E/S NO. 1052

(NASA-CR-147711) EARTHSAT SPRING WHEAT
YIELD SYSTEM TEST 1975 Final Report (Earth
Satellite Corp.) 491 p HC $12.50 CSCL 02C

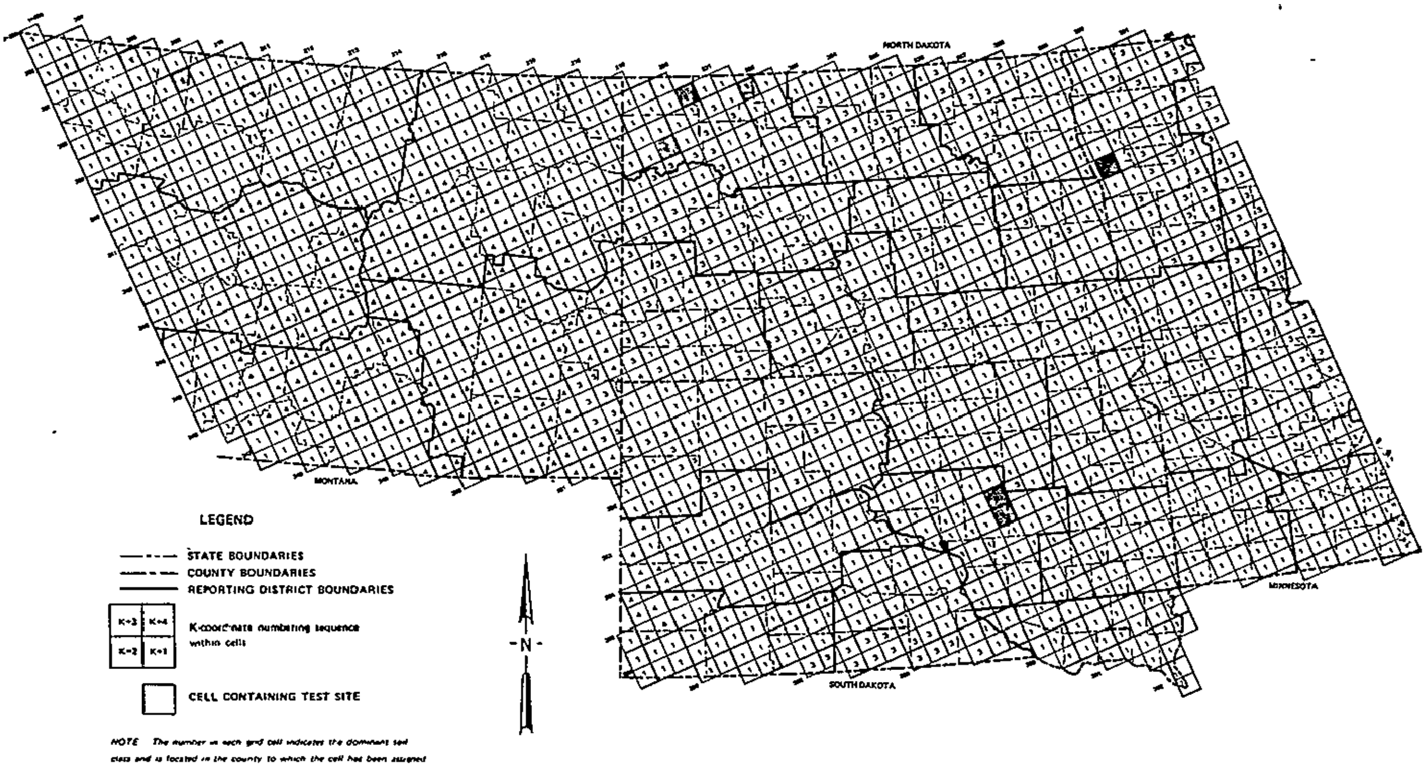
N76-28625

Unclas
G3/43 28240

EARTHSAT SPRING WHEAT YIELD SYSTEM TEST 1975

FINAL REPORT

NASA CR-
147711



prepared for

L. B. JOHNSON SPACE CENTER
Houston, Texas 77058

Contract NAS 9-14655

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APRIL 1976

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ACKNOWLEDGEMENTS

This report was prepared under the technical direction of Mr. Earl S. Merritt. Major technical contributions have been made by Romeo Sabatini, Nathaniel Belknap, Jack Meneely, Richard Anderson, James Haynes, Michael Place. Larry Heitkemper, Dennis Hlavka, William Hart and Archibal Park. The illustrative materials have been prepared by Edmund Schantz.

Special thanks should go to Mr. Charles Bristor and Dr. Charles Baker for their consultative contribution to the program and to Dr. J. Caprio of Montana State University and Dr. B. Worcester of North Dakota State University for their inputs on the soil moisture measurement subcontract work.

A note of special thanks should go to Ms. Terri Smith who coordinated the entire final report assembly and preparation for the printer.

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EXECUTIVE SUMMARY

Earth Satellite Corporation has tested its previously developed Spring Wheat Yield Model System over the hard red spring wheat regions of North Dakota, South Dakota, Montana and Minnesota in 1975. The system is directed to future applications of dynamic simulation models. The present "System" employs ground meteorological observations from first order observing stations and meteorological satellite cloud observations to derive daily estimates of the weather environment of the wheat plant. Soils, plant physiology, and local soil water to plant relationships are explicitly included in the "System". The daily operational implementation of the model is driven by a phenology "clock" which activates plant canopy cover estimates of crop albedo, derives rooting structure and initiates water extraction coefficients. Yield is derived from phenology interval accumulations of daily plant stress through a regression equation which includes a technology trend estimate.

The "System" is largely computerized and operates on a two-level geobased grid and cell structure which has been developed from the National Meteorology Center's standard Numerical Prediction grid mesh.

Significant items which have been derived from the 1975 test of the "System" include:

(a) The precipitation estimation sub-element of the "System" provides daily estimates accurate to within 3 mm. 72% of the time and 7 mm. 90% of the time. There is a distinct tendency to overstate light precipitation events (less than 12.5 mm.) and understate heavy precipitation events (greater than 12.5 mm.).

Estimates for larger areas (greater than the 25 n.m grid mesh), e.g. CRD or for longer time intervals up to one week show greater accuracy. (These results were prepared using cooperative observing network data as ground "truth" data. These stations were not a part of our 1975 operational data base.)

(b) The potential evapotranspiration (ETP) sub-element of the "System" produced estimates during the 1975 test that were within ± 2 mm. of Class A pan measurements 68% of the time. Correlation coefficients for three test stations range from 0.74 at Fargo, 0.66 at Sioux Falls and .57 at Pickstown. These results are in line with previous comparisons between the Penman (ETP) and Class A evaporation pan data.

(c) Solar radiation estimates, compared with a limited number of reasonably good pyranometer data, show a positive bias of approximately +55 Langleys/day and a random error of 80 Langleys/day.

(d) The growth stage "clock" was tested at seven USDA test site locations in Montana, North Dakota, South Dakota, and Minnesota. The results show a generally positive bias, i.e. the predicted growth stage appears to have a tendency to be early. The absolute error averages 3.4 days for all three stages that were evaluated, i.e. jointing (BMT=2), heading (BMT=3), and soft dough (BMT=4).

(e) Evapotranspiration (ET) estimates using the moisture release function whereby soil moisture is restricted after approximately 70% of maximum profile crop available moisture is too restrictive. The observed errors for seven day intervals were approximately -25 mm., i.e. the model estimated 25 mm. less ET than actually was observed at the neutron profile sites. Substitution of a moisture release curve that is non-restrictive to 35% of capacity seems to reduce the error to -8 mm. Tests of a, sandy soil, totally non-restrictive moisture release curve produced errors of +10 mm., i.e. the model estimated more ET than actually was observed.

(f) Yield forecasts prepared during the operational test period using a North Dakota model with North Dakota trends showed errors of approximately +2% in North Dakota, -12% in Montana, -7% in Minnesota and +30% in South Dakota. An acreage weighted four state aggregate showed errors of less than +4%. Re-evaluation of the T-A trends for each CRD produced state level errors of -8% for Montana, +4% in North Dakota, -6% in South Dakota, and +8% in Minnesota. The four state aggregate error is approximately +2%.

Correlation coeffients of yield estimated at the CRD level for Montana, North Dakota and Minnesota are approximately .75. At the county level in Montana and North Dakota correlation coefficients are approximately .45 and .55 respectively.

Spatial variance in yields is well described by the model at the two to three county aggregate level. The size of the area over which real variance is described seems to vary with the soil moisture level. Areas with high levels of soil moisture seem to show real variance at a 50 mile mesh level. Areas with low soil moisture and significant soils variance appear to show variances at the two-cell aggregate level.

All yield comparisons were with SRS data made available to the Project on either 1 December 1975 (State) or 10 March, 1976 (CRD and county).

The "system" implemented over the upper Great Plain in 1975 has been fully documented in Appendix IV of this report. The 1975 implementation is reasonably efficient in all areas except the initial ground data and satellite data entry and error checking. This was done in a manual manner in 1975.

Future plans for the NOAA TIROS-N program include the development of cloud state parameters on a routine basis, i.e. cloud type and amount. As soon as this is available, the full system could be operational on the NMC data base, assuming a decision was made to use the NMC system to supply agricultural data. In this configuration the "System" would be fully automated. The estimated added incremental operating cost for the AGMET System would be equal to one hour of CPU time per week for the entire 30,000 12.5 x 12.5 n.m cells that are estimated to encompass all the wheat areas of the world. For a 360/50 system, costs would be in the $500/week range. Personnel costs for evaluation and debugging would be relatively small but would necessarily increase the $500 cost.

The "System" is fully suitable for the operation of currently available simulation physiology models. Such models show potential accuracies on the order of 10%. The major benefits to be achieved with such models would be an improved understanding of plant physiological processes over large areas. Observations from remote sensing systems such as LANDSAT could be used over the large area to assess model descriptive performance and thereby permit adjustments of the model inputs. The use of physiological models in a hierarchical mode with "middle" models such as have been used in the 1975 test would prove a significant benefit to production estimation, and agricultural research.

The "System" has demonstrated an overall skill not heretofore available to agricultural weather related activities. The systematic evaluation and organization of agronomic data provide the potential for infinite applications. Some recommendations for further such applications include:

(a) Testing of existing corn, soy bean and cotton physiological simulation models over a large area concurrent with LANDSAT coverage.

(b) Testing of the daily stress yield adjusted model at selected locations in foreign producing areas using sub-sections of the total grid mesh in a sampling mode.

(c) Testing the use of the soil moisture BMT and stress outputs as an aid in signature extension for LANDSAT multispectral analysis.

(d) Develop the basic data fields in precipitation, potential evapotranspiration, ET, radiation, etc. to permit other investigators to derive new agronomic models.

The EarthSat "System" is obviously a different approach for an old problem. The basic approach of a distributive simulation model approach, whereby all computations are prepared on spatial five mesh grid, has many applications to agronomy, hydrology, solar energy studies, etc. The relative novelty of the approach, albeit somewhat complex, should not deter its future use.

1.0 INTRODUCTION

The United States has made a commitment to begin work on a satellite-based system to provide global food grain supply information. The system proposed will employ the LANDSAT satellite data to estimate area and to-be-developed techniques to estimate yield. Two yield estimating techniques were tested in the 1975 crop year.

The NOAA Center for Climatic and Environmental Assessment (CCEA) at Columbia, Mo. has developed a set of relatively traditional weather regression yield estimation models. These models are traditional in the sense that they utilize monthly averages of meteorological variables, in a regression approach that evaluates technology trends and large area average weather information in relation to historical yield. Soils and soil/water relationships are treated implicitly by geographic regionalization.

Earth Satellite Corporation has developed a Spring Wheat Yield Model System which is ultimately directed toward a dynamic simulation yield approach using plant-physiology models. EarthSat's "System" uses both ground observations and meteorological satellite cloud observations to derive daily estimates of the weather environment of the wheat plant. Soils, plant physiology, phenology, and local soils/water/plant relationships are explicitly included in the "System." Yield is derived from phenology-interval accumulations of daily plant stress through a regression equation which also includes technology trend as in the NOAA CCEA approach.

The relatively unique approach of the EarthSat "System" requires a careful test and evaluation period prior to considerations of any operational implementation in an advanced LACIE Program. This report presents the results of an operational test and subsequent evaluations of that test which have been conducted for NASA's Lyndon B. Johnson Space Center under Contract NAS9-14655.

The report presents:

- The results of an operational test of the EarthSat System during the period 1 June - 30 August 1975 over the spring wheat regions of North Dakota, South Dakota, and Minnesota.
- Detailed evaluations of the errors associated with each sub-element of the system during the operational test.
- Detailed evaluations of the sensitivity of the complete system and each major functional sub-element of the system to the observed errors.
- Evaluations and recommendations for future operational users of the system including;
    - changes in various system sub-elements
    - changes in the yield model to affect improved accuracy
    - changes in the number of geobased cells needed to develop an accurate aggregated yield estimate
    - changes associated with the implementation of future operational satellites and data processing systems
    - detailed system documentation.

The report organization follows the format used in the "Mid-Term Report" submitted under the contract in October 1975. Appendices present the Geobased File Structure, the Spring Wheat System Daily Operational Implementation, the format of the daily computer maps produced by the METRUN "System", the Soil Moisture Sub-Contracts and System Sofware Documentation.

2.0 SYSTEM OVERVIEW

The EarthSat Spring Wheat Yield "System" is largely automated; it operates on a globally-applicable two level geobased cell structure. The geobased area was limited in the 1975 test to four upper Great Plains spring wheat producing states. The "System" processes meteorologica data from first order ground observational stations and from meteorological satellites. The objectives of the meteorological diagnosis is to define the weather influencing plant growth with sufficient detail to permit estimation of growth stage (phenology) from a temperature and day length model (Robertson 1968). The phenology estimates are then utilized to drive a soil moisture budgeting model (Baier 1966). Plant moisture stress is then derived on a cell by cell basis for each crop day. Daily or end of year spring wheat yields are then derived as a function of the cell by cell stress. Figure 2-1 presents a schematic of the overall system.

The "System" is activated after manual entry[1/] on a cell by cell basis, of soil characteristics, i.e., texture related crop available moisture chatacteristics, starting soil moisture, planting dates, etc.

The processing activities in the system are initiated by entry[1/] of the meteorological data. Interpolation routines and diagnostic models transform the input data into daily estimates of precipitation and potential evapotranspiration on a 25 nautical miles I,J grid. Once the basic plant weather environment has been defined, the system develops estimates of the daily soil moisture profiles and plant stress at a 12.5 x 12.5 nautical mile "cell" level.

[1/] A procedure has been defined to permit entry of the vertices of polygons which outline the homogenous areas to be entered. This procedure is directly applicable to an interactive terminal operation.

Yield forecasts may be prepared from the daily cell by cell stress either as a function of the average stress from planting to ripe or as a daily weighted transform of stress to yield percentage reduction. Both techniques have been used with good results. The yield estimates are prepared at the 12.5 x 12.5 n.m. cell and then aggregated upward to county, Crop Reporting District, State or Region levels using historical averaged planted acreage data.

The forecast procedures applied to estimate future weather from a point in time within the crop year included (a) a simple "past is prologue," i.e., the past average stress is equal to the future; and (b) a Monte Carlo weather simulation model approach which includes future weather sequences as Markov chains initiates on the basis of the last day of actual weather. The 1975 test only included "normal" weather statistics in the Monte Carlo model. Future applications could include forecasts and long range outlooks by modifying the distributions of weather events.

All data calculated during the crop year are accumulated into a crop season master file for subsequent research and study availability. Specific site data are reformatted into time sequential files for ease in subsequent review and display.

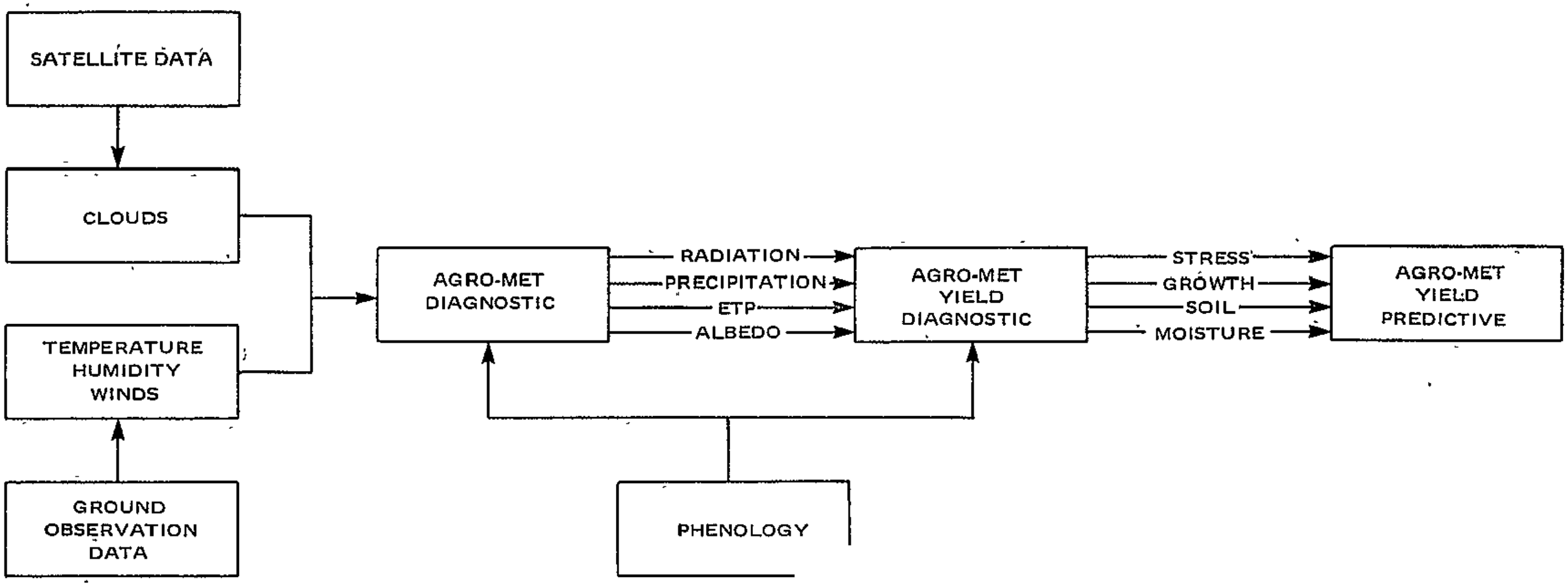

Figure 2-1: Schematic of EarthSat Spring Wheat Yield System.

3.0 REGIONAL DATA BASE

3.1 Coordinate Grid

A grid mesh system which is frequently used in operational meteorology was selected for this study as offering a convenient system in which to manage the computations and data manipulations. While some aspects of the grid definition might conveniently have been modified for the current application, this was not done, thereby allowing for future expansion to a global scale and remaining compatible with the format of possible future sources of input data.

The grid mesh system is rectangular to a polar stereographic projection of the northern hemisphere (see Figure 3-1). The spacing between successive grid points at middle latitudes is about 25 nautical miles. The J-axis is parallel to the great circle defined by 100 degrees east longitude and 80 degrees west longitude. The north pole is at (I = 257, J = 257). The equations relating latitude (Lat) and longitude (Lon) to I and J are:

$$I = 257 + R \cos A$$

$$J = 257 + R \sin A$$

where

$$R = 249.635 \tan ((90° - Lat)/2)$$

$$A = 10 - Lon$$

and longitude is defined as positive in the eastern hemisphere and negative in the western.

This grid mesh defines the points at which the meteorological input parameters are determined. The spring wheat region being examined in this study spans I - values from 206 to 232 and J - values from 335 to 362, a rectangle containing 756 grid points.

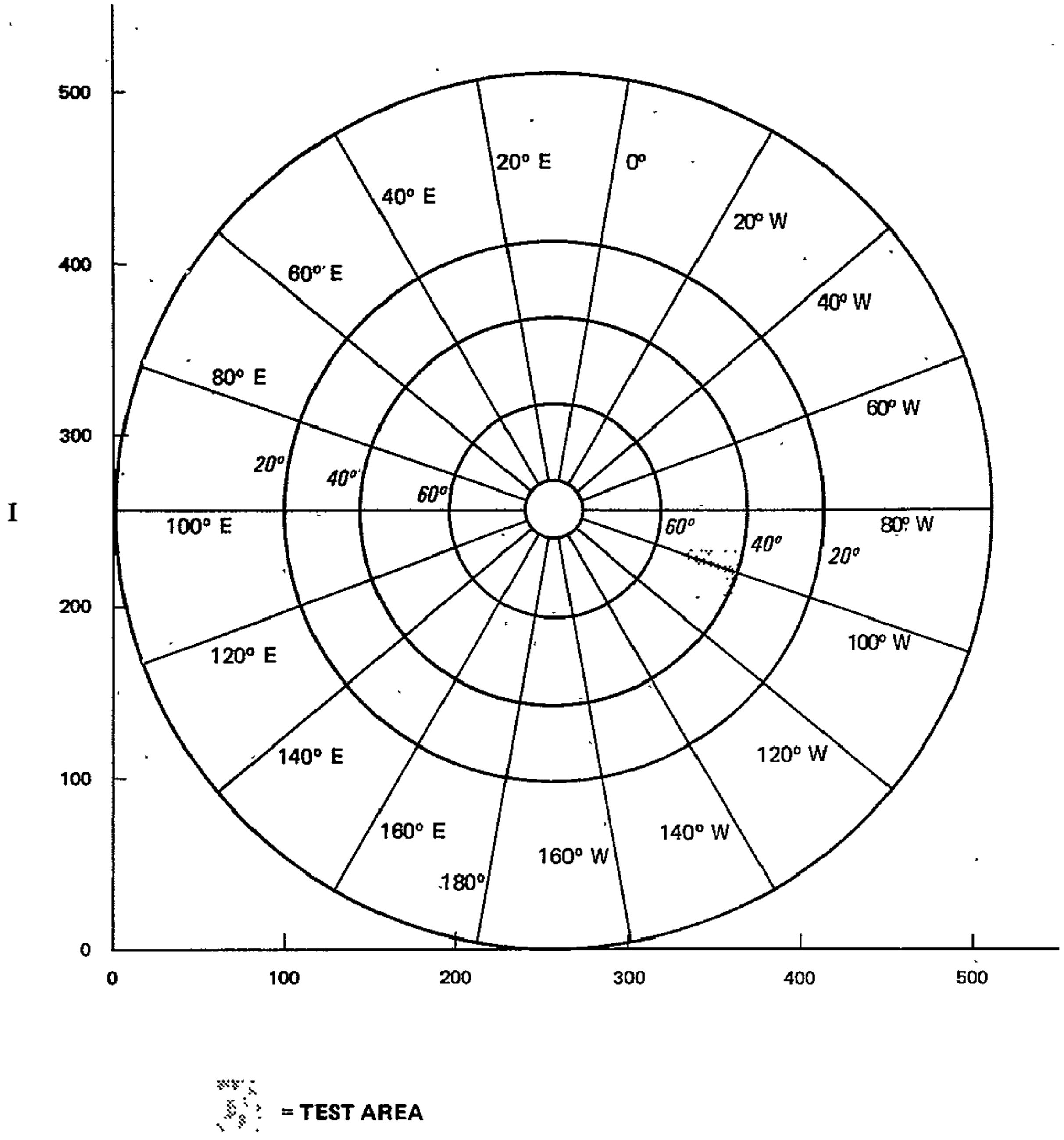

Figure 3-1: I-J coordinate grid on polar stereographic projection of Northern Hemisphere.

