.42	7.36	6.08	0.866	1613
N3	5.48	4.61	8.43	7.03	0.890	1728
N4	5.55	4.63	8.39	6.73	0.888	1780
N7	5.60	4.84	8.34	6.76	0.875	1633
N8	5.47	4.59	9.12	7.68	0.911	1846
N9	5.52	4.84	7.83	6.27	0.858	1592
N10	5.32	4.47	8.09	6.69	0.888	1736
NN1	5.48	4.89	8.22	6.87	0.868	1434
NN2	5.58	4.91	8.35	6.93	0.871	1479
NN3	5.67	5.28	8.40	6.96	0.854	1454
NN4	5.46	5.04	8.09	6.64	0.855	1376
NN5	5.45	4.81	8.75	7.48	0.889	1521
NN6	5.29	4.50	8.64	7.49	0.903	1598

Table G-1 (cont.)

Site	Band 4	Band 5	Band 6	Band 7	TVI6	Calculated Green Biomass (kg/ha)
O2	5.36	4.60	8.54	7.27	0.895	1805
O3	5.16	4.64	7.85	6.76	0.870	1704
O4	5.47	4.78	8.66	7.21	0.888	1790
O6	5.55	5.07	8.51	7.08	0.868	1714
P2	5.62	5.08	8.66	7.12	0.872	1672
P3	5.59	5.00	8.40	6.98	0.868	1691
P4	5.30	4.40	8.22	7.09	0.896	1841
P5	5.55	4.91	8.38	6.93	0.873	1635
P6	5.58	4.81	8.99	7.84	0.896	1826
Q2	5.69	5.10	8.55	7.02	0.868	1626
Q3	5.76	5.09	8.77	7.33	0.875	1659
Q4	5.63	4.88	8.76	7.30	0.886	1686
Q5	5.41	4.50	8.70	7.46	0.904	1813
Q6	5.63	5.03	8.42	7.04	0.867	1629
Q7	5.90	5.42	8.95	7.28	0.863	1602
Q8	5.86	5.35	8.44	7.06	0.851	1544
QQ1	5.04	4.16	9.10	8.02	0.934	1401
QQ2	5.43	5.00	8.00	6.67	0.855	1022
QQ3	5.68	5.22	8.54	7.22	0.861	1246
R2	5.47	4.57	7.70	6.13	0.869	906
R3	5.46	4.96	6.95	5.41	0.817	609
R4	5.33	4.70	7.36	5.93	0.849	790
R5	5.53	4.94	7.54	6.01	0.842	797
S1	5.08	4.53	7.59	6.29	0.867	1728
S2	5.25	4.91	7.70	6.43	0.849	1580
S3	5.14	4.64	7.07	5.79	0.841	1542
S4	5.03	4.33	7.66	6.35	0.882	1752
S6	4.85	4.18	7.95	6.51	0.901	1922
SEPTEMBER						
A3	6.79	4.35	5.96	5.22	0.810	545
A4	5.44	6.52	5.58	5.09	0.768	751
A5	7.63	5.20	6.14	5.09	0.763	467
A6	7.64	5.02	6.86	5.81	0.809	432
B3	7.45	4.82	6.49	5.60	0.805	733
B4	7.97	5.66	6.42	5.34	0.750	268
B5	7.86	5.44	6.49	5.51	0.767	451
BB1	7.09	4.59	5.87	5.07	0.789	217
BB2	6.97	4.36	6.03	5.12	0.813	82
BB3	7.38	4.78	6.50	5.66	0.808	235
BB4	7.62	5.03	6.58	5.57	0.796	47
C3	7.30	4.38	6.42	5.42	0.830	421
C4	7.71	4.86	7.02	5.99	0.825	419
D2	6.93	4.53	6.82	5.89	0.838	988
D3	7.17	4.18	8.55	7.60	0.918	1211
D4	7.25	4.75	7.32	6.32	0.845	85

Table G-1 (cont.)

Site	Band 4	Band 5	Band 6	Band 7	TVI6	Calculated Green Biomass (kg/ha)
E2	7.13	4.68	7.65	6.64	0.861	1463
E3	7.57	5.24	7.70	6.62	0.831	1320
E4	7.48	5.13	7.43	6.32	0.827	1300
EE1	7.14	5.03	6.36	5.55	0.786	237
EE2	7.02	4.98	6.16	5.33	0.779	423
EE3	6.64	4.34	6.00	5.30	0.813	107
EE4	6.83	4.64	6.26	5.57	0.805	146
EE5	7.34	4.75	7.50	6.53	0.851	75
F3	7.05	4.78	6.28	5.26	0.797	1080
F4	7.57	5.50	6.58	5.52	0.768	941
F5	7.22	5.01	6.18	5.07	0.777	427
FF1	7.34	5.33	5.92	4.79	0.743	665
FF2	7.63	5.75	6.55	5.35	0.752	708
FF3	7.38	4.91	6.75	5.75	0.811	992
FF4	7.86	5.92	6.48	5.20	0.738	641
FF5	7.53	5.63	6.24	5.05	0.743	666
G3	7.04	4.73	6.74	5.87	0.822	722
G4	7.50	5.66	7.23	6.18	0.788	94
G5	7.25	4.92	5.98	5.02	0.773	22
G6	7.75	5.30	6.65	5.64	0.783	214
GG1	7.35	4.99	6.64	5.64	0.801	1169
GG2	7.06	4.31	6.76	5.84	0.849	1399
GG3	6.71	3.99	6.21	5.40	0.847	166
GG4	6.95	4.15	7.55	6.81	0.889	368
GG5	6.97	4.29	6.99	6.15	0.860	758
GG6	7.13	4.41	6.70	5.90	0.840	662
GG7	7.23	4.97	6.93	5.83	0.815	1236
H2	7.52	5.13	6.34	5.26	0.778	351
H3	7.22	4.69	6.64	5.65	0.820	716
H6	6.70	4.46	5.71	4.99	0.789	891
H7	6.91	4.47	5.78	4.81	0.792	419
H8	7.03	4.44	5.93	4.99	0.803	471
H9	7.02	4.22	7.18	6.13	0.872	803
H10	6.72	4.05	6.11	5.22	0.839	1199
H11	6.37	3.67	5.54	4.70	0.838	1194
HH1	6.91	4.08	7.65	6.67	0.897	1718
HH2	6.98	4.44	6.56	5.66	0.833	1411
HH3	7.32	5.38	7.47	6.13	0.814	1296
I3	7.26	5.16	6.86	5.98	0.800	851
I4	6.97	4.67	6.91	6.05	0.833	615
I5	7.07	4.39	6.82	5.79	0.847	335
I6	6.92	4.55	5.45	4.52	0.769	664
JJ1	8.08	5.67	8.99	7.94	0.852	632
JJ2	7.65	4.52	9.86	9.02	0.933	1021
JJ3	7.00	4.95	6.76	5.90	0.809	466