3.2 Agromet Cells

For calculations of the response of the crop-soil system to the meteorological inputs, the 25 mile grid is further subdivided so that four 12.5 mile agromet cells surround each grid point. The four cells in each group thus receive identical meteorological input but greater resolution is provided with respect to soil class, planting date and starting soil moisture. The four cells at each grid point are each assigned a K-coordinate. The cell lying in the direction of increasing I and J is assigned K=1; values of 2 through 4 are then assigned in a clockwise direction.

The cells represent the smallest units into which the data base is partitioned; it therefore became necessary to assign each cell to a single county and to a single soil category. The assignments were performed by overlaying the cell configuration onto soil maps of the individual states. County assignments are based on the county occupying the major portion of the cell, while soil assignments are based on the dominant soil type in the portion of the assigned county lying within the cell. Three broad categories of soil type were recognized for this study, differing in the amount of plant-available water their profiles can hold. These categories are designated by the numbers 1, 3 and 4.

Category 1 is typified by deep loamy soils with a maximum profile plant-available capacity of 175 mm. Category 3 represents sandy soils having a maximum plant-available capacity of 115 mm, while Category 4 comprises soils of restrictive moisture availability. These can be either very shallow soils or soils of high salinity and are assumed to have a maximum plant-available capacity of 75 mm.

Figure 3-2 illustrates the 1562 cells used in this study overlayed on a map showing the state, crop reporting district and county boundaries. The soil category numbers are positioned in each cell in such a manner as to clearly indicate the county to which the cell has been assigned. The eastern and western limits of the cell array were selected based on maps showing the areas in which spring wheat is grown. Appendix I presents a list of the 1562 cells, giving the assigned county, crop reporting district, state and soil class. In Figure 3-3 the different soil classes are highlighted by shading to illustrate their distribution. Southeastern Montana is dominated by shallow, category 4 soils. The location of the Yellowstone River valley with its deeper (category 1) soils is apparent.

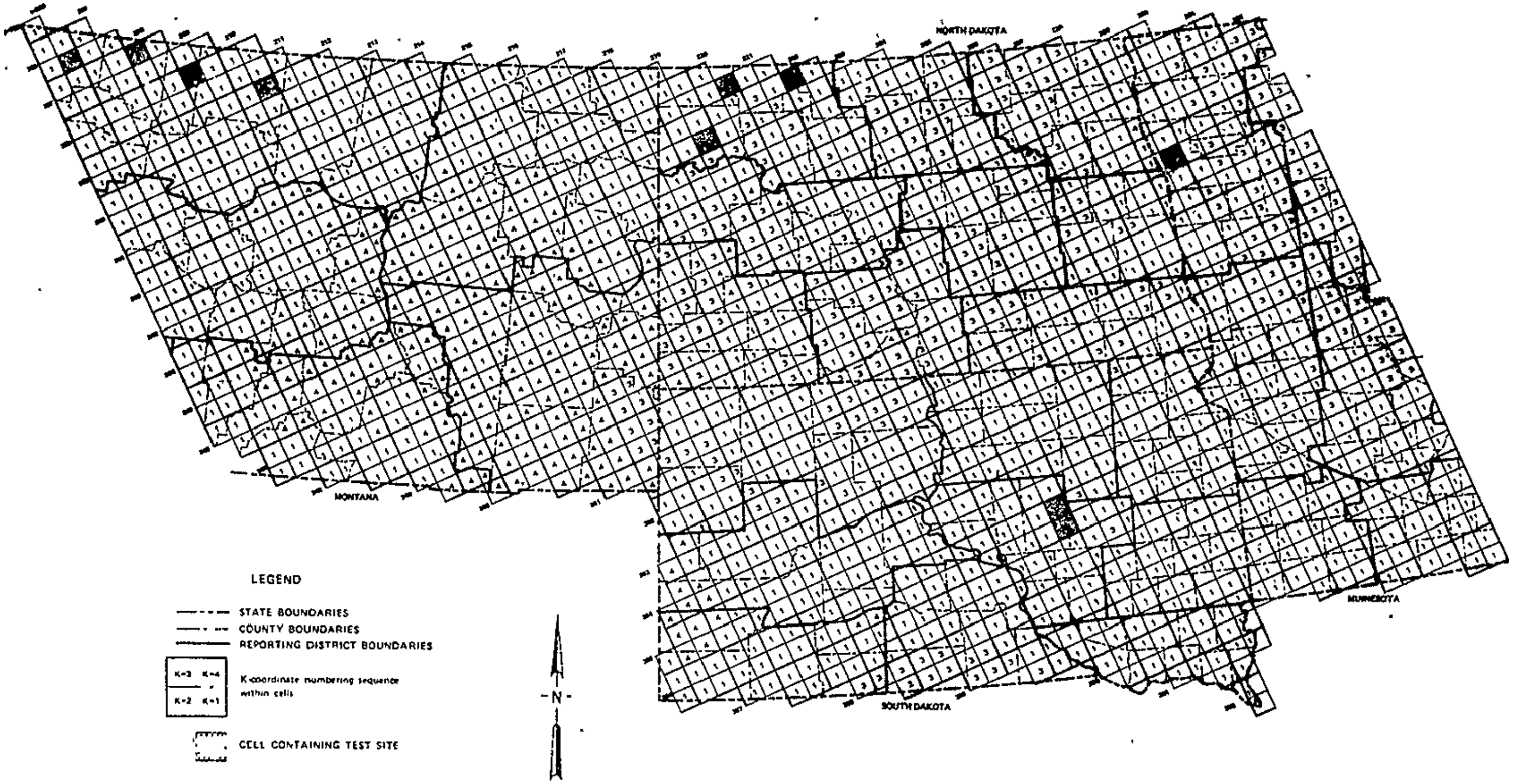

Figure 3-2: Cell Locations and Soil Class Assignments

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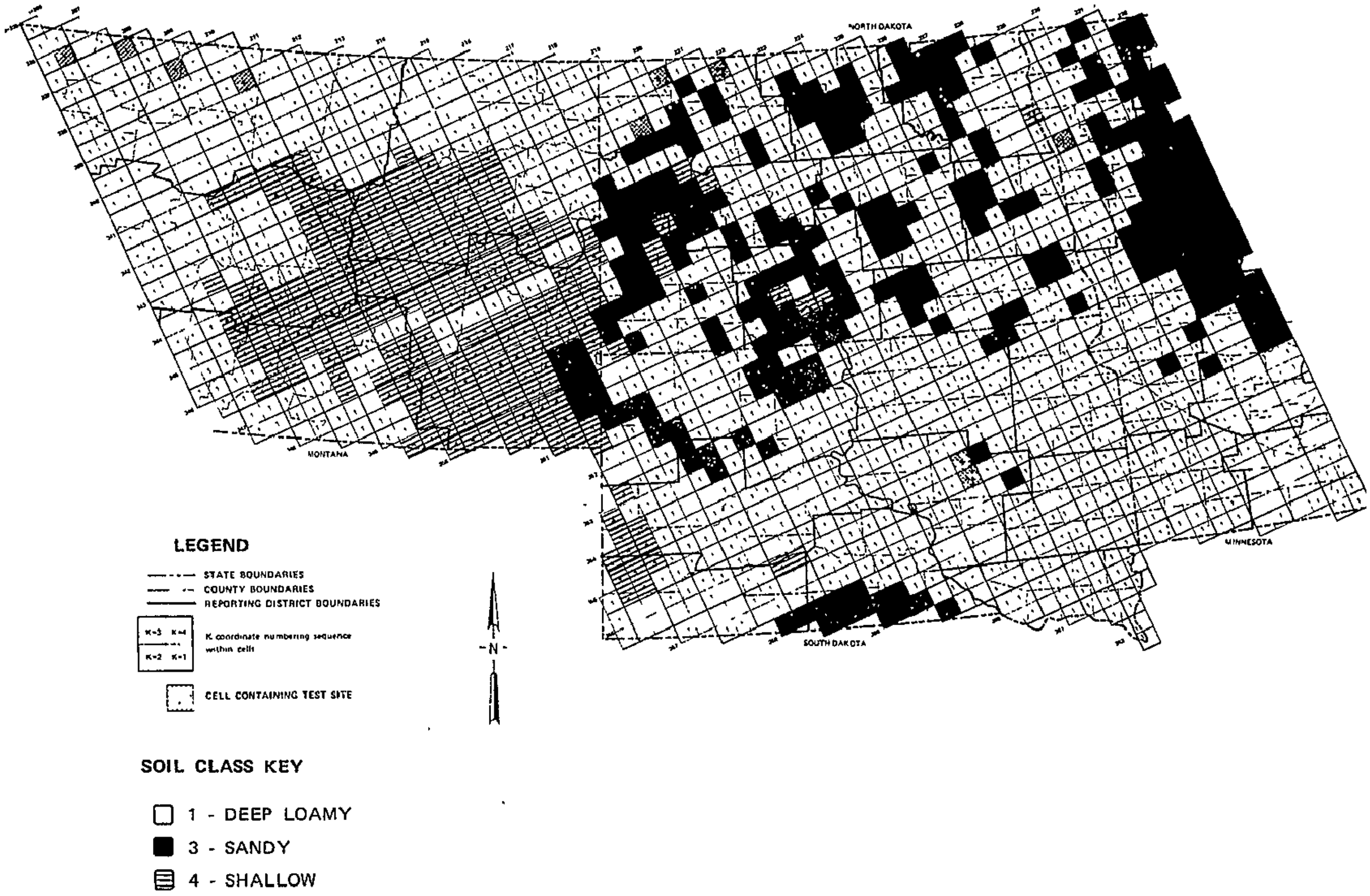

Figure 3-3: Soil Class Distributions

4.0 DATA COLLECTION/PROCESSING

4.1 Service C

The Teletype Service C station manual was searched for all available stations in and around the rectangular I, J grid of the study area ($206 \leq I \leq 232$; $335 \leq J \leq 362$). Also included, were the stations around the two lysimeter sites at Akron, Colorado and Manhattan, Kansas. Thirty-four 1st order stations (those having regular six-hour synoptic reports) were found to be available. These thirty-four stations report through five reporting districts on Service C: Seattle, Indianapolis, St. Louis, El Paso and the ninth Canadian district. A list of the thirty-four stations along with their I, J positions are shown in Figure 4-1. Figure 4-2 shows their locations overlayed on the study area.

The daily Service C Teletype data rolls and six-hourly surface weather maps were obtained from the World Weather Building in Suitland, Md., on a regular schedule. As the Service C data rolls were received, they were searched and the synoptic data for each six hour time period (00Z, 06Z, 12Z, 18Z) were stripped out.

Technicians extracted the significant synoptic coded data for the thirty-four stations onto computer coding sheets; visibility, wind direction, pressure and ceiling height were not included. Unfortunately, erroneous and missing data often hampered this effort; to compensate, the respective synoptic stations were telephoned bimonthly.

After all available data were accumulated, it was keypunched onto cards. In the extraction and keypunching process, some unavoidable errors were introduced into the system; in order to eliminate these errors as well as the original erroneous data, quality control

	ID	STATION	LAT	LON	I	J
1	72747	INTERNATIONAL FALLS	48.6N	93.4W	235.1	348.7
2	72659	ABERDEEN	45.4N	98.4W	224.7	354.0
3	72655	ST. CLOUD	45.6N	94.2W	232.0	355.9
4	72662	RAPID CITY	44.0N	103.1W	215.5	354.4
5	72654	HURON	44.4N	98.2W	224.2	356.8
6	72658	MINNEAPOLIS	45.0N	93.3W	233.3	357.7
7	72652	PICKSTOWN	43.1N	98.5W	222.6	359.8
8	72557	SIOUX CITY	42.4N	96.4W	225.9	362.7
9	72651	SIOUX FALLS	43.6N	96.7W	226.2	359.6
10	72650	SPENCER	43.1N	95.1W	228.8	361.4
11	72562	NORTH PLATTE	41.1N	100.7W	216.9	363.1
12	72775	GREAT FALLS	47.5N	111.4W	206.4	340.0
13	72777	HAVRE	48.5N	109.8W	210.1	339.0
14	72768	GLASGOW	48.2N	106.6W	214.3	342.2
15	72767	WILLISTON	48.2N	103.6W	218.8	344.4
16	72764	BISMARCK	46.8N	100.8W	221.9	349.5
17	72757	DEVILS LAKE	48.1N	98.9W	226.1	347.4
18	72753	FARGO	46.9N	96.8W	228.5	351.4
19	72755	BEMIDJI	47.5N	94.9W	232.1	350.9
20	72677	BILLINGS	45.8N	108.5W	208.6	346.1
21	72666	SHERIDAN	44.8N	107.0W	209.8	349.7
22	72851	PORTAGE LA PRAIRIE	49.9N	98.3W	228.4	343.5
23	72852	WINNIPEG	49.9N	97.2W	230.0	344.0
24	72862	ESTEVAN	49.1N	103.0W	220.6	342.8
25	72863	REGINA	50.4N	104.7W	219.5	338.6
26	72870	SWIFT CURRENT	50.3N	107.7W	215.1	336.9
27	72872	MEDICINE HAT	50.0N	110.7W	210.6	335.1
28	72874	LETHBRIDGE	49.6N	112.8W	207.3	334.2
29	72564	CHEYENNE	41.1N	104.8W	209.4	359.9
30	72465	GOODLAND	39.4N	101.7W	213.3	366.7
31	72458	CONCORDIA	39.5N	97.6W	221.3	369.1
32	72456	TOPEKA	39.1N	95.6W	225.0	371.5
33	72446	KANSAS CITY	39.3N	94.7W	226.9	371.4
34	72469	DENVER	39.8N	104.9W	207.8	363.2

Figure 4-1: Listing of meteorological stations used in the EarthSat Daily Weather Diagnosis

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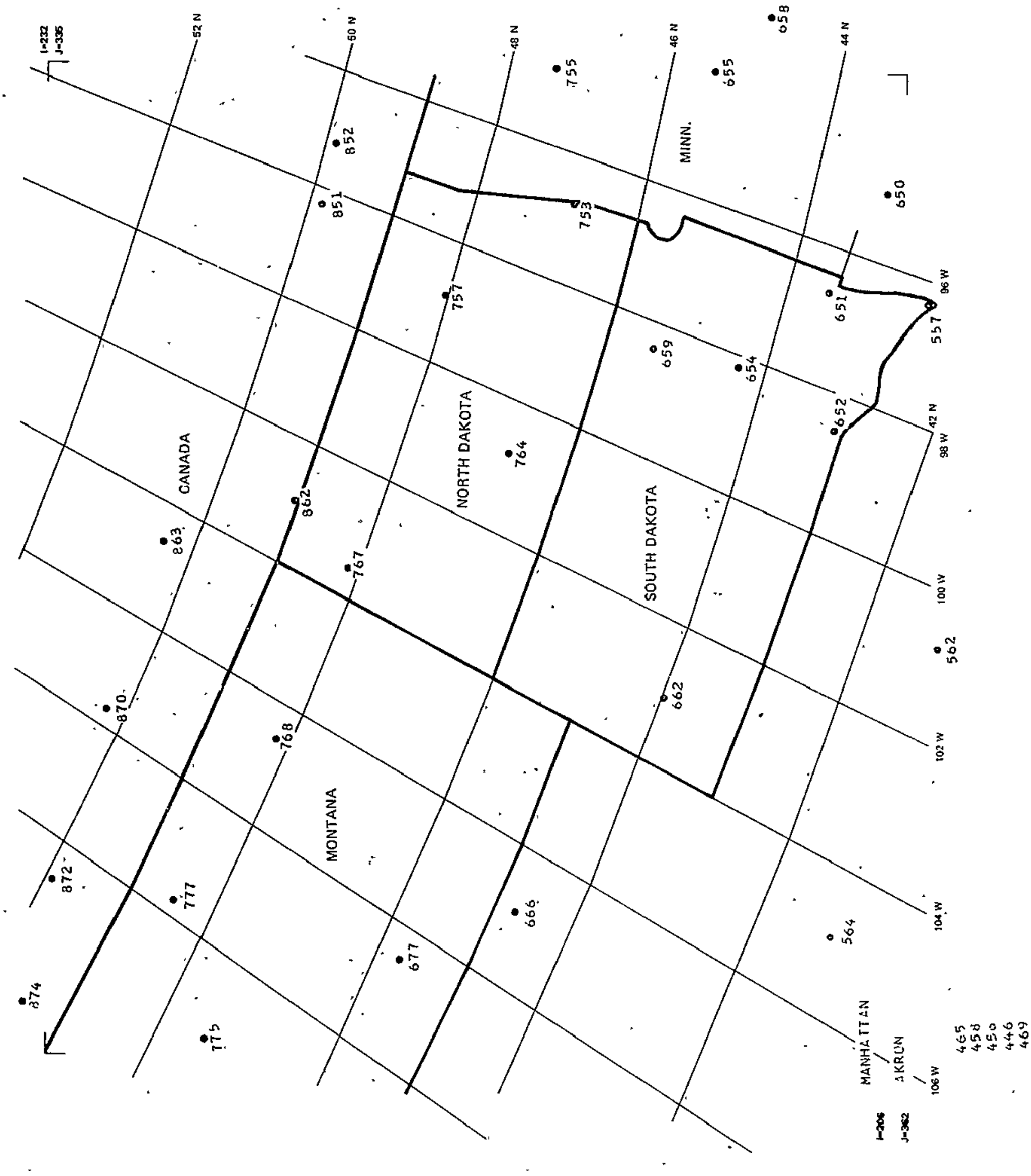

Figure 4-2:

Location of meteorological stations in the study area. This map overlays the computer produced maps of the METRUN subprogram. Stations are keyed to the listing in Figure 4-1 by the last three digits of their WMO identification. Stations listed at the bottom left are outside of the study area and are used to interpolate meteorological parameters for the two lysimeter sites - Manhattan, Kansas and Akron, Colorado, also outside the study area. The interpolated values for these sites are presented at the bottom left of the computer-produced maps.

```
 STA   MODYHR  TOT   WND   TEM  LOW   CL CM CH  DEW  SEVEN  PLUS      NINE        TWO       FOUR
               CLD              CLD             PT   GROUP  INCH      GROUP      GROUP      GROUP
72747  63024    8     4    23    5    0  7  7   19   0 0     0       0    0     2    4     47764
72659  63024    7    11    31    6    9  0  3   21   7 0     0       0    0     0    0     49272
72655  63024    8     0    29    2    1  0  1   22   0 0     0       0    0     0    0     48967
72662  63024    5     6    28    5    9  0  0   19   0 0     0       0    0     0    0     48562
72654  63024    2    13    33    2    9  0  0   18   0 0     0       0    0     0    0     49672
72658  63024    2     9    30    2    1  0  0   22   7 2     0       0    0     2    2     48970
72652  63024    2     6    32    2    1  0  0   20   0 0     0       0    0     0    0     49272
72557  63024    0    14    29    0    0  0  0   22   0 0     0       0    0     0    0     48870
72651  63024    1    14    31    1    1  0  0   20   0 0     0       0    0     0    0     49273
72650  63024    0     8    31    0    0  0  0   17   0 0     0       0    0     0    0     49272
72562  63024    1    13    31    0    0  0  8   16   0 0     0       0    0     0    0     48967
72775  63024    6    13    26    2    9  6  3   13   0 0     0       0    0     0    0     47845
72777  63024    3    10    28    1    2  0  3   13   0 0     0       0    0     0    0     48345
72768  63024    1    10    27    1    1  0  0    9   0 0     0       0    0     0    0     48352
72767  63024    2     9    27    1    1  7  0   11   0 0     0       0    0     0    0     48557
72764  63024    1     0    29    1    1  0  0   17   0 0     0       0    0     2   99     48663
72757  63024    2     5    27    1    2  0  1   21   0 0     0       0    0     2   97     48361
72753  63024    7     6    19    5    9  6  0   19   7 8     0       0    0     2   67     47564
72755  63024    8     5    21    5    5  0  7   17   7 9     0       0    0     2   12     47464
72677  63024    2    12    28    2    1  0  0   13   0 0     0       0    0     0    0     48454
72666  63024    2     9    27    2    9  0  0   17   0 0     0       0    0     0    0     48152
72851  63024    2     9    27    1    2  0  1   14   0 0     0       0    0     2    3     48466
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72870  63024    2     0    24    2    1  0  1    7   0 0     0       0    0     0    0     477-1
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72446  63024    8     8    28    4    9 -1 -1   21   0 0     0       0    0     0    0     49172
72469  63024    1     9    32    1    9  0  0    1   0 0     0       0    0     0    0     49357
```

Figure 4-3: Sample listing of meteorological station synoptic data entering Subprogram METRUN. See Table 4-1 for an explanation of headings.

software was developed and run. This step eliminated obvious errors such as the low cloud cover amount being greater than the total amount of cloud cover, the dew point being greater than the temperature, etc. These errors were either replaced with values found on the surface maps, if they seemed reasonable, or assigned a minus one to represent missing data. Meteorologists searched the data for suspicious values that did not violate any error conditions in the software. When suspicious values were observed, all data (synoptic & surface maps) were reviewed and changes were made as appropriate.

As the data was determined to be accurate, it was assembled, along with the satellite data for program METRUN. The format in which the synoptic data entered program METRUN is presented in Figure 4-3. Appendix II presents a discussion of each product produced by METRUN.

The synoptic data enters program METRUN still in its coded form. Table 4-1 explains the column headings in Figure 4-3. For explanation of the coded data, reference should be made to the WMO synoptic code manual. Minus one is the number arbitrarily assigned to missing data points.

4.2 Discussion of Satellite Images and Their Use in the LACIE Program

Visible and infrared imagery from the Synchronous Meteorological Satellites SMS-1 and SMS-2 were utilized in the estimation of cloud cover for ETP and rainfall calculations. The gridded SMS images were received from the Kansas City Field Service Station by mail

TABLE 4-1

Explanation of Synoptic Abbreviations used in Figures

STA		Station Identifier
MODYR	-	Month, Day, Year
TOT CLD	-	Amount of total cloud cover in eighths
WND	-	Wind Speed in knots
TEM	-	Present temperature in degrees centigrade
LOW CLD	-	Amount of low clouds or middle clouds
CL	-	Low cloud type
CM	-	Middle cloud type
CH	-	High cloud type
DEW PT	-	Present dew point in degrees centigrade
Seven GROUP	-	Previous six hour rainfall, in hundreths of an inch
Plus INCH	-	Inches of rainfall in ones
Nine GROUP	-	Special phenomena group
Two GROUP	-	Previous twenty-four hour rainfall in hundreths of an inch
Four GROUP	-	Maximum and minimum temperature in degrees fahrenheit

after real time acquisition. Only that portion of the full earth disk SMS images covering the Central U.S. (sector KB-8) was utilized. The visible and infrared images used had a resolution of approximately 1.5 and 8 miles respectively.

Four images per day, approximately one per each six-hour interval, were made available. The images were not evenly spaced in time; Table 4-2 shows the approximate times of the images received, and how they were assigned to 6-hour time intervals for purposes of estimating ETP and precipitation.

TABLE 4-2

Time of Occurrence of SMS Images

APPROX. GMT	APPROX. SOLAR TIME AT 105 W	TYPE OF IMAGE	GMT INTERVAL OF CALCULATION FOR PREC.	FOR ETP
01	6 PM	INFRARED	00-06	03-09
07	12 AM	INFRARED	06-12	09-15
15	8 AM	VISIBLE	12-18	15-21
24	5 PM	VISIBLE	18-24	21-03

The overriding consideration for image assignment was the estimation of the 6-hour precipitation at 06, 12, 18 and 24 GMT to coincide with the precipitation observations. Each image was therefore assigned to the time interval of precipitation estimation in which they occurred. The 01 GMT image was used to estimate 6-hour precipitation ending at 06 GMT, etc. Such an assignment caused a misalignment with the ETP calculations which are done for 6 hour intervals centered at observation times (06, 12, 18, 00 GMT) and summed for

24 hours. The misalignment does not cause problems because: 1) it occurs mostly during the nighttime hours when ETP values are near zero; and 2) since ETP is summed for 24 hours an erroneous estimation of cloud cover in one six-hour interval would most likely be compensated in the following periods.

Figures 4-4 and 4-5 show examples of visible and infrared SMS images. The following discussion of the cloud cover analysis procedures will refer to these two images. Cloud cover analysis was done by technicians who visually extracted the information from the images and encode it on computer forms. A transparent overlay such as shown in Figure 4-6 and 4-7 is placed upon the images on a light table. The analyst then defined polygons enclosing uniform or nearly-uniform cloud types in the visible images, and cloud brightness in the infrared images. For each polygon the analyst determined cloud types and amounts in eighths and the latitude-longitude vertices of the polygon. Seven cloud types were identified in the visible images: cumulonimbus, nimbostratus, cumulus congestus, stratus, stratocumulus, cumulus humilis, and cirrus. Two classes of brightness were identified in the infrared images: 1) bright, having a gray-white appearance; and 2) very bright, having a white appearance.

Figures 4-6 and 4-7 include the corresponding computer listings of the encoded cloud-polygon information contained in the SMS images shown in Figures 4-4 and 4-5. Each line represents data for one polygon. For example, the first line at the bottom of Figure 4-4 shows the analysis for the polygon covering northwestern North Dakota. The data were for day 181 (June 30) at 23:45 GMT. The

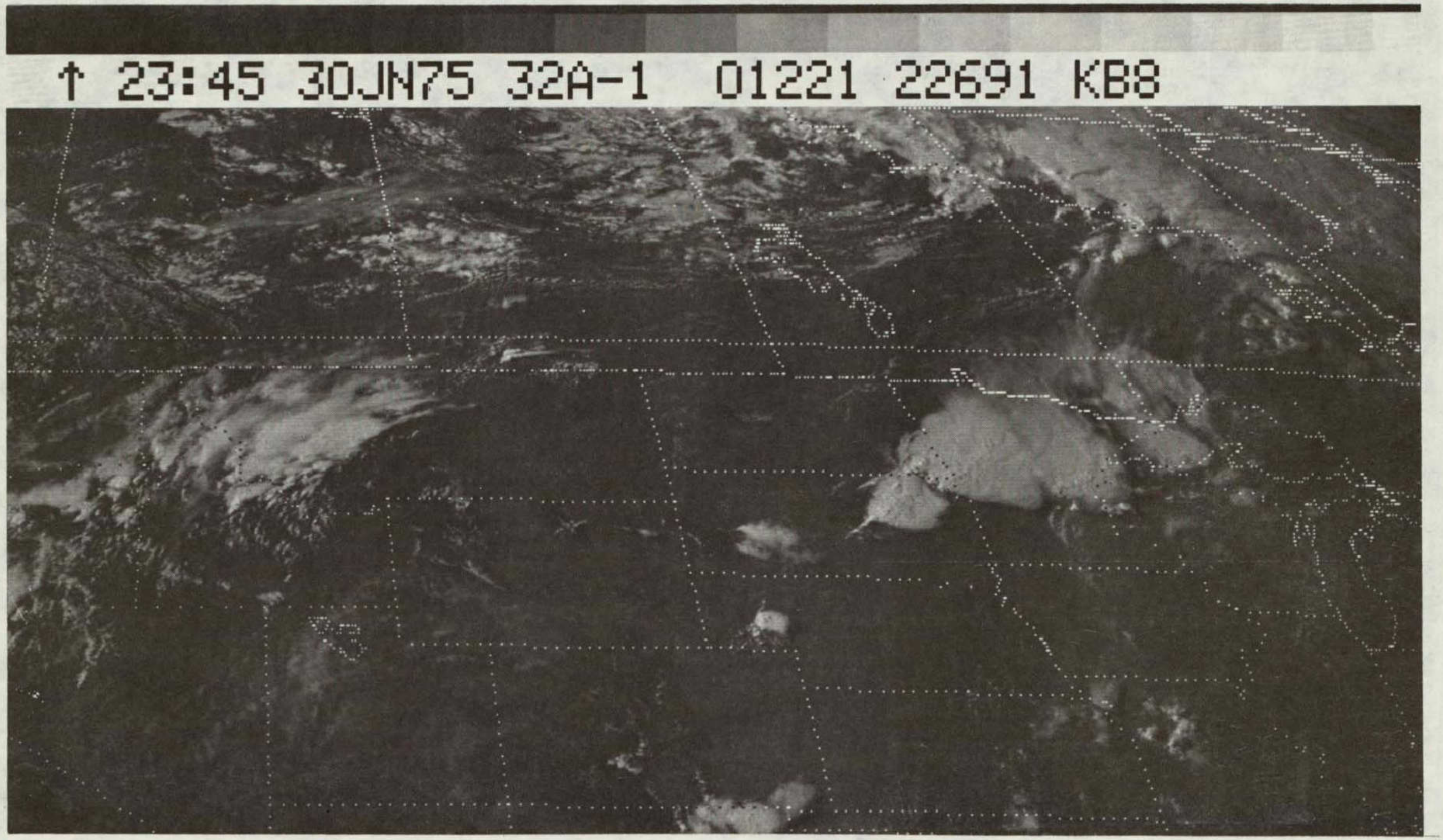
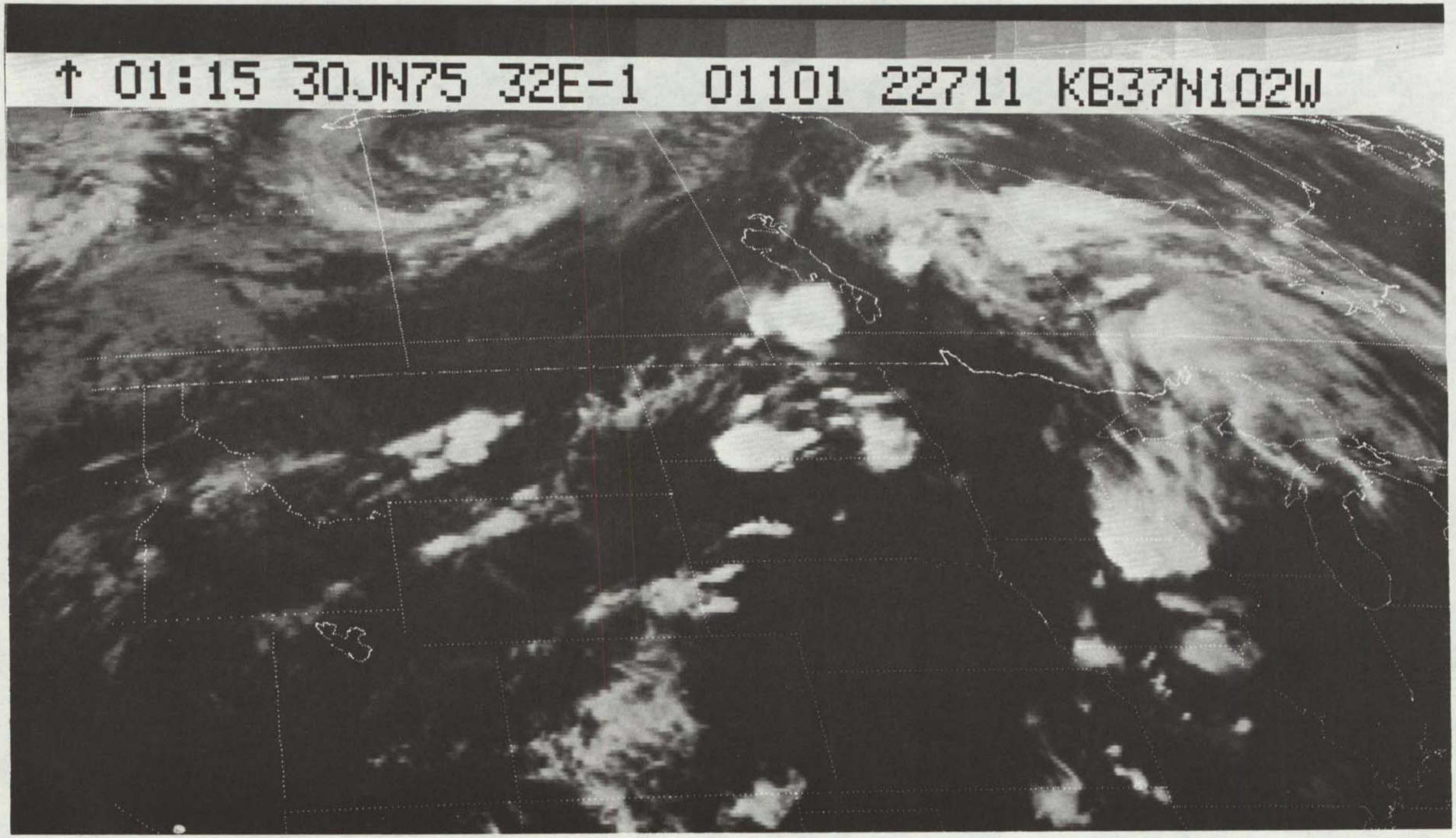


Figure 4-4: An example of a Synchronous Meteorological Satellite (SMS) image in the visible, used for cloud cover estimation. The image was taken at 23:34 GMT, 30 June 1975.



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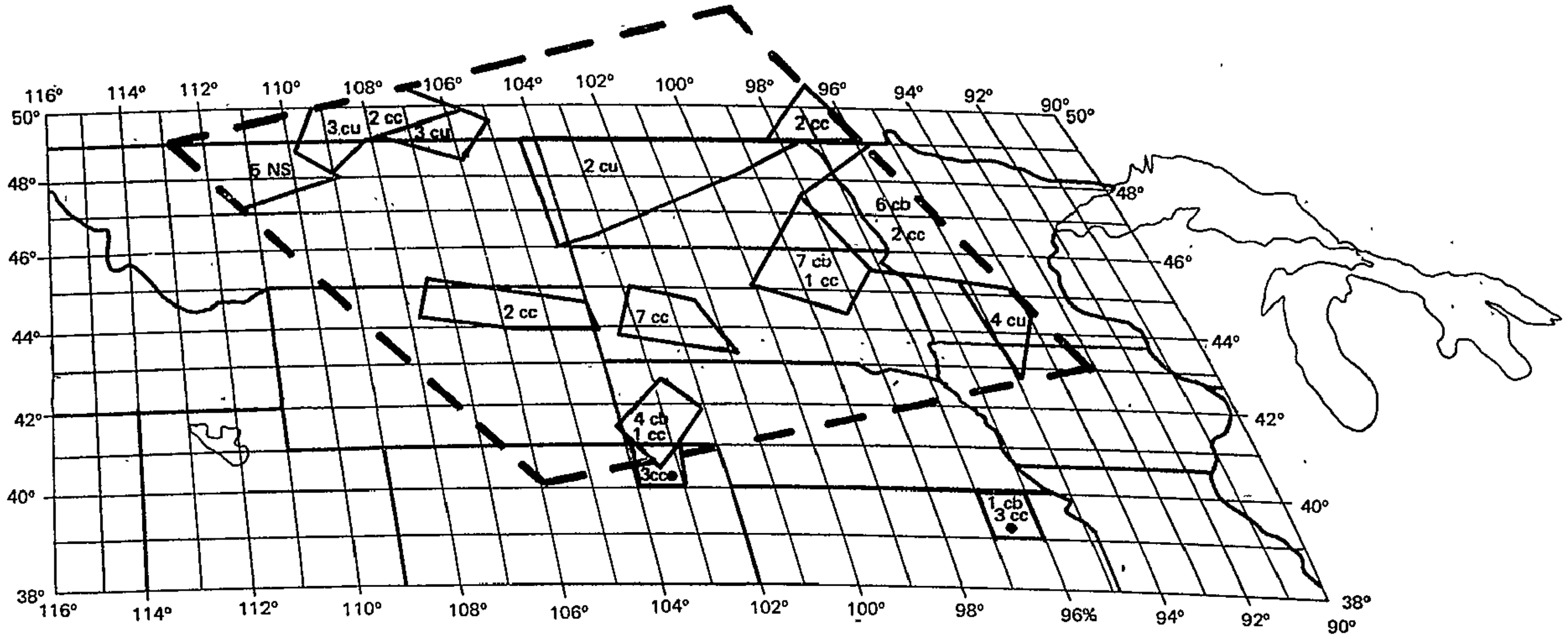
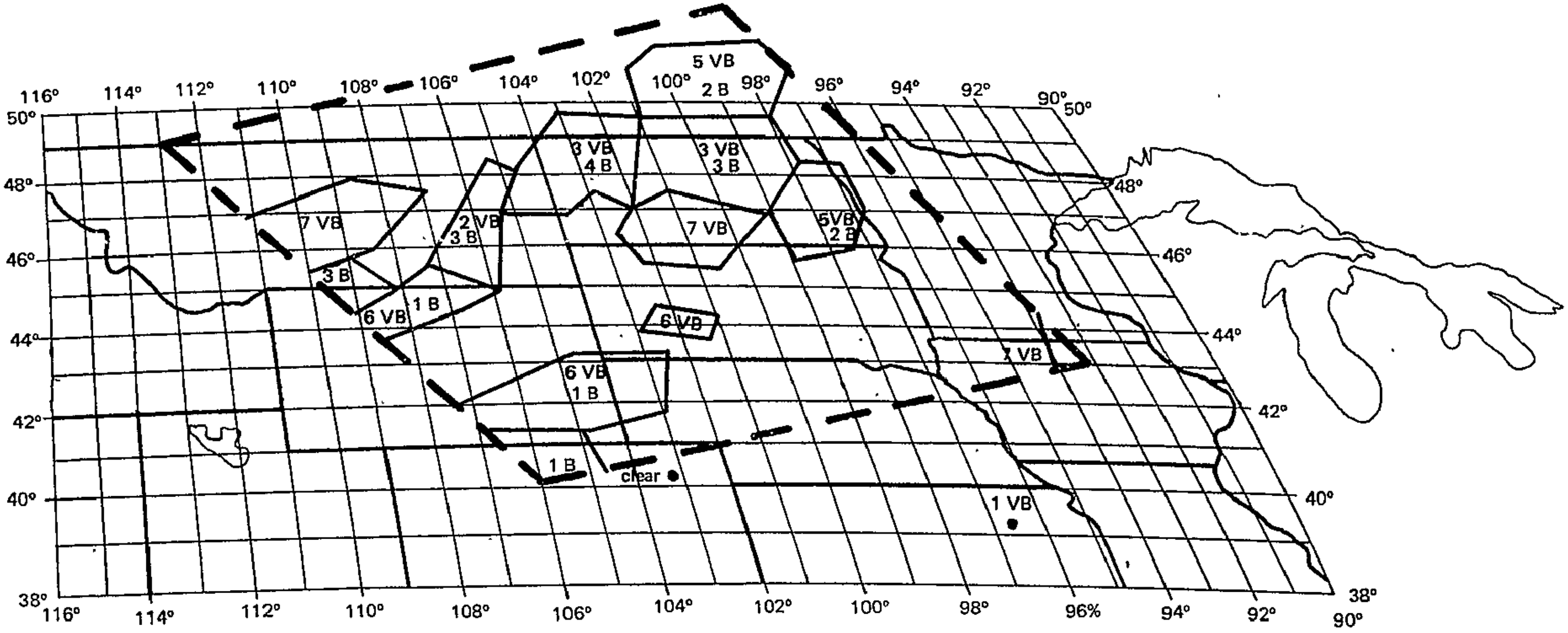
ORIGINAL PAGE IS POOR

Figure 4-5: An example of Synchronous Meteorological Satellite (SMS) image in the infrared used for cloud cover estimation. The image was taken at 0145 GMT, 30 June 1975.



```
DAY  GMT CLOUDS  K LATITUDES-LONGITUDES(W) OF CLOUD  POLYGON VERTICES
181 23450000020003 50.5   96.2 49.1  96.0 49.0  98.3
181 23456020000004 48.9   95.7 45.3  94.0 45.6  97.2 47.6  98.1
181 23450000040004 45.2   94.2 44.4  93.8 42.7  94.8 45.3  95.1
181 23457010000004 47.3   98.1 45.6  97.3 44.3  98.3 45.0 100.0
181 23450000020003 49.0 104.3 49.0  97.7 46.2 104.1
181 23450070000004 45.0 102.8 44.7 101.4 43.1 100.8 43.8 103.3
181 23454010000004 42.5 102.9 42.0 102.1 40.4 103.4 41.3 104.0
181 23450020000004 45.2 107.4 44.6 104.0 43.9 103.9 44.2 107.8
181 23450000030004 49.9 105.7 49.6 105.2 48.5 105.9 49.1 107.9
181 23450020030006 51.0 107.0 50.0 105.7 49.1 108.1 48.2 109.0 48.9 109.9 50.0 109.3
181 23450500000005 49.0 113.0 50.0 109.4 48.8 109.9 48.0 109.0 47.2 111.3
181 23450000030004 41.0 104.0 41.0 102.0 39.0 102.0 39.0 104.0
181 23451030000004 40.0  97.0 40.0  96.0 39.0  96.0 39.0  97.0
```

Figure 4-6: Overlay for SMS image analysis. The heavy dashes outline the area of the cloud cover analysis corresponding to a "rectangle" for which $206 \leq I \leq 232$ and $335 \leq J \leq 362$. Shown on the overlay is the polygon cloud cover analysis for the SMS visible image presented in Figure 4-4. At the bottom is the corresponding computer listings of the encoded cloud-polygon information contained in the SMS image.



```
DAY  GMT CLOUDS  K LATITUDES-LONGITUDES(W) OF CLOUD  POLYGON VERTICES
181  115000000526 53.0   97.5 51.5  97.0 49.6  98.0 49.6 101.0 51.5 101.0 52.8 100.2
181  115000000336 49.6   98.0 48.4  97.8 47.0  99.0 47.6 101.0 47.0 102.1 49.6 101.0
181  115000000526 48.4   97.8 48.4  96.7 47.0  96.8 46.0  97.4 45.8  98.8 47.0  99.0
181  115000000706 47.0   99.0 45.5 100.5 45.7 102.4 46.3 102.7 47.0 102.1 47.6 101.0
181  115000000347 49.6 101.0 47.0 102.1 47.6 102.8 46.9 103.8 46.9 105.5 48.2 104.7 49.6 103.2
181  115000000235 48.2 104.7 46.9 105.5 45.0 106.0 45.5 107.4 48.5 105.3
181  115000000614 45.0 106.0 43.7 108.7 44.3 109.2 45.5 107.3
181  115000000034 45.7 109.0 45.0 108.3 44.4 109.2 45.3 110.2
181  115000000705 48.0 108.7 47.5 107.0 46.0 108.4 45.5 110.1 46.8 111.3
181  115000000604 44.2 101.0 43.6 101.5 43.8 103.0 44.5 102.4
181  115000000616 43.2 102.5 41.8 102.8 41.3 104.0 41.3 107.0 42.0 107.5 43.2 104.5
181  115000000514 41.3 105.0 40.4 104.7 40.0 106.0 41.3 107.0
181  115000000703 44.5   93.7 43.0  93.0 42.8  94.0
181  115000000004 41.0 104.0 41.0 102.0 39.0 102.0 39.0 104.0
181  115000000104 40.0   97.0 40.0  96.0 39.0  96.0 39.0  97.0
```

Figure 4-7: Overlay for SMS image analysis showing the cloud cover analysis and the corresponding computer listings for the SMS infrared image presented in Figure 4-5.

next seven digits represent the cloud amounts in eighths for each of the seven cloud types mentioned. In this example the analyst estimated two-eighths of cumulus humilis. The next two digits represent eighths of very bright and bright areas in the infrared images, and are used only for infrared image analyses. The last digit in this group is the number of vertices in the polygon; three in this example.

The next set of numbers are latitude-longitudes of the cloud polygon vertices, which are used to determine the I, J met cells in the polygon. The cloud amounts and types determined for a polygon are assigned to each of the I, J cells in the polygon and used by the METRUN subprogram with ground station data to calculate ETP and precipitation for each cell. The procedures for these calculations will be discussed in Section 6.

4.3 Historical and Climatological Data

A variety of historical and climatological data has been collected and processed during the study. This data is in five basic forms: 1) station weather observations at 3-hour intervals, 2) station daily temperature extremes and precipitation, 3) station daily class A pan evaporation, 4) monthly temperature and precipitation for climatic divisions, and 5) county annual summaries of spring wheat planted and harvested acreage and total production.

4.3.1 Station 3-hourly Observations

Weather Observations at 3-hour intervals were obtained on magnetic tape covering the months April through September for the years 1950 through 1974. These data were for five stations:

Fargo, North Dakota
Great Falls, Montana
Huron, South Dakota
Pierre, South Dakota
Williston, North Dakota

The data consists of a complete synoptic report each three hours; the data actually used for our purposes were temperature, dew point, wind speed, and cloud types and amounts at six-hour intervals. These quantities are used to calculate daily values of evapotranspiration potential (ETP). The method used for ETP calculation is that of Penman discussed in detail in Section 6. No ETP calculations could be made for Pierre, S.D. due to the lack of cloud type information in the data base.

The twenty-five years of ETP values were used in two applications. One was the calculation of daily soil moisture and plant stress to support the yield model evaluations. The other was to support the weather simulation analyses.

4.3.2 Station Daily Weather Summaries

Daily values of maximum and minimum temperature and total precipitation were obtained on magnetic tape covering the months April through September beginning in 1950. Data for fourteen stations were acquired:

- St. Cloud, Minnesota
- Billings, Montana
- Glasgow, Montana
- Great Falls, Montana
- Havre, Montana
- Miles City, Montana
- Bismarck, North Dakota
- Fargo, North Dakota
- Williston, North Dakota
- Aberdeen, South Dakota
- Huron, South Dakota
- Rapid City, South Dakota
- Sioux Falls, South Dakota
- Sheridan, Wyoming

These data have been in ETP calculations and in the calculation of daily soil moisture and plant stress and in the weather simulation analyses. Historical yield estimates were prepared from these overall analyses.