Table G-1 (cont.)

Site	Band 4	Band 5	Band 6	Band 7	TVI6	Calculated Green Biomass (kg/ha)
JJ4	7.33	5.14	6.43	5.47	0.782	336
JJ5	7.47	5.56	6.69	5.46	0.769	286
JJ6	7.05	4.81	6.32	5.26	0.798	426
JJ7	7.61	5.49	6.93	5.87	0.785	333
L2	7.03	4.26	6.84	6.00	0.856	547
L3	7.05	3.95	7.54	6.53	0.902	768
L4	7.33	4.61	7.25	6.29	0.850	556
L5	7.47	4.80	6.90	5.97	0.825	571
L6	7.31	4.38	7.48	6.39	0.873	703
LL1	7.26	4.48	6.88	6.02	0.844	939
LL2	7.61	5.01	7.87	7.02	0.850	1009
LL3	7.03	4.45	5.77	5.04	0.793	523
LL4	7.17	4.42	6.73	5.81	0.841	712
LL5	6.98	4.33	6.81	6.15	0.850	1009
LL6	7.35	4.80	7.03	6.21	0.830	807
M2	8.00	5.26	7.69	6.61	0.829	943
M3	7.84	5.08	7.78	6.87	0.843	942
M4	7.51	4.47	8.20	7.15	0.892	1177
M5	7.50	4.68	7.29	6.25	0.848	999
M6	7.65	5.14	6.91	5.84	0.805	816
M7	7.72	4.85	7.59	6.42	0.849	999
N2	7.28	4.40	7.00	6.32	0.853	1112
N3	7.53	4.64	6.98	6.08	0.838	1040
N4	7.44	4.73	6.97	5.83	0.832	988
N5	7.50	4.84	7.90	7.05	0.860	1092
N7	7.73	4.94	7.15	6.29	0.826	1077
NN1	7.57	4.89	7.41	6.51	0.839	1311
NN2	7.87	5.33	7.84	6.85	0.831	1277
NN3	7.53	5.06	7.38	6.41	0.828	1285
NN4	7.36	4.48	7.40	6.40	0.863	1391
NN5	7.54	4.89	7.95	6.89	0.859	1688
NN6	7.09	4.58	7.36	6.67	0.856	1656
O2	7.44	4.98	7.92	7.15	0.853	1310
O3	7.12	5.04	6.98	6.28	0.813	1122
O4	7.79	5.02	8.75	7.95	0.878	1434
O5	7.48	5.02	7.56	6.53	0.838	1238
O6	7.61	5.46	7.08	6.13	0.793	1032
P2	7.84	5.10	7.39	6.38	0.827	1041
P3	7.86	5.40	7.54	6.31	0.816	1[illegible]31
P4	7.29	4.73	6.76	5.90	0.823	747
P5	7.64	5.21	6.98	5.89	0.804	1207
P6	7.81	5.31	7.33	6.31	0.812	1012

Table G-1 (cont.)

Site	Band 4	Band 5	Band 6	Band 7	TVI6	Calculated Green Biomass (kg/ha)
Q2	7.80	5.16	7.30	6.31	0.819	842
Q3	7.94	5.11	7.67	6.44	0.837	929
Q4	7.72	5.04	7.57	6.57	0.837	1232
Q5	7.55	4.96	7.68	6.72	0.846	1067
Q6	7.94	5.62	7.16	6.13	0.788	767
Q7	8.01	5.47	8.00	6.80	0.829	890
Q8	8.14	5.77	7.33	6.26	0.787	689
QQ1	7.21	4.26	7.86	6.88	0.893	1092
QQ2	7.63	5.36	6.63	5.62	0.778	540
QQ3	7.59	5.12	7.01	6.01	0.810	694
R2	7.48	4.25	7.32	6.23	0.875	87
R3	7.27	4.24	6.65	5.74	0.849	168
R4	7.43	4.57	6.67	5.81	0.829	105
R5	7.50	4.66	6.75	5.81	0.827	59
S1	7.56	4.63	7.27	6.16	0.850	499
S2	7.53	4.82	6.91	5.90	0.823	497
S3	7.48	4.71	6.54	5.59	0.814	468
S4	7.74	4.72	7.16	6.17	0.840	647
S5	7.64	4.62	7.26	6.26	0.850	514
S6	7.48	4.50	7.65	6.91	0.871	600
S7	7.57	4.61	7.23	6.14	0.849	676
S8	7.43	4.75	6.55	5.53	0.812	500
S9	7.76	4.95	7.74	6.68	0.849	606
S10	7.59	4.47	7.68	6.53	0.874	700

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.