4.3.3 Daily Evaporation Data

Daily values of reported Class A Pan evaporation data were obtained in hard copy format in the NOAA publication "Climatological Data" for each of the four states for the months April through September of 1950-1974. The number of reporting stations varies from year to year within the states, but in general, 3 to 10 stations report each month in each state. These data were used to verify the calculation technique for ETP and to facilitate spreading of the four-point ETP calculations throughout the region. Figure 4-8 shows the distribution of average daily pan evaporation for the decade

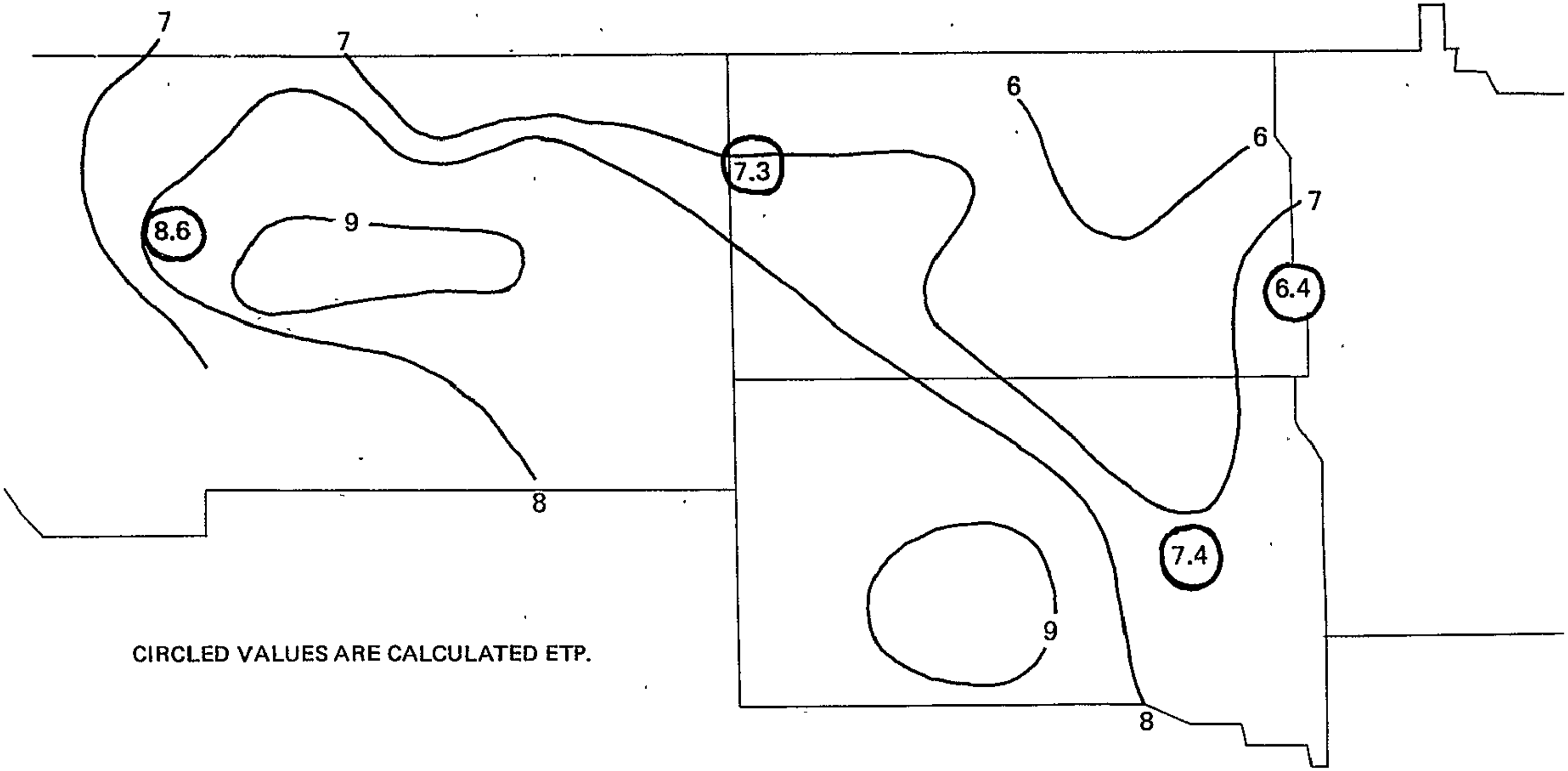


Figure 4-8: Average daily evaporation (1950-1974) for the ten-day period July 10 to July 19.

July 10-19. Circled values are calculated ETP averages for the same decade.

4.3.4 Divisional Climatic Data

These data are in the form of a computer listing and contains, for each of the 34 crop reporting districts in the four states, month-by-month average temperatures and precipitation total for the years 1931-1974. These data have been used in several evaluations, primarily in the formulation and use of algorithms to estimate historical planting dates and initial soil moisture content needed for the historical soil moisture/stress calculations. Using planting date information from Nuttonson (1955), a set of 60 data points was established for various years between 1934 and 1952 at five locations distributed through the region. Four predictive parameters were selected: 1) mean March temperature, 2) mean April temperature, ranking of the 3) March and 4) April precipitation totals within the 44-year data set. A subjective approach was derived in which advances or setbacks in planting date were accumulated as these parameters or combinations of them fell within certain bounds. The weighting factors were iteratively tuned to bring as many as possible of the predicted planting dates within ten days of the reported.

A subjective approach was also used to estimate the moisture content of the soil at the start of each historical growing season. The input parameters were the summed departures from normal rainfall in the previous growing season and the total late summer and fall rainfall which followed the previous growing season.

4.3.5 Spring Wheat Acreage and Production

This information consists of a magnetic tape and hard copy listing of spring wheat acreage planted, acreage harvested and total production at the county level for North Dakota (1929-1973), South Dakota (1926-1974) and Montana (1919-1974). For Minnesota (1921-1973), data is at the crop reporting district level and no planted acreage is given. This information is used to calculate yields and to examine technology adoptation trends. Table 4-3 is an example of processed output for the state of South Dakota. The area shown is the harvested area and is the basis for the yield calculation. The percent abandonment gives the percentage of planted area that was not harvested, and points out three particularly disastrous years: 1933, 1934 and 1936. Figure 4-9 is a visual display of this same data, where the numbers plotted indicate abandonment to the nearest ten percent (i.e., 1 = 10%, 2 = 20%, ..., x = 100%). A rough cyclical pattern is observed: low yields in the 30's, higher yields in the 40's, low yields in the 50's and improving yields through the 60's as agricultural practices were refined. This cyclical pattern is observed to an extent throughout the spring wheat region.

TABLE 4-3: Historical spring wheat data (from NOAA CCEA).

SOUTH DAKOTA

YEAR	AREA (1000 ACRES)	PRODUCTION (1000 BUSHELS)	YIELD (BU/A)	PERCENT ABANDONMENT
1926	2231.0	13294.	5.96	21.1
1927	3084.0	45751.	14.83	1.7
1928	3550.0	36719.	10.34	2.9
1929	3508.0	33734.	9.62	4.6
1930	3586.0	41239.	11.50	4.5
1931	2807.0	16672.	5.94	14.8
1932	3660.0	48153.	13.16	1.2
1933	976.0	3860.	3.95	75.4
1934	117.0	548.	4.68	95.7
1935	3033.8	23785.	7.84	12.6
1936	727.0	3405.	4.68	81.4
1937	2653.0	14276.	5.38	23.5
1938	2971.0	26801.	9.02	20.1
1939	2075.0	17151.	8.27	23.1
1940	2586.0	25137.	9.72	11.1
1941	2714.0	33708.	12.42	4.8
1942	2502.0	39414.	15.75	3.2
1943	2724.0	28468.	10.45	6.6
1944	2854.0	35010.	12.27	3.5
1945	2953.0	45688.	15.47	3.7
1946	3280.0	47653.	14.53	2.7
1947	3349.0	47079.	14.06	2.7
1948	3613.0	47237.	13.07	2.7
1949	3833.0	29455.	7.68	5.5
1950	3054.0	29523.	9.67	4.3
1951	3542.0	51726.	14.60	1.8
1952	3529.0	26145.	7.41	4.6
1953	3137.0	26357.	8.40	6.6
1954	2379.0	22381.	9.41	1.8
1955	2077.0	21809.	10.50	3.7
1956	1394.0	12416.	8.91	39.7
1957	1610.0	29549.	18.35	1.6
1958	1832.0	38472.	21.00	3.1
1959	1505.5	11334.	7.53	27.8
1960	1734.0	28903.	16.67	2.7
1961	1686.0	22213.	13.17	8.3
1962	1273.0	24896.	19.56	2.0
1963	1498.0	19583.	13.07	1.6
1964	1598.0	22484.	14.07	3.7
1965	1634.0	29058.	17.78	1.5
1966	1627.0	24831.	15.26	3.3
1967	1806.0	43976.	24.35	1.6
1968	1684.0	39571.	23.50	2.9
1969	1278.0	26526.	20.76	7.1
1970	1289.0	25188.	19.54	3.4
1971	1614.0	45554.	28.22	2.0
1972	1207.0	30538.	25.30	3.1
1973	218.5	5095.	23.32	2.0

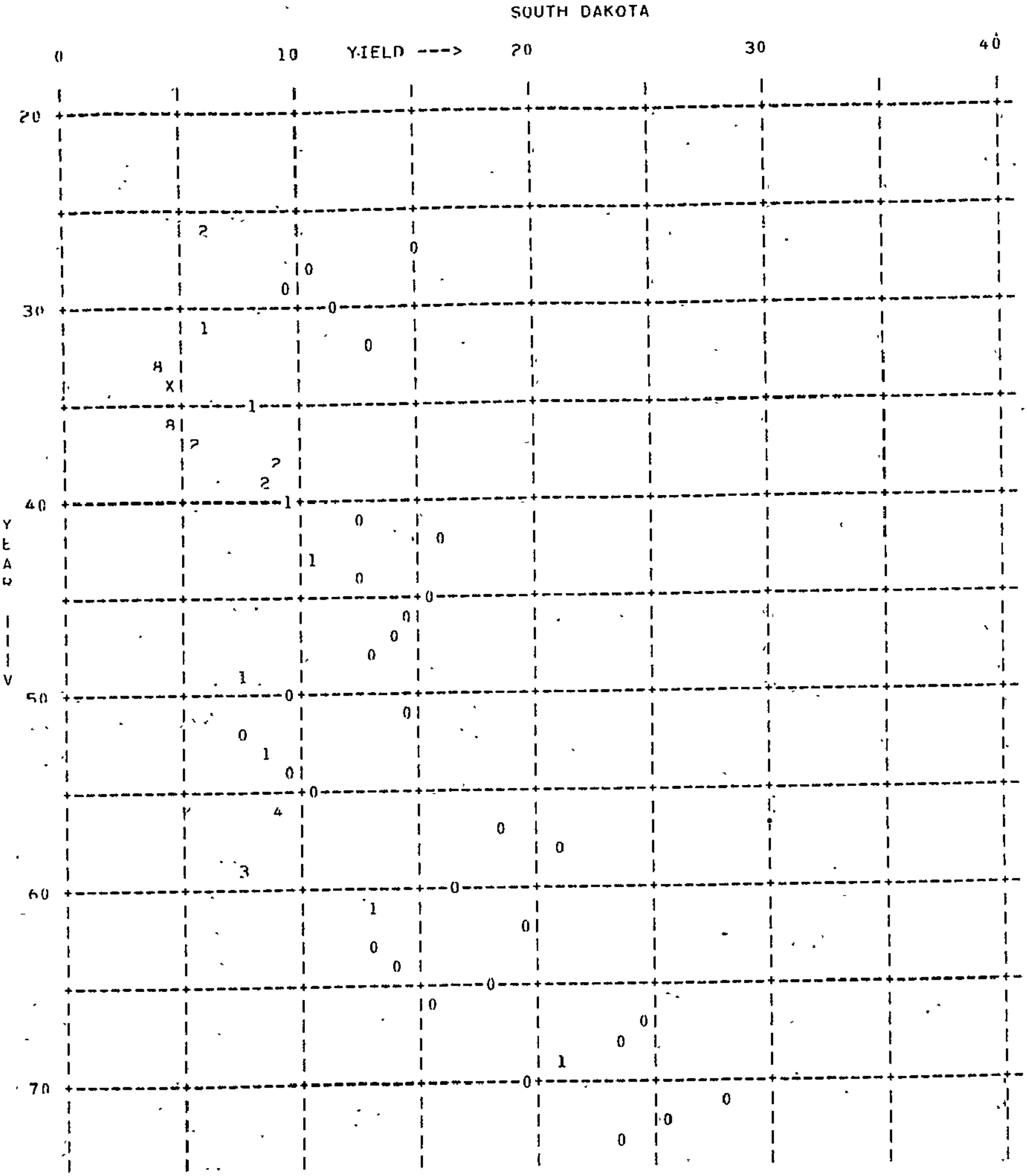


Figure 4-9: Graphical display of S. Dakota yield data 1919-1973. (Numbers, i.e. 1, 2, 3....8 are percentages of abandoned acreage.)

4.4 Ground Truth

4.4.1 University Subcontracts

A subcontract was negotiated with Montana State University and an identical one with North Dakota State University each containing the following statement:

Requirements for the subcontract include the following:

(1) Neutron probe soil moisture profile measurements in,

(a) Three soil categories

Fine Textured Loam
> 150 mm Plant Available Moisture

II. Coarse Texture Sandy Loam
100-150 mm Plant Available Moisture

III. Saline or Other Limited Profile
Mixtures with less than 100 mm water
available to plant

(b) Depth SFC - 10 cm, 10-40 cm, 40 cm-100

(c) Timing weekly or at:

Emergence
Jointing
Heading
Soft Dough
Ripe
Harvest

Both Universities chose to acquire additional data on soil moisture values at greater depths. Appendix III presents the data acquired by each sub-contract. These data have been used extensively in evaluations of system element performance.

4.4.2 Soil Moisture Data Considerations

Several limitations are to be noted with respect to the neutron probe data. Some of these points are presented in the reports by each of the subcontract Project Investigators but they will be presented here for clarity:

(a) The late award of the primary contract delayed entry into the field thus all growth stages were not covered.

(b) Because of the late start, some of the probe access holes could not be located in the field, rather they had to be located on the boundary of the field which often had a reduced plant density.

(c) All soil textures were not equally present in all sites. Therefore the samples are not all inclusive.

(d) The Montana sites have some problems regarding the slope around the probe access hole. Runoff will be affected by the micro-slope as well as by evaporation due to aspect.

(e) Gravel conditions were present in Montana. These conditions will influence the moisture holding capacity and the soil moisture release characteristics.

A meeting was held with the Project Investigators to discuss these limitations in October 1975. The concensus regarding the items noted in a-e was that care should be taken in data evaluation and that an early start is absolutely required, i.e., first week in May in any future program. They felt that the acquired neutron probe data were acquired as carefully as possible but there are inherent limitations to the approach. North Dakota overcame one limitation of the neutron probe approach, i.e., near surface inaccuracy, by taken gravimetric measurements for the top 10 centimeters.

4.4.3 Description of USDA Ground Truth Data

There are four types of data collected for the USDA Ground Truth program: Inventory, ground observation, rainfall, and yield. Inventory data is generally collected at the beginning of the season and contains information such as crop type and field size which should remain constant throughout the season.

Ground observations are taken for a subset of fields in a test site and are scheduled every 18 days to coincide with the ERTS pass. Ground observation data contains information pertaining to the current crop condition such as plant height, growth stage, yield detractants, stand quality, etc. Rainfall data may be collected several times between ground observations and an individual rainfall data card appears for each occurrence of rain. A cumulative total of the amount of rain between ground observations is included on the ground observation card.

Yield data is collected for wheat fields only.

Forty-two test sites are included in the USDA Ground Truth program, however, only 10 lie within the region of interest. Only 9 of the 10 sites have reports. The following information was extracted from these 9 reporting test sites:

1. Growth Stage
2. Stand Quality
3. Rainfall data for all fields
4. Weed Growth
5. Yield Detractants
6. Field Operations
7. Surface Moisture
8. Ground Cover

Software was developed to read the USDA master tape, edit and produce a listing of all pertinent data entries, keep a summarization table, indexed by crop type (spring vs. winter wheat) and observation date, of growth stage, stand quality, ground cover, surface moisture, weed growth, field optns., and yield detractants for each site.

There are two "super sites" in the USDA program where ground observations are taken roughly every 9 days. One of these, Williams County, N.D. is in the region of interest.

The Williams site contains no winter wheat fields but has at the present reported observations for spring wheat fields on the following dates: 5-27-73, 6-3-75, 6-4-75, 6-13-75, 6-24-75, 7-1-75, 7-2-75, 7-9-75, 7-10-75, 7-17-75, 7-18-75, 7-28-75, 7-29-75, 8-5-75, 8-6-75, 8-14-75, 8-15-75. It should be noted that dates occurring in consecutive pairs (i.e., 7-1-75 and 7-2-75) are considered the same observation, with part of the site reporting on the first date and the remaining part on the second. For each date, a separate summary sheet is printed.

Looking at the summary (Figure 4-10) it can be found that 325 fields (9428 acres) were reported by inventory cards to be planted in spring wheat. Of these 325 only 55 (2107 acres) were included in the ground observation data. Each of the seven crop variables is listed followed by its corresponding list of numerical values and a brief description of the meaning of these values. Beside the list of values is a list of the number of acres and the percentage of total acres to which each value was assigned on that particular date. For example, on 6-3-75 165 acres (7.8%) were in Growth Stage #2 (planted - no emergence) and 1942 acres (92.2%) were in Growth Stage #3 (emergence). In this case the total percentage equals 100 but if some fields had neglected to report growth stage the total percentage would reflect this. When viewed consecutively (Figure 4-11) the summary sheets provide a chronological crop history for each test site. (Figure 4-11 graph of USDA data).

```
          DATE               LAND USE CODE & CROP TYPE
       6/ 3/75(154)          100  SPRING WHEAT

  325 FIELDS PLANTED WITH  SPRING WHEAT                 GROUND OBSERVATIONS REPORTED FOR  55 FIELDS (17%)
 9428. ACRES PLANTED WITH  SPRING WHEAT                 GROUND OBSERVATIONS REPORTED FOR 2107. ACRES (22%)

  GROUND      ACREAGE IN      SURFACE MOISTURE      ACREAGE IN      WEED GROWTH      ACREAGE IN
 COVER(%)      CATEGORY         CONDITIONS           CATEGORY                         CATEGORY
 1   0- 19  1957.0( 92.9%)    1-DRY              2107.0(100.0%)     1-NEGLIGIBLE   2107.0(100.0%)
 2  20- 39     0.0(  0.0%)    2-DAMP                0.0(  0.0%)     2-SLIGHT          0.0(  0.0%)
 3  40- 59     0.0(  0.0%)    3-WET                 0.0(  0.0%)     3-MODERATE        0.0(  0.0%)
 4  60- 79     0.0(  0.0%)    4-STANDING WATER      0.0(  0.0%)     4-HEAVY           0.0(  0.0%)
 5  80-100     0.0(  0.0%)

     GROWTH STAGES .                    ACREAGE IN                  STAND            ACREAGE IN
                                         CATEGORY                  QUALITY            CATEGORY
 01-NOT PLANTED                          0.0(  0.0%)               1-POOR               0.0(  0.0%)
 02-PLANTED NO EMERGENCE               165.0(  7.8%)               2-BELOW AVERAGE    275.0( 13.1%)
 03-EMERGENCE                         1942.0( 92.2%)               3-AVERAGE         1303.0( 61.8%)
 04-TILLERING,PREBOOT,PREBUD             0.0(  0.0%)               4-ABOVE AVERAGE    257.0( 12.2%)
 05-BOOTED OR BUDDED                     0.0(  0.0%)               5-EXCELLENT          0.0(  0.0%)
 06-BEGINNING TO HEAD OR FLOWER          0.0(  0.0%)               6-DOES NOT APPLY   165.0(  7.8%)
 07-FULLY HEADED OR FLOWERED             0.0(  0.0%)
 08-BEGINNING TO RIPEN                   0.0(  0.0%)
 09-RIPE MATURE                          0.0(  0.0%)
 10-HARVESTED                            0.0(  0.0%)
 11-DOES NOT APPLY                       0.0(  0.0%)

    FIELD OPERATIONS                  ACREAGE IN                   GROWTH/YIELD      ACREAGE IN
                                       CATEGORY                    DETRACTANTS        CATEGORY
 01-BARE GROUND                        0.0(  0.0%)                 01-SALINITY         0.0(  0.0%)
 02-BARE DISKED/CULTIVATED             0.0(  0.0%)                 02-INSECTS          0.0(  0.0%)
 03-BARE PLOWED                        0.0(  0.0%)                 03-DISEASE          0.0(  0.0%)
 04-BARE SEEDED                     1981.0( 94.0%)                 04-DROUGHT          0.0(  0.0%)
 05-STANDING STUBBLE                   0.0(  0.0%)                 05-MOISTURE         0.0(  0.0%)
 06-STUBBLE DISKED/CULTIVATED          0.0(  0.0%)                 06-WIND             0.0(  0.0%)
 07-STUBBLE PLOWED                     0.0(  0.0%)                 07-HAIL             0.0(  0.0%)
 08-STUBBLE SEEDED                   126.0(  6.0%)                 08-FROST            0.0(  0.0%)
 09-BURNED                             0.0(  0.0%)                 09-BIRDS            0.0(  0.0%)
 10-GRAZED                             0.0(  0.0%)                 10-POT HOLES        0.0(  0.0%)
 11-WINDROWED OR SWATHED               0.0(  0.0%)                 11-UNEVEN STAND     0.0(  0.0%)
 12-MOWED OR COMBINED                  0.0(  0.0%)                 12-WEEDS            0.0(  0.0%)
 13-STACKED OR BALED                   0.0(  0.0%)                 13-WINTERKILL       0.0(  0.0%)
 14-OTHER                              0.0(  0.0%)                 14-LODGING          0.0(  0.0%)
 15-NOT REPORTED                       0.0(  0.0%)                 15-OTHER            0.0(  0.0%)
                                                                   16-NONE          2107.0(100.0%)
```

Figure 4-10: Summary of ground observation data for test site #6 Williams, N.D.

WILLIAMS COUNTY, NORTH DAKOTA

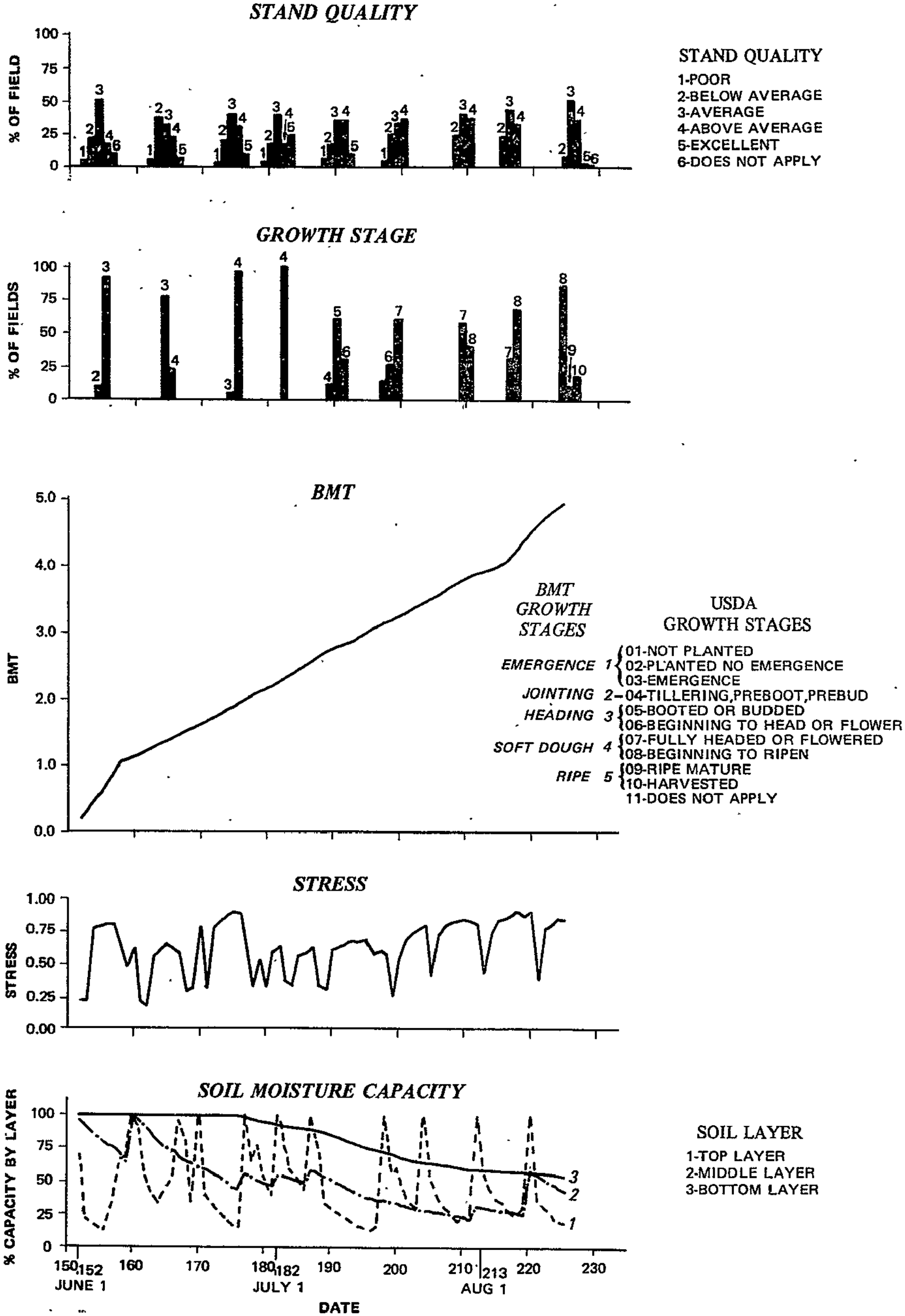


Figure 4-11

5.0 "SYSTEM" TEST OVERVIEW DISCUSSION

The EarthSat Spring Wheat Yield Model System was implemented and test run over the hard red spring wheat regions of Montana, N. Dakota, S. Dakota and western Minnesota during the period 1 June - 30 August 1975. This period included crop phenologies from approximately jointing to ripe in the southern counties of S. Dakota and Minnesota and near planting to ripe over the northern counties of S. Dakota, all of N. Dakota and Montana. The discussions in the remaining sections of Section 5, and in Sections 6, 7 and 8 will provide; (a) an agronomic review of the 1975 Spring Wheat Growing Season, (b) describe the "System" functional elements and internal data flow (c) define operating costs, (d) discuss in detail the performance, i.e., errors and sensitivities of each of the "System" functional elements.

5.1 Agronomic Review of 1975 Spring Wheat Growing Season

The spring wheat planting season was late in all areas due to cool wet conditions. Normally late planting of spring wheat results in lower than normal yields, however the effect of the late planting during the 1975 season varied from state to state. In Montana, the planting season was completed approximately by the middle of June, which is two to three weeks later than normal. During the growing season, Montana had above normal levels of soil moisture, Table 5-1 presents temperature and precipitation averages by state and CRD for 1975. Moreover, the fall season remained warmer than normal with the result that production was much better than normal.

In South Dakota, the planting started later than normal but harvest started at the normal time. South Dakota experienced good growing conditions after planting through the end of June. Starting

TABLE 5-1

	JUNE				JULY				AUGUST			
	1975		AVERAGE		1975		AVERAGE		1975		AVERAGE	
State/CRD	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
Montana	16	108	16	70	24	83	20	34	20	44	19	31
N.C.	16	109			23	100			20	55		
N.E.	17	100			24	88			20	39		
C	16	104			24	92			21	54		
S.C.	16	105			24	81			21	34		
S.E.	16	122			24	52			21	37		
S. Dakota	19	152	20	91	26	44	24	56	24	61	22	50
N.W.	18	141			24	41			23	52		
N.C.	19	157			26	43			24	45		
N.E.	20	143			26	41			23	45		
W.C.	18	150			25	45			24	65		
C	20	157			27	43			24	62		
E.C.	20	135			27	30			24	67		
S.W.	17	145			24	67			24	82		
S.C.	19	191			26	51			25	67		
S.E.	20	149			27	25			24	70		
N. Dakota	18	135	18	80	24	47	21	64	21	41	20	54
N.W.	17	102			23	54			20	53		
N.C.	17	129			24	44			20	26		
N.E.	18	145			23	49			20	34		
W.C.	17	118			24	53			20	47		
C	18	138			24	37			21	34		
E.C.	18	171			24	45			21	43		
S.W.	17	129			24	49			21	48		
S.C.	18	129			24	49			22	44		
S.E.	19	171			25	43			22	39		
Minnesota	19	157	19	103	24	47	22	87	21	39	21	84
N.W.	18	168			24	62			21	37		
N.C.	18	151			23	74			21	31		
W.C.	19	164			25	45			21	39		
C	19	165			24	39			21	32		
S.W.	20	126			26	30			23	60		
S.C.	20	147			25	23			22	40		

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with the first week in June dry winds reduced soil moisture. Moreover, high temperatures occurring during the first, third, and fourth weeks in July increased the rate of ripening. The enhanced ripening rate influenced head filling significantly thereby reducing yields in southern South Dakota. The western and northwestern parts of the state escaped severe drying effects. The hot dry winds extended into the south central zone of North Dakota but the effects were not as severe as in South Dakota.

Except for the south central region of North Dakota, the growing conditions of the spring wheat were better than normal in the northwest and the northeast corners of the state. Like Montana, the northern tier of counties in North Dakota had a warm fall so that no difficulty was experienced during the ripening stages in the harvest of the crop. Minnesota had also a late start in planting but finished at approximately a normal time.

In general, the late plantings of spring wheat suffered more from the effects of hot dry winds than did the earlier plantings. During Mid July, on lighter soils, some of the leaves died back. Some abortion of spiklets within the head were observed in S. Dakota. Montana had an excellent year in spite of the poor prospects normally associated with late planting in that state due to the combination of unusually high soil moisture through the season and warm fall. In North and South Dakota below average rainfall during July was compounded in S. Dakota by the occurrence of unusual durations of hot dry winds.

5.2 "System" Functional Elements and Data Flow Discussion

The EarthSat "System" consists of three main functional elements:

(a) The Plant Environment Diagnostic element

(b) The Plant Growth/Moisture Stress Diagnostic element

(c) The Phenology/Stress Yield Predict element

Figure 5-1 presents the overall data flow structure within the system and identifies the various report volumes (maps and/or listings) that are produced by the current system. Appendix II presents a discussion of the operational daily implementation of the "System". Appendix IV provides detailed software documentation. The test system is currently constrained to IBM 360/370 series systems that have capabilities equal to or greater than the IBM 360/50.

5.2.1. Data Flow and Error Checking

The overall data flow into and through the system is largely automated. The initial processing phases of the satellite data, ground weather observations, soils data, initial soil moisture, growth stage, etc. have, in this 1975 test year utilized manual processes to transform raw hard copy data into digital formats. The processes employed in this manual phase are documented in Section 4 and portions of Section 5. Detailed documentation of the error check software is in Appendix IV. A series of both internal and external logical error checking routines have been introduced into the initial processing modules.

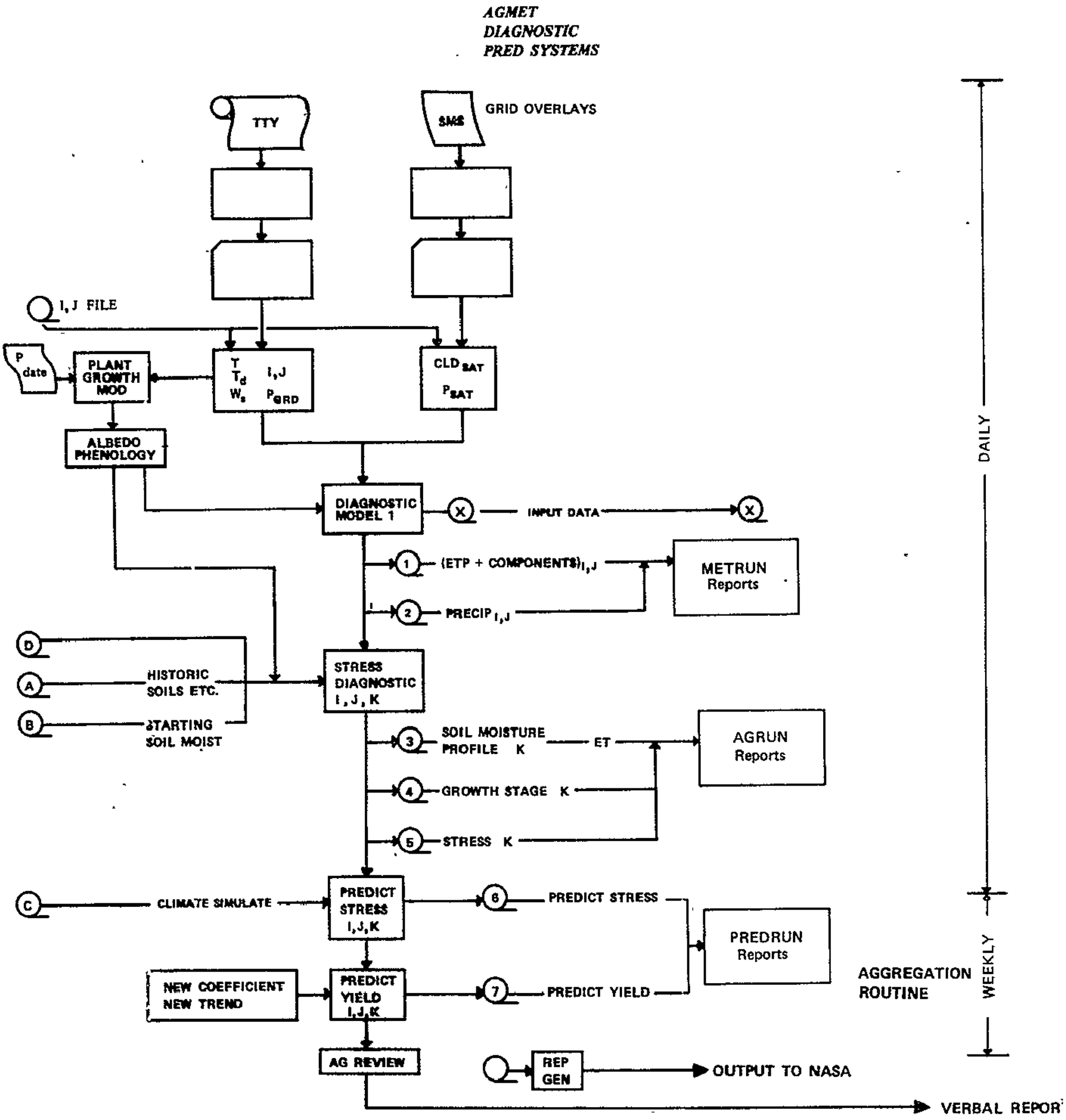


Figure 5- 1 EarthSat "System" data flow and report schedules.

5.2.2 Internal Data Flow

The process of storing data on tape or disc for subsequent use constitutes the majority of internal data flow problems. The EarthSat AGMET "System" uses data internally in either I, J or I, J, K formats. The logical handling of these data requires efficient file manipulation techniques.

The system files include two historic and two current archive files. The historic files are only read and are therefore never updated; the current archive files are continuously updated to reflect current I, J or I, J, K status. The historic files contain soil type, planting data, location, etc. while the current archives contain soil moisture, growth stage, etc.

The major logical processing elements shown in Figure 5-2 use various historical or archive files. Diagnostic I uses the meteorological historical file in an I, J format, the old meteorological archive file in I, J format and produces a new I, J format meteorological file. The Stress Diagnostic uses the new meteorological archive in I, J format, the Agronomic historical archive in I, J, K format and produces a new I, J, K format Agronomic archive file. The Predict Yield processor utilizes the I, J, K format Agronomic historic and Agronomic archive and produces printer output. No data file is created.

The speed of processing in the EarthSat "System" was a major consideration because of the large amounts of data in the system. An analysis early in the study program indicated that the use of Assembler I/O rather than FORTRAN would increase the system speed dramatically. The decision was made to rewrite the file handling into Assembler and an increase in speed by a factor of 2-20 was achieved for both wall clock time and CPU time as compared with the original FORTRAN version. IBM ASSEMBLER F was the primary language used.

5.2.3 Hard Copy Output

The EarthSat AGMET System produces a large amount at printed output. Section 5.4 will discuss the overall data base generated by the 1975 spring wheat test program.

5.3 Test Region Characteristics

The test region which was selected to provide a relatively wide range of latitudes, soils, climates, and farm technologies. The data to be presented in later sections generally show that the selected area was a good one.

5.4 System Test Data Base Discussion

The project objective was to "test EarthSat's Spring Wheat Yield Model System." The test data base for the "System" and each sub-element was developed by daily operations of the full "system" over the four states which contain 29 USDA Crop Reporting Districts (CRD's), 216 counties and approximately 1560 of the 12.5 X 12.5 n.m. cells used in the diagnostic elements of the system. The "System" component elements and the test data base which has been generated for 1975 are included in the following sections.

5.4.1 Plant Environment Diagnostic Data

The plant environment diagnostic element of the "System" has provided the following basic and derived data on a daily basis for the period 1 June - 1 September. The data base developed by this diagnostic element is on the 25 n.m. I, J grid mesh which covers the test states, the boundary regions of the test states and two selected lysimeter sites at Manhattan, Kansas and Akron, Colorado. The data include:

Basic

(1) Temperature (6 hour actuals, maximum and minimum) for 39 first order stations and interpolated to 756 I, J's.

(2) Dew point (6 hour actuals) for 39 first order stations and interpolated to 756 I, J's.

(3) Wind speed (6 hour actuals) for 39 first order stations and interpolated to 756 I, J's.

(4) Cloud amount and type (6 hour actuals).

(5) Ground observed precipitation (6 hour and 24 hour actuals)

Derived

(1) Wheat field albedo (derived from the BMT calculations) at 756 I J's.

(2) Satellite cloud amount and type estimates, i.e., 7 visible cloud types and 2 IR brightness types (derived from the SMS images at 6 hour intervals) for 756 I, J's.

(3) Satellite precipitation estimates (derived statistically from the cloud data) at all appropriate locations for 6 hours, 24 hours and 7 days total.

(4) Incoming Solar radiation (RSOL) attenuated by atmospheric water content, cloud type and amount (derived from the satellite cloud field for daylight hours) at 756 I, J's.

(5) Net radiation (RNET) each 24 hours derived from satellite cloud data and ground observations at all I, J's.

(6) Potential evapotranspiration (ETP) (derived from satellite and ground data using a modified Penman approach) at 24 hour intervals at 756 I, J's.

(7) Precipitation estimates (derived from the satellite cloud data and the ground precipitation observation) for each 6 hours, 24 hours and 7 days.

5.4.2 Plant Growth/Moisture Stress Diagnostic Data

The plant growth/moisture stress diagnostic operates in the 12.5 X 12.5 nautical mile cells and utilizes as basic inputs the Precipitation and ETP diagnoses from the Plant Environment Diagnostic spread equally into the four K cells which surround each 25 n.m. I, J grid point. The data developed during the test by this diagnostic element includes:

(1) Total soil moisture and 3 zone soil profiles in each of the 1560 K cells each 24 hours.

(2) Actual transpiration (ET) in each of the 3 zones derived from calculations using the Baier ET model and the Robertson BMT models in each of the 1560 cells at 24 hour intervals.

(3) Plant growth stage (BMT) derived from the Robertson BMT models for each cell at 24 hour intervals. (BMT stages will vary from I, J, K to I, J, K, as the planting date changes in the K cells).

(4) Stress derived from the relationship $1-\frac{ET}{ETP}$ is derived daily using the Baier model for ET and the previously discussed ETP. Stress values are available in the system for each 24 hours and also for averages over each of the five phenology intervals at all the 1560 K cells.

5.4.3 Phenology/Stress Yield Predict Data

The yield model represents the integration of each of the data elements, basic and derived from each of the other functional elements. The yield element provides data which represents an end of year yield estimate aggregated at several levels:

(1) Cells
(2) Countries
(3) Crop Reporting Districts
(4) States

These levels of aggregation (and disaggregation) provide an ability within the EarthSat system to explain unexpected yields through ground observation, remote sensing (ERTS), etc.

The data base afforded by the 1975 crop year test operation is extensive and provides a substantial basis for detailed quantitative analysis of each functional element of the "System". The results achieved are the subject of the following sections of this report.

5.5 "System" Cost

The implementation and operation of the EarthSat "system" in 1975 provide a partial basis for estimation of future operating cost. Estimated total cost for setup and operation of the "system" was $19,616.00, of this figure $13,116.00 was labor cost and $6,500.00 computer cost. A breakdown of the component costs of setup and operation is shown in Table 5-2.

Setup costs are incurred in creating the data bases, season initialization data files. Costs in this phase of system generation are labor oriented as shown in Table 5-2. Assuming that necessary meteorological and agronomic data are readily available, system setup is linearly dependent on the geographic area (approximately 1,600 active cells) processed. Therefore, a linear increase of the setup subtotal (Table 5-2), is a fair estimate of the cost to set the system up for any geographic area.

Operational costs for day to day operation are clearly dependent on the area size. During 1975 all meteorologic daily data was manually prepared and operational labor costs reflect this. The operation costs (Table 5-2) given are for the 1,600 cells processed for 91 days, during the 1975 growing season.

System Cost Summary

System Setup Costs:	
LABOR	
Systems analyst @ $8.00 for 200 hours	$1,600.00
Meteorologist @ $6.00 for 160 hours	$ 960.00
Technician @ $3.00 for 320 hours	$ 960.00
COMPUTER	$1,000.00
SETUP Subtotal	$4,520.00
System Operation	
LABOR	
System Analyst @ $8.00 for 208 hours	$1,664.00
Meteorologist @ $6.00 for 724 hours	$4,344.00
Technician @ $3.00 for 1,196 hours	$3,588.00
COMPUTER	$5,500.00
OPERATIONAL Subtotal	$15,096.00
Total Cost	$19,616.00

*Unburdened

TABLE 5-2

6.0 PLANT ENVIRONMENT DIAGNOSTIC DISCUSSION, ERROR ANALYSIS AND SENSITIVITY ANALYSES

6.1 Precipitation Diagnoses

Precipitation reports are available every six hours from about two dozen stations in the area of interest (see Figure 4-2). These are used in conjunction with cloud cover determined from SMS imagery to derive precipitation estimates in those I, J cells which do not have precipitation reports. The technique employed in estimating precipitation from cloud cover is based upon "calibration" of cloud types as to their rain potential, and is a refinement, of a technique used by Follansbee (1973). Follanbee's equation for estimating 24 hour average areal precipitation from cloud cover is:

$$P\ (24\ \text{hour}) = k_1\ Cb + k_2 N_s + k_3 Cc$$

where Cb, Ns, and Cc represent percentage of cumulonimbus, nimbostratus, and cumulus congestus clouds and k_1, k_2, k_3 are coefficients of 24 hour rainfall potential for each of the three rain producing cloud types.

Our modified Follansbee equation for six-hour precipitation amount for an I, J cell is:

$$P\ (6\text{-hour}) = [k_1 Cb + k_2 Ns + k_3 Cc]F \cdot \qquad [6\text{-}1]$$

where k_1, k_2, k_3 are coefficients for 6-hour rainfall potential. The initial values for k_1, k_2, k_3 were derived from those given by Follansbee for 24 hours scaled down a factor of four for six-hours, and scaled down another factor of 2.5 to account for the fact that air masses in the north central U.S. have less moisture than the subtropical air masses considered in Follansbee analysis. Additionally, the values of the coefficients are scaled up or down each week by the ratio of precipitation estimated to precipitation observed at the 24 stations in the area.

When cloud cover is expressed by a fraction (0 to 1) and precipitation is in mm/6-hour, the initial values of the coefficients (used in the first week, 1-6 June, calculations) become:

$$k_1 = 2.12; \; k_2 = 0.507; \; k_3 = 0.042$$

F is an adjustment factor calculated from precipitation ground reports and satellite cloud cover at the location of the ground reports as follows:

$$F = \sum_1^n P_R / \sum_1^n P_E \qquad [6\text{-}2]$$

The numerator is simply the summation of the reported 6-hour precipitation, P_R, at stations 1 to n. The denominator is the summation of the estimated 6-hour precipitation, P_E, for the I, J cells of the stations 1 to n, and is calculated by:

$$P_E = k_1 Cb + k_2 Ns + k_3 Cb \qquad [6\text{-}3]$$

F is not allowed to exceed 3 or to be below 1/3. In these cases F is set equal to 1. These are arbitrary limits meant to exclude conditions of insufficient cloud cover information or insufficient rainfall reports over the ground stations, which would make the calculation of the factor F unreliable.

When only infrared images are available (00-06 GMT and 06-12 GMT intervals) then the equation used is simply:

$$P_E = [k_4 B]F \qquad [6\text{-}4]$$

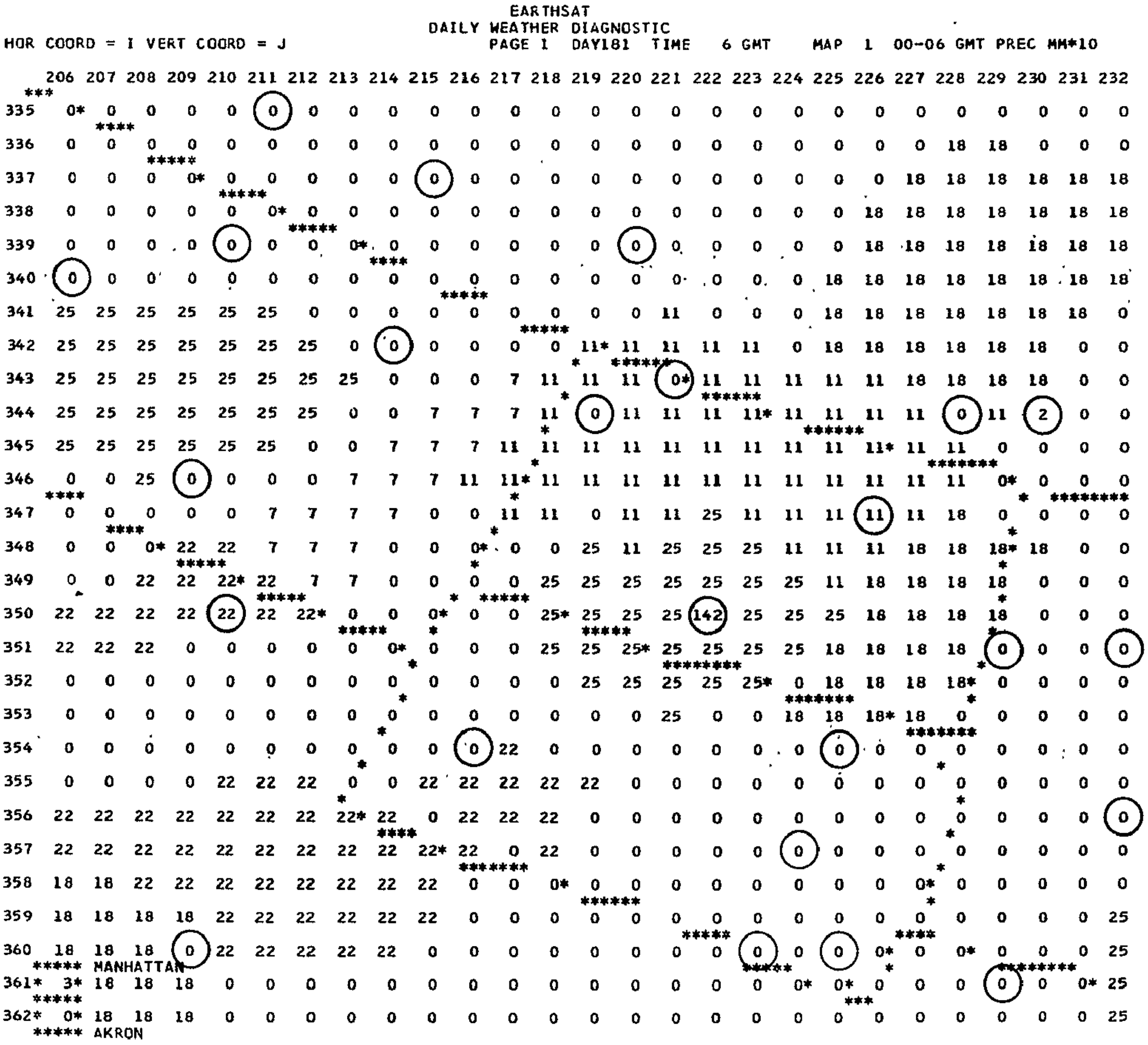
where B is fraction (0 to 1) of brightest (coldest) area; k_4 is an empirically determined constant, and F is an adjustment factor calculated by:

$$F = \sum_1^n P_R / \sum_1^n k_4 B_n \qquad [6\text{-}5]$$

F is calculated from the available stations rainfall reports and the observed infrared brightnesses above these stations. Again, F is not allowed to exceed 3 or to be below 1/3. In these cases F is set equal to 1.

An initial value of $k_4 = 1/3(k_1 + k_2 + k_3) = 0.890$ was chosen for the first week (1-6 June 1975 calculations). Each following week the value of k_4 was scaled up or down by the ratio of precipitation estimated to precipitation observed at the 24 stations in the area during the 12 hour period (00-12 GMT) in which infrared images are used for the precipitation estimates.

Figures 6-1 to 6-3 present samples of the precipitation maps produced daily by METRUN from the cloud cover analysis and ground station reports. Although precipitation is entered once per 24 hours in the AGRUN, it is calculated by METRUN for every 6-hour interval and then summed for the 24 hours. Figures 6-1 and 6-2 are



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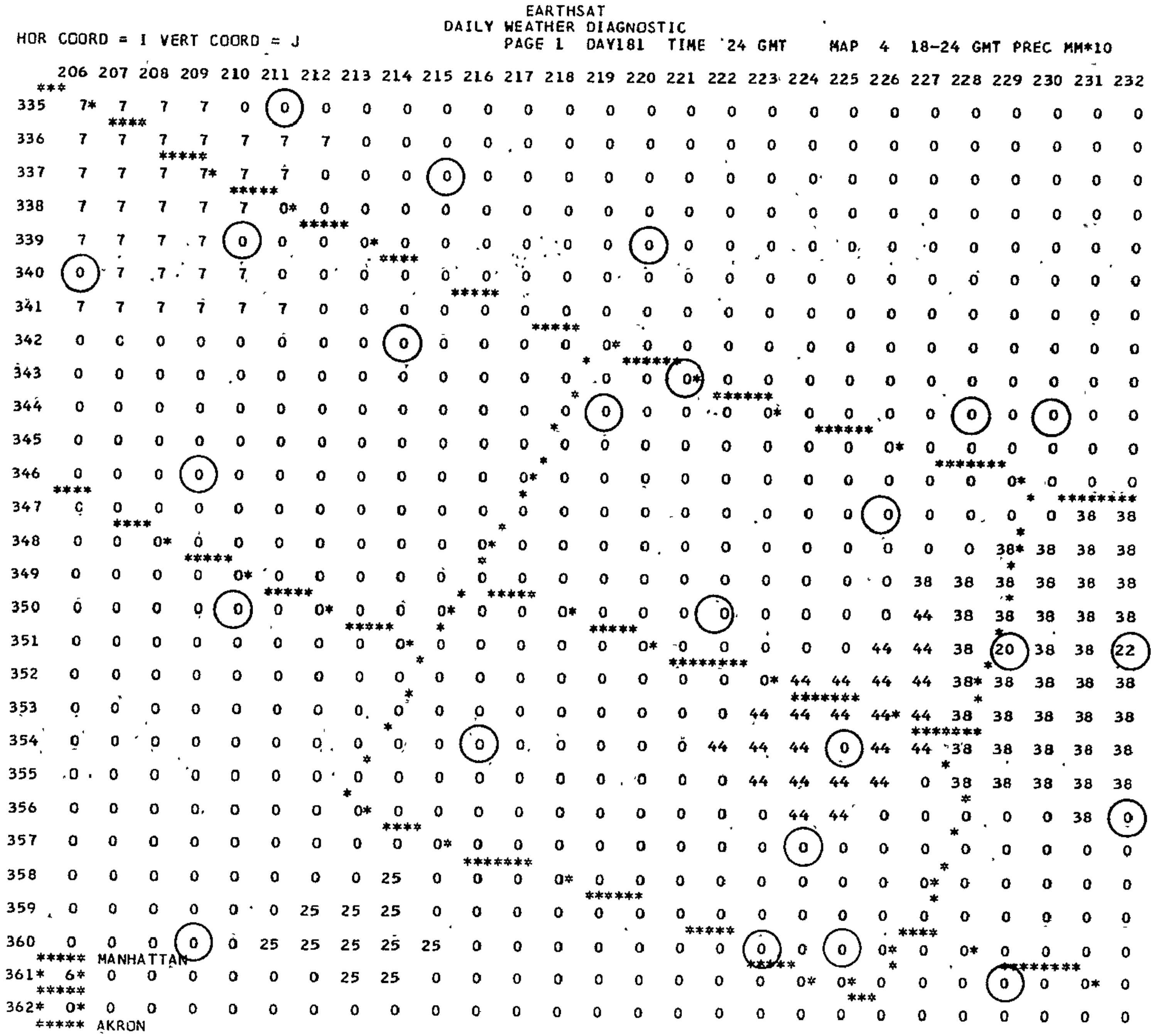
                                                              EARTHSAT
                                                   DAILY WEATHER DIAGNOSTIC
HOR COORD = I VERT COORD = J                              PAGE I   DAY181   TIME    6 GMT     MAP  1  00-06 GMT PREC MM*10

     206  207  208  209  210  211  212  213  214  215  216  217  218  219  220  221  222  223  224  225  226  227  228  229  230  231  232
 ***
335    0*   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
          ****
336    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   18   18    0    0    0
                *****
337    0    0    0    0*   0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   18   18   18   18   18   18
                         *****
338    0    0    0    0    0    0*   0    0    0    0    0    0    0    0    0    0    0    0    0    0   18   18   18   18   18   18   18
                                  *****
339    0    0    0    0    0    0    0    0*   0    0    0    0    0    0    0    0    0    0    0    0   18   18   18   18   18   18   18
                                            ****
340    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   18   18   18   18   18   18   18   18
                                                    *****
341   25   25   25   25   25   25    0    0    0    0    0    0    0    0    0   11    0    0    0   18   18   18   18   18   18   18    0
                                                              *****
342   25   25   25   25   25   25   25    0    0    0    0    0    0   11*  11   11   11   11    0   18   18   18   18   18   18    0    0
                                                                     *   ******
343   25   25   25   25   25   25   25   25    0    0    0    7   11   11   11    0*  11   11   11   11   11   18   18   18   18    0    0
                                                                   *                ******
344   25   25   25   25   25   25   25    0    0    7    7    7   11    0   11   11   11   11*  11   11   11   11    0   11    2    0    0
                                                                 *                               ******
345   25   25   25   25   25   25    0    0    7    7    7   11   11   11   11   11   11   11   11   11   11*  11   11    0    0    0    0
                                                                *                                               *******
346    0    0   25    0    0    0    0    7    7    7   11   11*  11   11   11   11   11   11   11   11   11   11   11    0*   0    0    0
    ****                                                     *                                                              *  ********
347    0    0    0    0    0    7    7    7    7    0    0   11   11    0   11   11   25   11   11   11   11   11   18    0    0    0    0
           ****                                            *                                                              *
348    0    0    0*  22   22    7    7    7    0    0    0*   0    0   25   11   25   25   25   11   11   11   18   18   18*  18    0    0
                    *****                               *                                                                *
349    0    0   22   22   22*  22    7    7    0    0    0    0   25   25   25   25   25   25   25   11   18   18   18   18    0    0    0
                              *****                   *  *****                                                           *
350   22   22   22   22   22   22   22*   0    0    0*   0    0   25*  25   25   25  142   25   25   25   18   18   18   18    0    0    0
                                        *****      *                  *****                                             *
351   22   22   22    0    0    0    0    0    0*   0    0    0   25   25   25*  25   25   25   25   18   18   18   18    0    0    0    0
                                                 *                              *********                             *
352    0    0    0    0    0    0    0    0    0    0    0    0    0   25   25   25   25   25*   0   18   18   18   18*   0    0    0    0
                                                *                                             *******                *
353    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   25    0    0   18   18   18*  18    0    0    0    0    0
                                             *                                                               *******
354    0    0    0    0    0    0    0    0    0    0    0   22    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
                                          *                                                                       *
355    0    0    0    0   22   22   22    0    0   22   22   22   22   22    0    0    0    0    0    0    0    0    0    0    0    0    0
                                        *                                                                           *
356   22   22   22   22   22   22   22   22*  22    0   22   22   22    0    0    0    0    0    0    0    0    0    0    0    0    0    0
                                             ****                                                                  *
357   22   22   22   22   22   22   22   22   22   22*  22    0   22    0    0    0    0    0    0    0    0    0    0    0    0    0    0
                                                       *******                                                   *
358   18   18   22   22   22   22   22   22   22   22    0    0    0*   0    0    0    0    0    0    0    0    0*   0    0    0    0    0
                                                                      ******                                    *
359   18   18   18   18   22   22   22   22   22   22    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   25
                                                                                  *****                     ****
360   18   18   18    0   22   22   22   22   22    0    0    0    0    0    0    0    0    0    0    0    0*   0    0*   0    0    0   25
  ***** MANHATTAN                                                                        ******            *             ********
361*   3*  18   18   18    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0*   0*   0    0    0    0    0    0*  25
  *****                                                                                               ***
362*   0*  18   18   18    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0   25
  ***** AKRON
```

Figure 6-1: Sample computer printout map of rainfall (in mm x 10) for the period 00-06 GMT, 30 June 1975 produced by Subprogram METRUN. Rainfall values for each I, J cell were calculated as explained in text from the SMS infrared image shown in Figure 4-4. Circled values are actual rainfall reports for the same time period.



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                                                  EARTHSAT
                                          DAILY WEATHER DIAGNOSTIC
HOR COORD = I VERT COORD = J                    PAGE 1  DAY181  TIME  24 GMT    MAP  4  18-24 GMT PREC MM*10

    206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232
  ***
335   7*  7   7   7   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
         ****
336   7   7   7   7   7   7   7   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
              *****
337   7   7   7   7*  7   7   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
                     *****
338   7   7   7   7   7   0*  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
                            *****
339   7   7   7   7   0   0   0   0*  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
                                   ****
340   0   7   7   7   7   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
                                          *****
341   7   7   7   7   7   7   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
                                                  *****
342   0   0   0   0   0   0   0   0   0   0   0   0   0   0*  0   0   0   0   0   0   0   0   0   0   0   0   0
                                                        *  ******
343   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0*  0   0   0   0   0   0   0   0   0   0   0
                                                       *            ******
344   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0*  0   0   0   0   0   0   0   0   0
                                                     *                        ******
345   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0*  0   0   0   0   0   0
                                                   *                                      *******
346   0   0   0   0   0   0   0   0   0   0   0   0*  0   0   0   0   0   0   0   0   0   0   0   0*  0   0   0
   ****                                          *                                                 *  ********
347   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  38  38
         ****                                  *                                                  *
348   0   0   0*  0   0   0   0   0   0   0   0*  0   0   0   0   0   0   0   0   0   0   0   0  38* 38  38  38
                ******                       *                                                   *
349   0   0   0   0   0*  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  38  38  38  38  38  38
                        *****              *  *****                                              *
350   0   0   0   0   0   0   0*  0   0   0*  0   0   0*  0   0   0   0   0   0   0   0  44  38  38  38  38  38
                                *****    *              *****                                   *
351   0   0   0   0   0   0   0   0   0*  0   0   0   0   0   0*  0   0   0   0   0  44  44  38  20  38  38  22
                                       *                        *********                      *
352   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0* 44  44  44  44  38* 38  38  38  38
                                      *                                     *******           *
353   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  44  44  44  44* 44  38  38  38  38  38
                                    *                                                   *******
354   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  44  44  44   0  44  44  38  38  38  38  38
                                  *                                                        *
355   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  44  44  44  44   0  38  38  38  38  38
                                *                                                            *
356   0   0   0   0   0   0   0   0*  0   0   0   0   0   0   0   0   0   0  44  44   0   0   0   0   0  38   0
                                    ****                                                    *
357   0   0   0   0   0   0   0   0   0   0*  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
                                            *******                                        *
358   0   0   0   0   0   0   0   0  25   0   0   0   0*  0   0   0   0   0   0   0   0   0*  0   0   0   0   0
                                                        ******                            *
359   0   0   0   0   0   0  25  25  25   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
                                                                  *****                ****
360   0   0   0   0   0  25  25  25  25  25   0   0   0   0   0   0   0   0   0   0   0*  0   0*  0   0   0   0
  ***** MANHATTAN                                                       *****         *         *********
361*  6*  0   0   0   0   0   0  25  25   0   0   0   0   0   0   0   0   0   0*  0*  0   0   0   0   0   0*  0
  *****                                                                           ***
362*  0*  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
  ***** AKRON
```
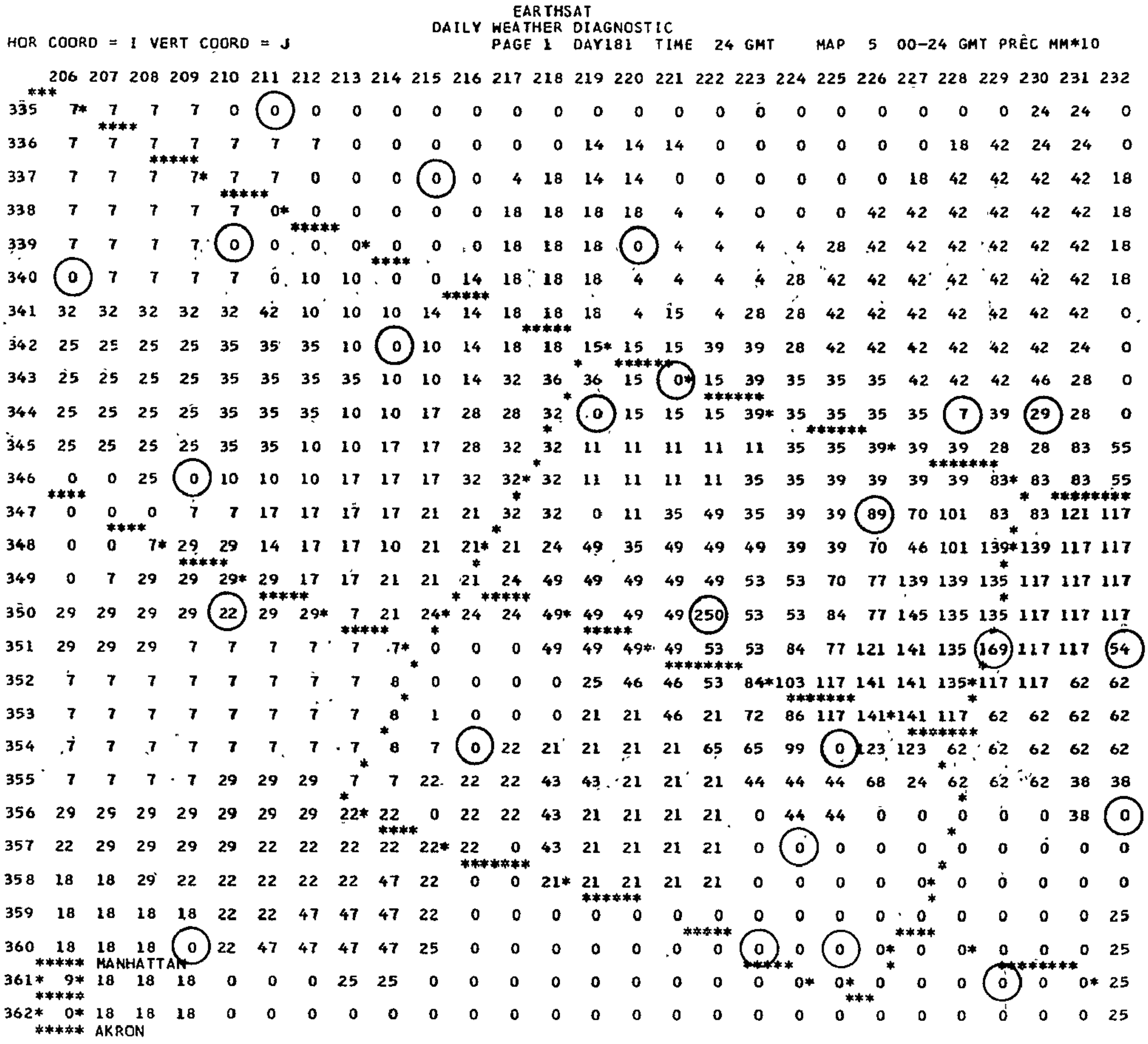

Figure 6-2: Sample computer printout map of rainfall (in mm x 10) for the period 18-24 GMT, 30 June 1975 produced by Subprogram METRUN. Rainfall values for each I, J cell were calculated as explained in text from the SMS visible image cloud cover shown in Figure 4-4. Circled values are actual rainfall reports for the same time period.



```
                                                  EARTHSAT
                                          DAILY WEATHER DIAGNOSTIC
HOR COORD = I VERT COORD = J                    PAGE 1  DAY181  TIME  24 GMT    MAP  5  00-24 GMT PREC MM*10

    206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232
  ***
335   7*  7   7   7   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  24  24   0
         ****
336   7   7   7   7   7   7   7   0   0   0   0   0   0  14  14  14   0   0   0   0   0   0  18  42  24  24   0
              *****
337   7   7   7   7*  7   7   0   0   0   0   0   4  18  14  14   0   0   0   0   0   0  18  42  42  42  42  18
                     *****
338   7   7   7   7   7   0*  0   0   0   0   0  18  18  18  18   4   4   0   0   0  42  42  42  42  42  42  18
                            *****
339   7   7   7   7   0   0   0   0*  0   0   0  18  18  18   0   4   4   4   4  28  42  42  42  42  42  42  18
                                    ****
340   0   7   7   7   7   0  10  10   0   0  14  18  18  18   4   4   4   4  28  42  42  42  42  42  42  42  18
                                           *****
341  32  32  32  32  32  42  10  10  10  14  14  18  18  18   4  15   4  28  28  42  42  42  42  42  42  42   0
                                                   *****
342  25  25  25  25  35  35  35  10   0  10  14  18  18  15* 15  15  39  39  28  42  42  42  42  42  42  24   0
                                                        *   ******
343  25  25  25  25  35  35  35  35  10  10  14  32  36  36  15   0* 15  39  35  35  35  42  42  42  46  28   0
                                                       *             ******
344  25  25  25  25  35  35  35  10  10  17  28  28  32   0  15  15  15  39* 35  35  35  35   7  39  29  28   0
                                                     *                         ******
345  25  25  25  25  35  35  10  10  17  17  28  32  32  11  11  11  11  11  35  35  39* 39  39  28  28  83  55
                                                    *                                      *******
346   0   0  25   0  10  10  10  17  17  17  32  32* 32  11  11  11  11  35  35  39  39  39  39  83* 83  83  55
    ****                                          *                                                 *  ********
347   0   0   0   7   7  17  17  17  17  21  21  32  32   0  11  35  49  35  39  39  89  70 101  83  83 121 117
          ****                                  *                                                  *
348   0   0   7* 29  29  14  17  17  10  21  21* 21  24  49  35  49  49  49  39  39  70  46 101 139*139 117 117
                 *****                        *                                                   *
349   0   7  29  29  29* 29  17  17  21  21  21  24  49  49  49  49  49  53  53  70  77 139 139 135 117 117 117
                         *****              *  *****                                              *
350  29  29  29  29  22  29  29*  7  21  24* 24  24  49* 49  49  49 250  53  53  84  77 145 135 135 117 117 117
                                 *****    *              *****                                   *
351  29  29  29   7   7   7   7   7   7*  0   0   0  49  49  49* 49  53  53  84  77 121 141 135 169 117 117  54
                                        *                        ********                       *
352   7   7   7   7   7   7   7   7   8   0   0   0   0  25  46  46  53  84*103 117 141 141 135*117 117  62  62
                                       *                                     *******           *
353   7   7   7   7   7   7   7   7   8   1   0   0   0  21  21  46  21  72  86 117 141*141 117  62  62  62  62
                                     *                                                   *******
354   7   7   7   7   7   7   7   7   8   7   0  22  21  21  21  21  65  65  99   0 123 123  62  62  62  62  62
                                   *                                                        *
355   7   7   7   7  29  29  29   7   7  22  22  22  43  43  21  21  21  44  44  44  68  24  62  62  62  38  38
                                 *                                                            *
356  29  29  29  29  29  29  29  22* 22   0  22  22  43  21  21  21  21   0  44  44   0   0   0   0   0  38   0
                                     ****                                                    *
357  22  29  29  29  29  22  22  22  22  22* 22   0  43  21  21  21  21   0   0   0   0   0   0   0   0   0   0
                                             *******                                        *
358  18  18  29  22  22  22  22  22  47  22   0   0  21* 21  21  21  21   0   0   0   0   0*  0   0   0   0   0
                                                         ******                            *
359  18  18  18  18  22  22  47  47  47  22   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  25
                                                                   *****                ****
360  18  18  18   0  22  47  47  47  47  25   0   0   0   0   0   0   0   0   0   0   0*  0   0*  0   0   0  25
   ***** MANHATTAN                                       *****         *          ********
361*  9* 18  18  18   0   0   0  25  25   0   0   0   0   0   0   0   0   0   0*  0*  0   0   0   0   0   0* 25
   *****                                                                           ***
362*  0* 18  18  18   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  25
   ***** AKRON
```

Figure 6-3: Sample computer printout map of rainfall (in mm x 10) for the period 00-24 GMT, 30 June 1975 produced by Subprogram METRUN, as explained in text. Circled values are actual rainfall reports for the same period.

the computer-produced precipitation maps for June 30, 1975, for 00-06 GMT and 18-24 GMT, obtained from an analysis of SMS images shown in Figure 4-4 and 4-5. Values of station observed precipitation are encircled. Figure 6-3 presents the total precipitation for 30 June.

6.2 Precipitation Error Analysis

In comparing the METRUN precipitation estimates with precipitation observations to determine how good the METRUN estimates are, we should be aware that the point precipitation observations themselves have errors when these are translated to area averages. We will, therefore, define the range of these errors before presenting the comparisons with the METRUN estimates.

For the error analysis on the precipitation observations we shall apply results obtained by other researchers that have analyzed precipitation variability in the Midwest U.S., and results obtained by our own analyses.

6.2.1 Metcell Rainfall Analysis

When the point precipitation observations are translated to areal averages they yield values which may depart from the true average by an error E. Huff (1972), using observations from a dense raingauge network in Illinois, was able to express the summertime areal precipitation error by means of the following regression equations:

For monthly rainfall,

$$\log E = 1.3132 + 0.72 \log Pm + 0.73 \log G - 0.56 \log A \qquad [6\text{-}6]$$

For individual storms,

$$\log E = -1.5069 + 0.65 \log P + 0.82 \log G - 0.22 \log T - 0.45 \log A \qquad [6\text{-}7]$$

where E is the average sampling error in inches,

P is areal mean precipitation in inches,

G is gauge density in mi^2 $(gauge)^{-1}$,

T is storm duration in hours,

A is area in mi^2.

Figure 6-4 illustrates graphically the Huff precipitation errors expected for an area the size of our I, J cell (approximately 827 square miles) for one and three observations per cell for periods of one summer month, and for three-hour storm duration, the median summer storm duration in our area of interest. Figure 6-4 may be used only to give an order of magnitude estimation of the error because our cell is larger than the maximum area (550 square miles) considered by Huff, and because, as Huff found, there is considerable difference in the magnitude of the storm sampling errors. Table 6-1 lists the range of concentration of Cooperative Observers climatic stations for the Crop Report Districts (CRD) in the test area. Cooperative stations reports represent the densest precipitation information available routinely. These can be obtained from the NOAA Climatic Center a few months after the fact. Cooperative stations reports range from about one to three per cell, and from 10 to 57 per Crop Reporting District. Approximately half take precipitation observations in the evening hours (5-6 p.m.) the rest at all other times of the

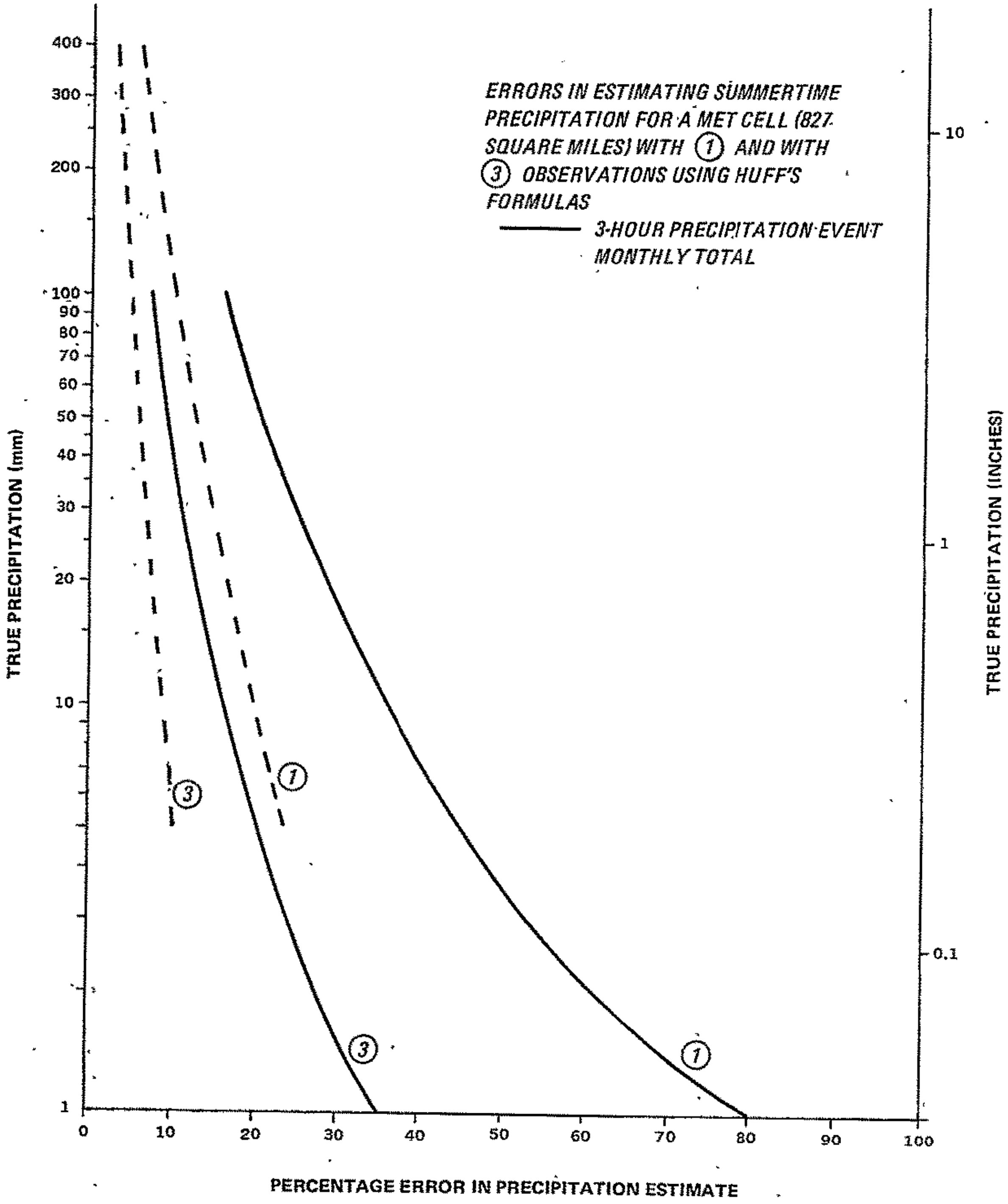


Figure 6-4: Percentage error in precipitation estimate for a Met Cell (827 square miles) with one and with three observing stations using Huff's formulas (1972).

TABLE 6-1

Range of Concentration of Cooperative Observers Climatic Stations (COCS) for Crop Reporting Districts (CRD) in the Test Area.

	number	miles^2/COCS	COCS/cell	COCS/CRD
South Dakota	189	259-664*	3.2-1.2*	12-35*
North Dakota	163	342-551	2.4-1.5	10-27
Eastern Montana	204	467-647	1.8-1.3	32-57
Western Minnesota	96	437-625	1.9-1.3	12-23

* Figures represent maximum and minimum values for Crop Reporting Districts in the State.

day. Although the observation time difference does not appreciably affect precipitation estimation for periods longer than a few days, it essentially reduces in half the usable reports on a per day basis.

In our daily rainfall error analysis, we have utilized only those stations that take observations within one hour of 00 GMT (5-6 p.m., local time). This reduced the number of usable Metcells to 239 (32% of total), the great majority (164) having only one report.

Finally, we need to know the range of daily precipitation amounts expected in order to estimate the range of errors on a cell basis. Figure 6-5 illustrates such daily precipitation amount for June-August 1975 as a frequency distribution and as cumulative percentages. A total of 6,399 rain observations (31% of all observations) from all the cooperative stations reporting between 5 and 6 p.m. were used to construct Figure 6-5. Thus, we see that approximatley two-thirds of the daily rainfall values were below 6 mm (< 1/4") and 95% were below 25 mm (< 1"). Figure 6-6 presents, in a similar manner, frequency distributions of monthly rainfall observed by all cooperative stations during June-August, 1975. Table 6-2 presents typical errors in percentage of true precipitation for a Metcell with one, two, or three observations covering the range of expected daily (three-hour event) and monthly amounts. More than 90% of the times errors in areal rainfall estimates for a cell will fall within the four values boxed by dashed lines. In the above conclusion we have made the implicit assumption that the frequency distribution of the

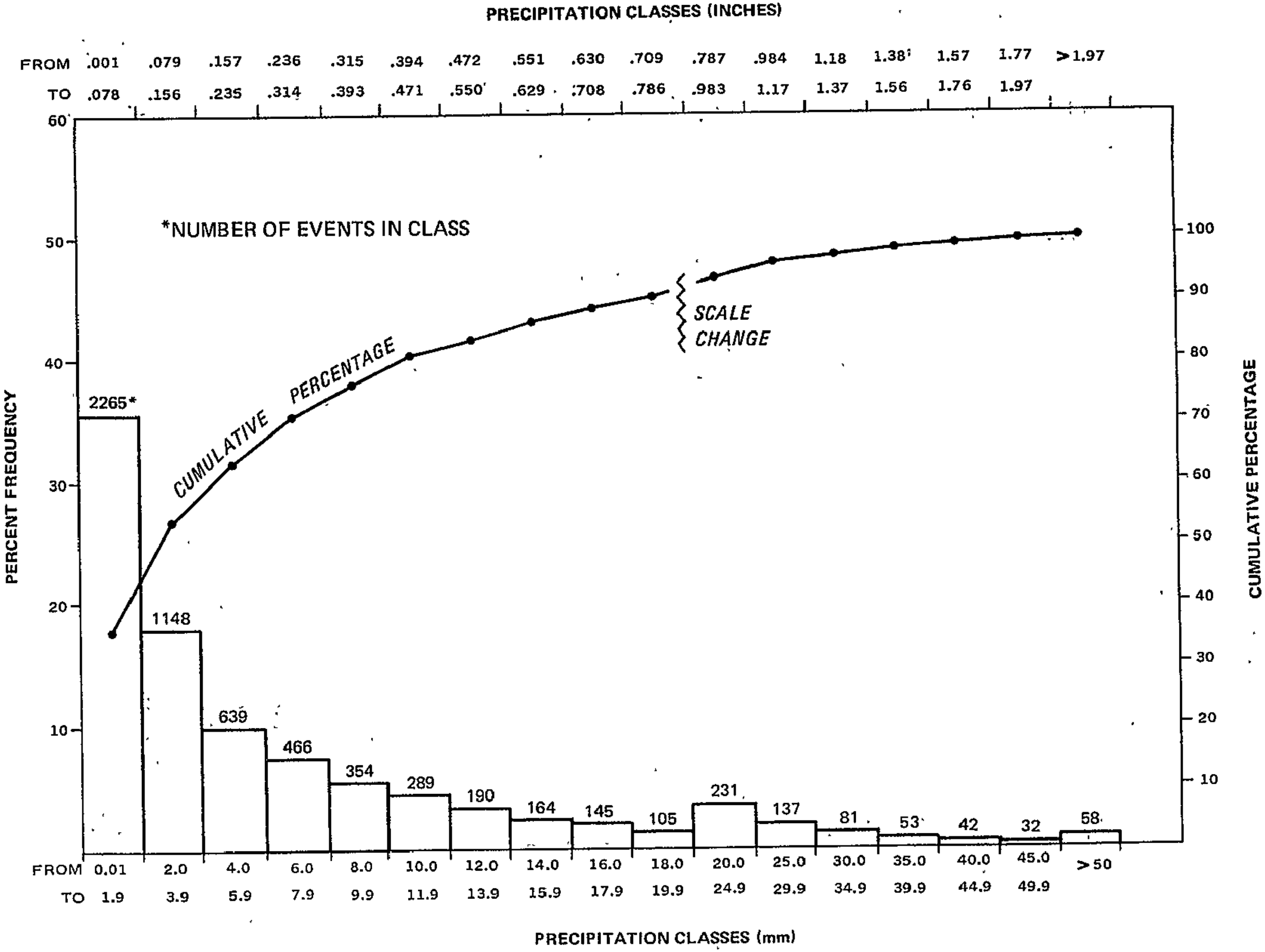
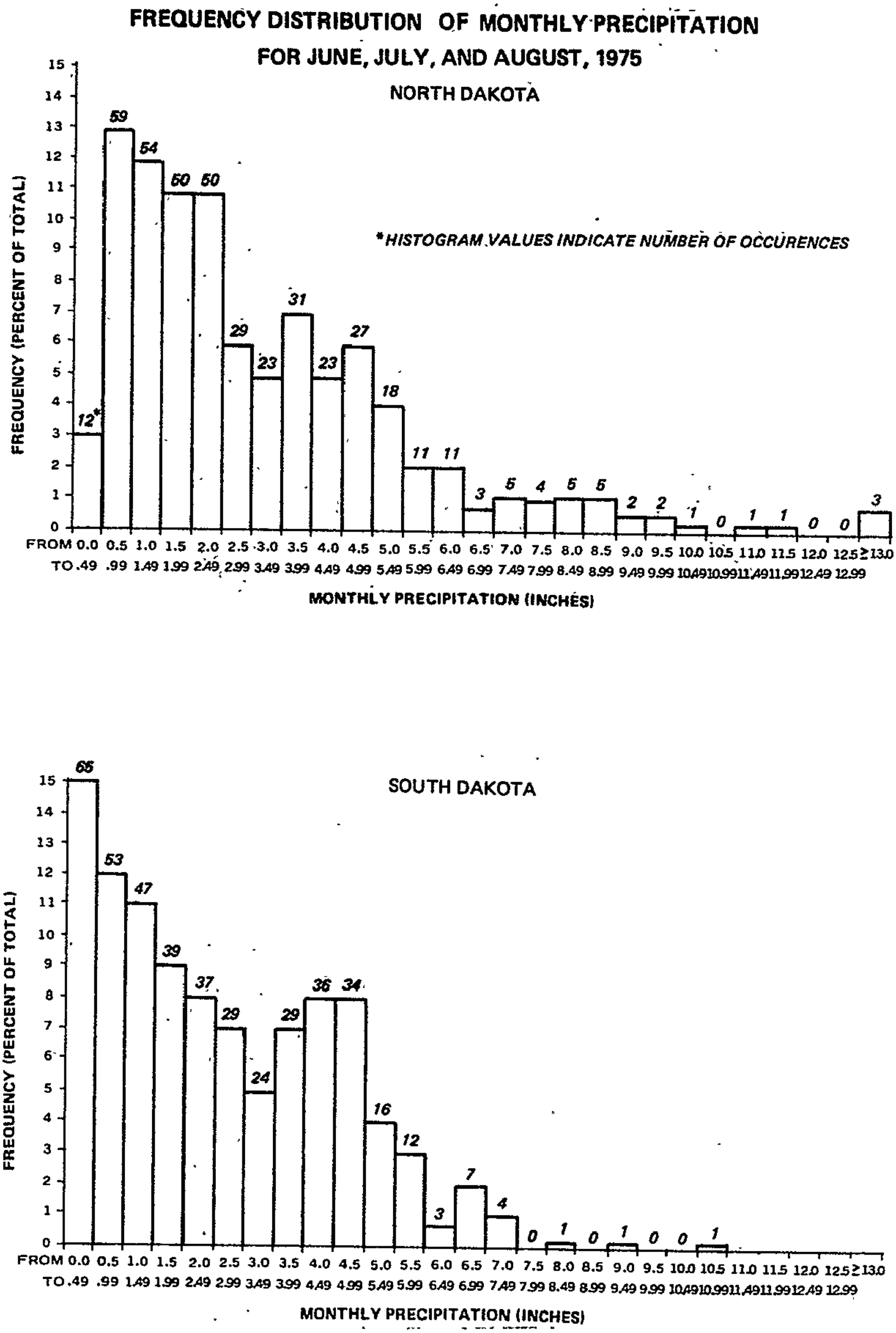


Figure 6-5: Frequency distribution and cumulative percentages of daily precipitation amounts for June, July, August 1975, from all cooperative stations observations in the test area reporting between 5 and 6 p.m. local time.



FREQUENCY DISTRIBUTION OF MONTHLY PRECIPITATION FOR JUNE, JULY, AND AUGUST, 1975

NORTH DAKOTA

*HISTOGRAM VALUES INDICATE NUMBER OF OCCURENCES

SOUTH DAKOTA

Figure 6-6: Frequency distribution of monthly precipitation amounts for June, July, August 1975, from all cooperative stations observations in the test area.

FREQUENCY DISTRIBUTION OF MONTHLY PRECIPITATION FOR JUNE, JULY, AND AUGUST, 1975

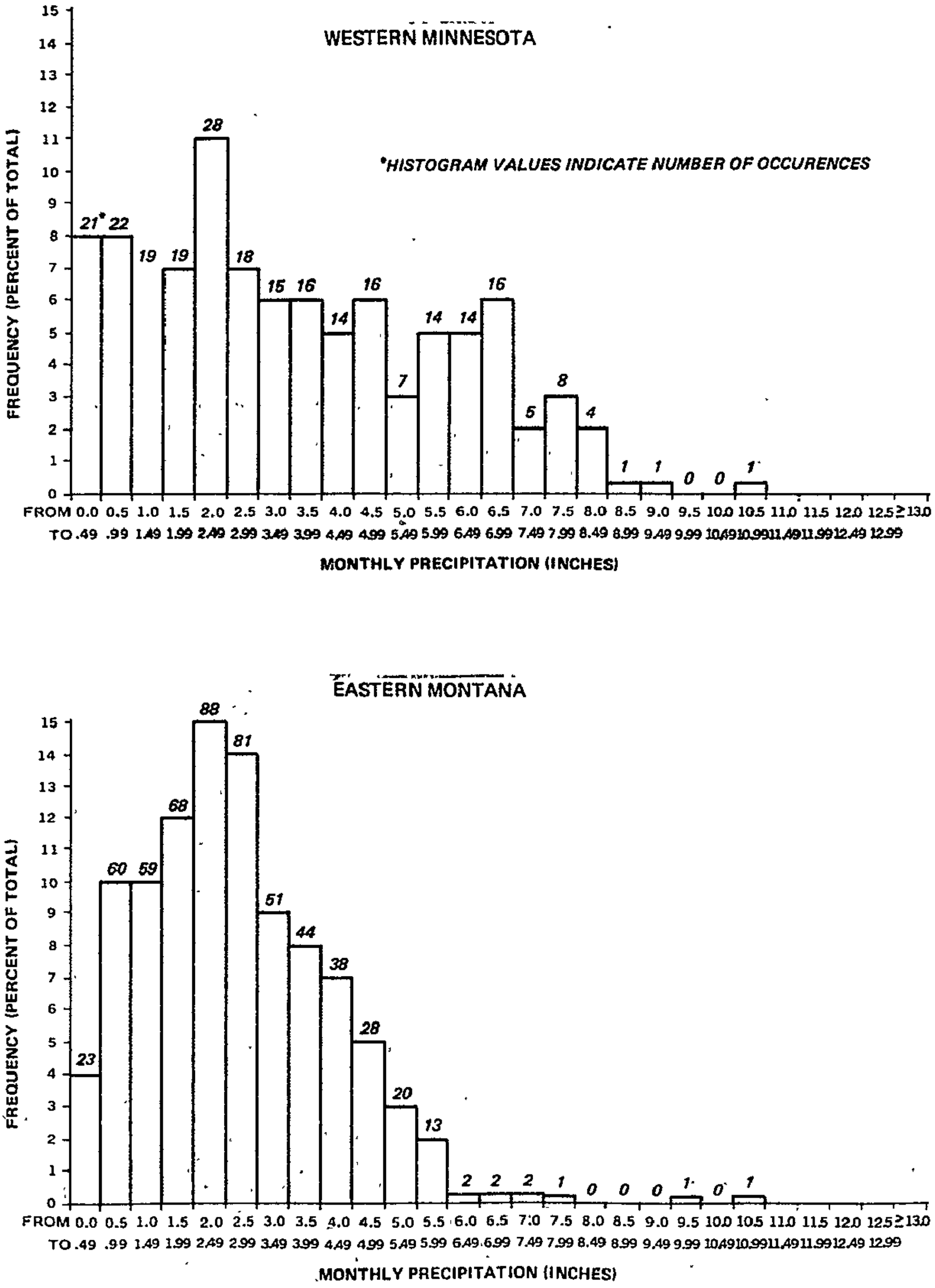


Figure 6-6 continued

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TABLE 6-2

Precipitation Errors in percentage of true precipitation of a Met Cell (827 sq. miles) calculated by means of Huff's Equations.

Reports per cell	True Rainfall, 3-hour event (mm)				True Monthly Precipitation (mm)		
	1	5	25	50	100	200	400
1	80	46 *	26	20	10	8 *	5
2	53	29	17	13	6	5	4
3	35	20	12	9	5	4	3

* Boxed values cover more than 90% of the rainfall events in the Test area during June-August 1975.

actual Metcell precipitation does not differ greatly from the estimated distributions (such as presented in Figures 6-5 and 6-6). In the case of the monthly precipitation, the errors in the estimates are relatively small (5-10%) and these should not affect greatly the distribution shown in Figure 6-3 when we consider that estimated values in the distribution, if corrected to the true values, would cause each class to gain and and lose about the same. In the case of the daily precipitation the errors are much larger, ranging from 29% upwards to 80% and higher; each class would also gain and lose about the same if the estimates were corrected to their true value, with the exception that some of the cell averages presently in the no-rain class (not included in Figure 6-5) because of insufficient sampling within the cell, actually belong to precipitation classes. The net effect would be to increase the total number of precipitation events with the low-value classes gaining the most.

The percentage of no-rain days for Metcells that actually belong to a rain class may be estimated by comparing the number of raindays averaged for cells that have one, two, or three cooperative stations reporting, shown in Table 6-3. There is a noticeable increase in the number of rain days registered as the number of reports increase from one to three which can hardly be due to chance, nor to bias due to cell location.

By comparing the average number of rain days for one-, two-, and three-stations cells we may safely deduce that at least 14% and 5% of the no-rain days for cells with one and

TABLE 6-3

Average Number of Rain Days per Metcell During June-August 1975 as a function of Cooperative Stations Reports per Metcell

Reports Per Metcell	Number of Metcells	Average Number of Rain Days/Metcell	
0	516	-	
1	164	25.9	
2	62	32.3	All Metcell
3	13	35.8	
4	1	44.0	
1	62	26.7	Adjacent sets
2	62	32.3	of Metcells*
1	13	26.6	Adjacent sets
2	13	29.9	of Metcells*
3	13	35.8	

* To reduce to a minimum the possibility of bias caused by location we have performed the statistics for sets of Metcells with 1 and 2 reports and 1, 2, and 3 reports which are adjacent to each other.

two observations respectively, belong to some rain class. This would add approximately 2,000 to the number of rain events, mostly in the low value classes shown in Figure 6-5.

Up to this point we have only dealt with errors associated with what we call "ground-truth" precipitation data, showing that when these point precipitation data are translated to area averages noticeable errors are produced. With the awareness of the magnitude of these errors, we can now present a comparison between METRUN estimates of precipitation and average cell precipitation estimated from the cooperative observers stations. Such comparison for daily rainfall is shown in the form of a verification table (Figure 6-7) and a graph (Figure 6-8), with the percent of METRUN estimates within a certain departure (in mm) from the cooperative station average. Of the 20,642 METRUN daily precipitation estimates, 45% were within 1 mm (.04") of the cooperative stations average, 72% were within 3 mm (.12"), and 95% were within 13 mm (.51"). The verification table and the graph in Figure 6-5 were derived from all cooperative stations that reported between 5 and 6 p.m. local time (0000-0100 GMT) during June-August 1975. Only those cells that have at least one station reporting have been considered. The average number of stations per cell was 1.3. The verification table generally shows that the METRUN tends to overestimate low precipitation below 1/2" and to underestimate heavy precipitation. Nevertheless, if we consider that about 14% of the reported 14,243 no-rain cells actually belong to some class, the comparison would look somewhat better at least for the

VERIFICATION TABLE OF 24 HOUR PRECIPITATION FOR ALL 91 DAYS

OBSERVED PRECIPITATION (mm)

ESTIMATED PRECIPITATION (mm)	< 0.01	0.01 - - 1.99	2.00 - - 3.99	4.00 - - 5.99	6.00 - - 7.99	8.00 - - 9.99	10.00 - - 11.99	12.00 - - 13.99	14.00 - - 15.99	16.00 - - 17.99	18.00 - - 19.99	20.00 - - 24.99	25.00 - - 29.99	30.00 - - 34.99	35.00 - - 39.99	40.00 - - 44.99	45.00 - - 49.99	50.00 - - 59.99	60.00 - - 69.99	70.00 - - 79.99	80.00 - - 89.99	90.00 - - 99.99	100.00 - - 109.99	110.00 - - 119.99	≥ 120.00	TOTAL
< 0.01	5739	344	88	45	33	16	7	6	4	2	3	7	3	1	1	0	0	0	0	0	0	0	0	0	0	6299
0.01-- 1.99	4993	737	313	118	64	46	32	24	17	11	11	25	13	7	2	6	3	3	0	0	0	0	0	0	0	6425
2.00-- 3.99	1831	522	281	176	120	103	59	40	36	24	17	38	15	18	7	4	4	5	0	2	1	1	0	0	0	3287
4.00-- 5.99	695	259	155	96	66	45	53	25	21	20	12	20	16	4	7	2	3	2	0	1	1	1	1	0	0	1503
6.00-- 7.99	511	213	139	96	75	52	34	31	26	11	16	36	16	9	4	6	3	3	0	1	0	0	0	0	0	1282
8.00-- 9.99	192	63	45	26	23	22	27	15	11	19	7	20	17	9	4	2	5	3	2	0	1	0	0	0	0	506
10.00-- 11.99	106	50	48	26	29	18	29	17	12	12	13	22	16	9	3	1	4	0	0	0	0	0	0	0	0	414
12.00-- 13.99	52	20	19	14	15	20	14	6	12	12	3	22	10	12	5	8	3	2	2	1	0	0	1	0	0	253
14.00-- 15.99	35	9	15	12	5	12	12	5	3	12	8	13	8	4	3	2	0	1	0	0	0	0	0	0	0	140
16.00-- 17.99	29	17	11	8	13	5	4	4	7	2	4	7	4	7	9	5	5	4	5	0	1	0	0	0	0	151
18.00-- 19.99	5	12	5	10	11	9	8	9	6	6	4	5	4	2	1	1	1	2	0	0	1	0	0	0	2	104
20.00-- 24.99	26	12	18	7	9	4	11	7	6	10	7	20	9	6	5	3	1	2	0	0	1	0	0	0	0	164
25.00-- 29.99	28	6	10	4	4	2	3	1	3	4	0	3	5	1	2	2	0	3	1	0	0	1	0	0	0	83
30.00-- 34.99	0	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	8
35.00-- 39.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40.00-- 44.99	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
45.00-- 49.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50.00-- 59.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60.00-- 69.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70.00-- 79.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80.00-- 89.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90.00-- 99.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100.00--109.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
110.00--119.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
≥ 120.00 25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
TOTAL	14,243	2265	1148	639	466	354	289	190	164	145	105	231	137	81	53	42	32	30	10	5	6	3	2	0	2	20,642

Figure 6-7: Verification table of daily METRUN I, J, cell precipitation for June, July, August 1975. Only those cells in the area of interest which contain at least one reporting station observing at 5 to 6 P.M. are considered. The METRUN estimates are compared with the cooperative stations observations.

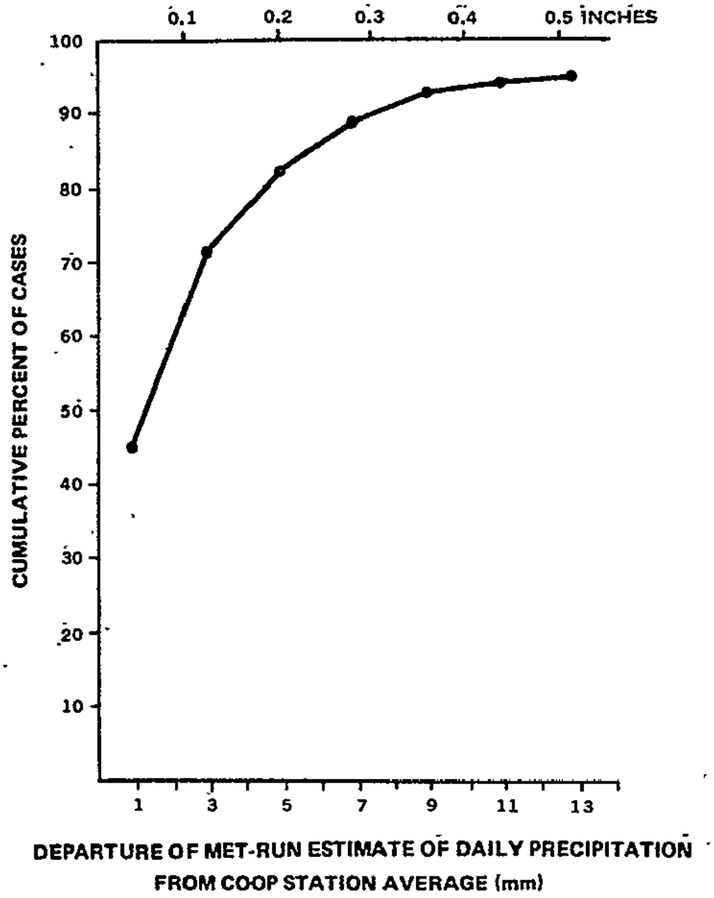


Figure 6-8: Percent of METRUN cell daily rainfall estimates which depart by less than a certain amount from the cooperative station average.

classes of low rainfall. The METRUN estimate of average total rain per cell for the entire season is 244 mm, 17.3% higher than the 208 mm obtained from the cooperative stations. Our analysis of reported rainfall days for one-, two-, and three-station cells indicates that the cooperative station network misses at least 14% of the daily precipitation events, and therefore may underestimate daily precipitation.

We also performed a comparison of estimated versus observed weekly precipitation for all the Metcells having at least one cooperative station reporting. The weekly comparison is shown by the verification table of Figure 6-9 and the graph in Figure 6-10. METRUN overestimates weekly precipitation below 18 mm (< 0.7") and underestimates precipitation above 18 mm. The METRUN weekly estimates per cell average 19.3 mm, 18% higher than the observed average of 16.3 mm. The graph in Figure 6-10, which also contains the daily curve of Figure 6-10 for comparison, shows that about 2/3 of the weekly estimates are within 12.5 mm (1/2") of the observations. As expected, the weekly estimates are more accurate on a percentage of observed precipitation than the daily estimates.

An idea of how well the METRUN spatial precipitation patterns compare with observed patterns may be obtained by comparing Figure 6-11 with Figure 6-12, and Figure 6-13 with Figure 6-14. Figures 6-11 and Figure 6-13 are typical daily and weekly precipitation maps produced by METRUN from satellite cloud cover and synoptic stations observations. Figures 6-12 and Figure 6-14 are the corresponding coop-stations observed daily and weekly precipitations. Cells with no reports are

VERIFICATION TABLE OF WEEKLY PRECIPITATION FOR ALL 13 WEEKS

OBSERVED PRECIPITATION (mm)

ESTIMATED PRECIPITATION (mm)	< 0.01	0.01--1.99	2.00--3.99	4.00--5.99	6.00--7.99	8.00--9.99	10.00--11.99	12.00--13.99	14.00--15.99	16.00--17.99	18.00--19.99	20.00--24.99	25.00--29.99	30.00--34.99	35.00--39.99	40.00--44.99	45.00--49.99	50.00--59.99	60.00--69.99	70.00--79.99	80.00--89.99	90.00--99.99	100.00--109.99	110.00--119.99	≥ 120.00	TOTAL
< 0.01	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0.01-- 1.99	18	13	4	6	2	2	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	50
2.00-- 3.99	42	35	12	12	11	8	4	7	0	2	0	3	2	1	2	0	1	0	0	0	0	0	0	0	0	142
4.00-- 5.99	86	48	55	26	19	8	9	9	3	2	0	6	2	1	1	0	1	1	0	1	0	0	0	0	0	278
6.00-- 7.99	66	36	44	23	18	15	10	4	6	6	4	8	7	3	1	1	1	1	0	1	0	0	0	0	0	255
8.00-- 9.99	36	48	30	21	22	30	22	10	10	7	7	11	8	4	6	1	4	3	1	0	0	0	0	0	0	281
10.00-- 11.99	42	32	39	24	19	17	12	11	18	8	8	21	9	7	0	2	1	2	0	0	0	0	1	0	0	273
12.00-- 13.99	33	19	20	15	12	12	12	8	8	6	4	11	12	3	3	3	1	4	1	0	0	0	1	0	0	188
14.00-- 15.99	11	14	20	15	21	15	11	13	9	9	0	8	13	4	7	4	8	4	2	0	0	2	1	0	0	191
16.00-- 17.99	9	8	17	6	15	11	10	9	10	8	14	15	3	5	6	1	0	2	0	0	1	0	0	0	0	150
18.00-- 19.99	6	12	13	13	14	12	8	5	4	4	6	13	11	8	3	1	1	4	0	0	0	0	0	0	0	138
20.00-- 24.99	16	15	13	15	22	15	13	11	10	6	7	18	21	13	6	7	3	4	2	1	0	0	0	0	1	219
25.00-- 29.99	10	8	12	10	9	12	10	6	8	6	4	11	9	8	4	4	5	4	1	0	1	0	0	0	0	142
30.00-- 34.99	5	5	9	6	8	9	8	9	5	11	7	18	15	12	10	3	2	7	3	3	1	0	1	0	0	157
35.00-- 39.99	4	2	4	3	8	3	4	6	4	13	4	15	12	6	16	8	5	1	9	3	4	0	2	1	1	138
40.00-- 44.99	2	1	0	2	1	0	1	2	1	3	1	4	8	10	3	5	5	6	5	3	1	1	1	0	1	67
45.00-- 49.99	1	0	0	0	0	1	0	3	3	1	5	3	7	5	6	4	10	12	10	4	7	1	2	1	3	89
50.00-- 59.99	0	1	1	1	2	0	4	0	0	4	1	5	7	7	4	10	11	11	11	4	2	2	3	2	3	96
60.00-- 69.99	0	1	0	0	1	0	1	1	0	2	1	1	4	2	0	1	2	2	6	2	2	2	1	0	0	32
70.00-- 79.99	4	1	3	2	0	0	0	1	0	2	0	0	3	1	0	0	2	0	1	0	0	0	0	0	1	21
80.00-- 89.99	0	0	0	0	1	0	0	0	0	0	0	0	0	1	2	0	2	2	3	1	0	0	0	0	0	12
90.00-- 99.99	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	2	0	0	1	1	0	0	0	0	7
100.00--109.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	2
110.00--119.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
≥120.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	392	299	296	200	205	170	140	116	100	100	74	172	154	102	80	56	71	67	56	24	20	8	13	4	10	2929

Figure 6-9: Verification table of weekly METRUN I, J, cells precipitation for June, July, August 1975. Only those cells containing at least one reporting station observing at 5 to 6 p.m. are considered.

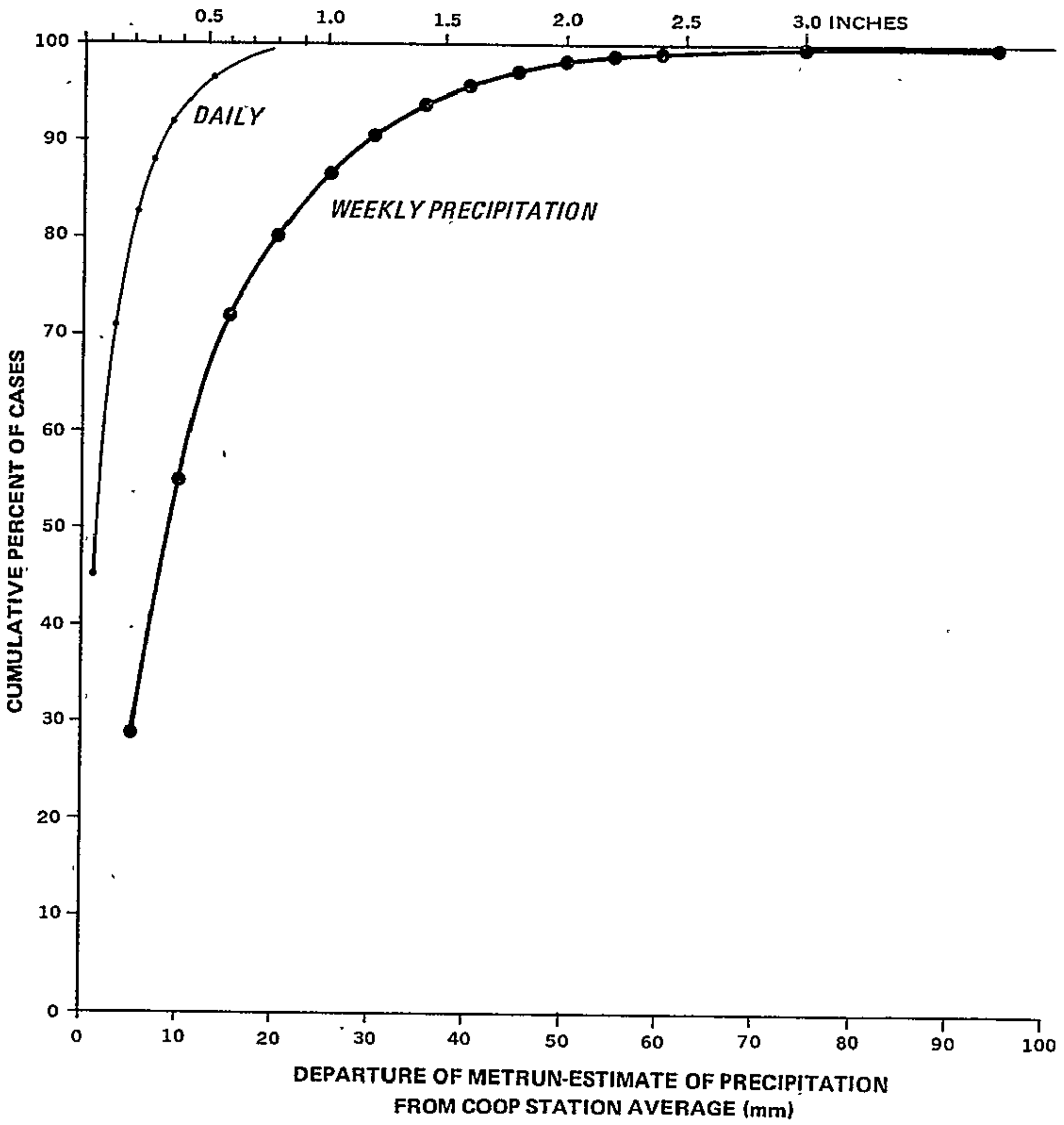
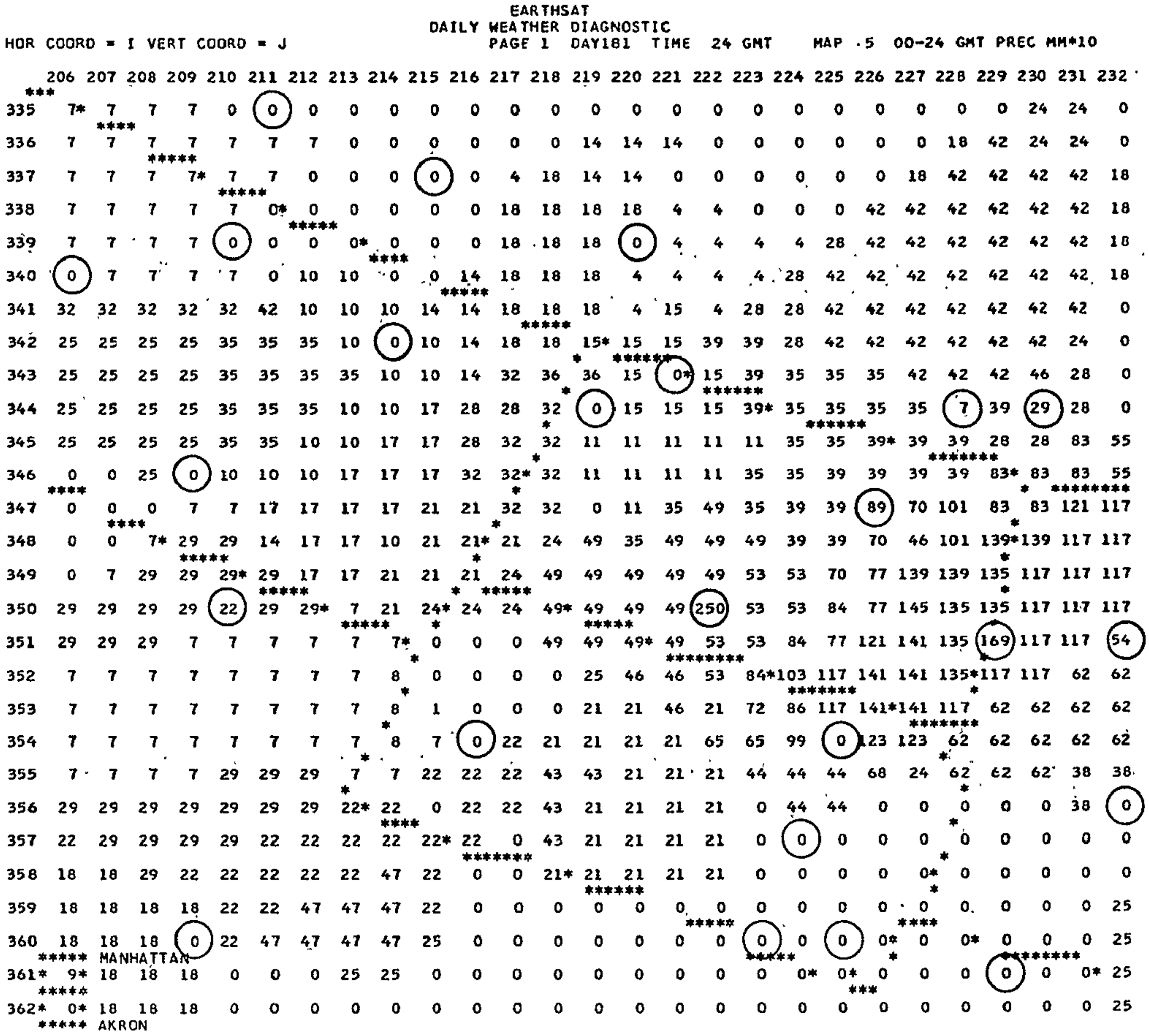


Figure 6-10: Percent of METRUN celldaily and weekly rainfall estimates which depart by less than a certain amount from the cooperative station average.

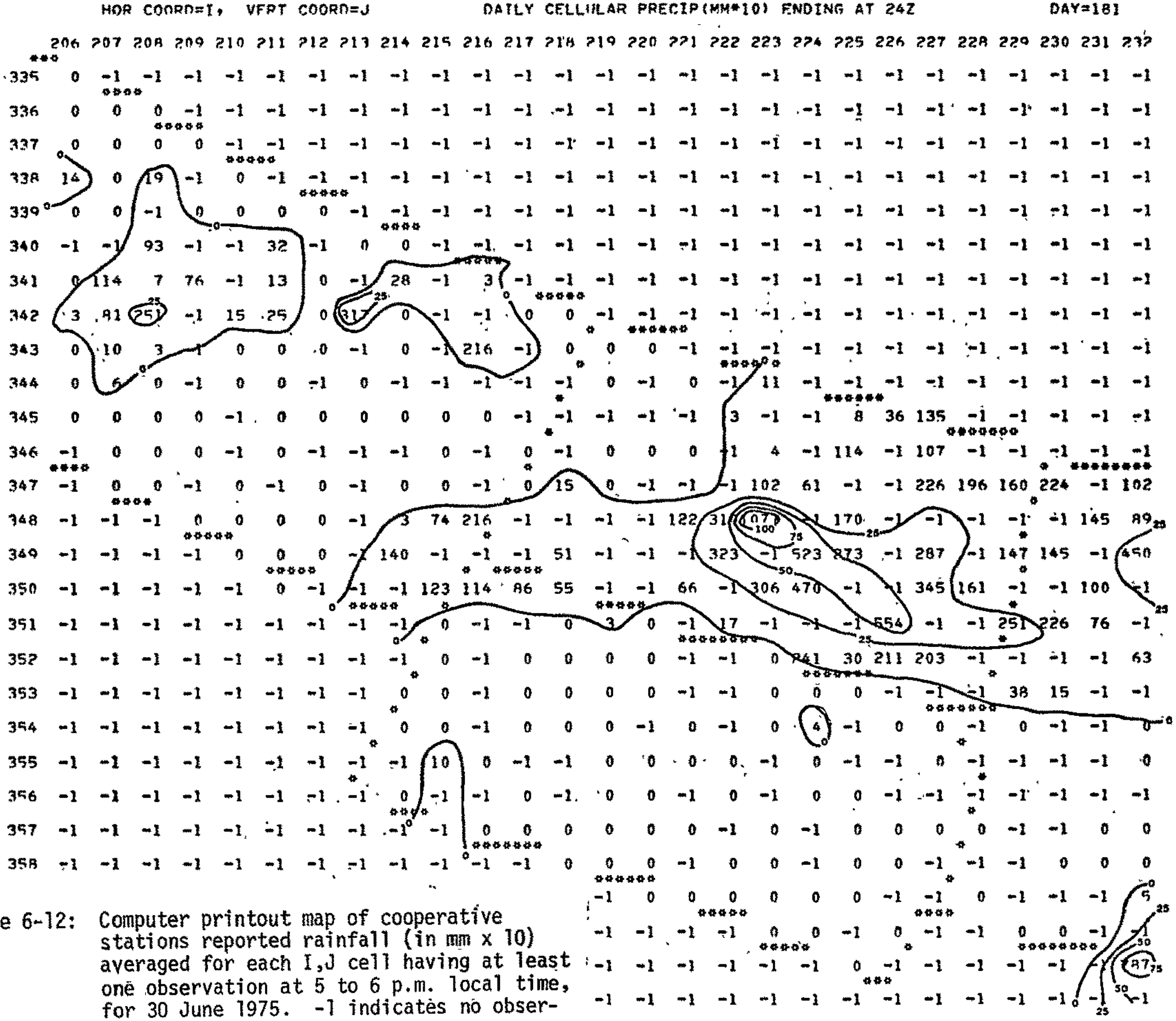


```
                                                  EARTHSAT
                                          DAILY WEATHER DIAGNOSTIC
HOR COORD = I VERT COORD = J                    PAGE 1  DAY181  TIME  24 GMT    MAP .5  00-24 GMT PREC MM*10

    206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232
  ***
335   7*  7   7   7   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  24  24   0
         ****
336   7   7   7   7   7   7   7   0   0   0   0   0   0  14  14  14   0   0   0   0   0   0  18  42  24  24   0
              *****
337   7   7   7   7*  7   7   0   0   0   0   0   4  18  14  14   0   0   0   0   0   0  18  42  42  42  42  18
                     *****
338   7   7   7   7   7   0*  0   0   0   0   0  18  18  18  18   4   4   0   0   0  42  42  42  42  42  42  18
                            *****
339   7   7   7   7   0   0   0   0*  0   0   0  18  18  18   0   4   4   4   4  28  42  42  42  42  42  42  18
                                    ****
340   0   7   7   7   7   0  10  10   0   0  14  18  18  18   4   4   4   4  28  42  42  42  42  42  42  42  18
                                           *****
341  32  32  32  32  32  42  10  10  10  14  14  18  18  18   4  15   4  28  28  42  42  42  42  42  42  42   0
                                                   *****
342  25  25  25  25  35  35  35  10   0  10  14  18  18  15* 15  15  39  39  28  42  42  42  42  42  42  24   0
                                                        *   ******
343  25  25  25  25  35  35  35  35  10  10  14  32  36  36  15   0* 15  39  35  35  35  42  42  42  46  28   0
                                                       *             ******
344  25  25  25  25  35  35  35  10  10  17  28  28  32   0  15  15  15  39* 35  35  35  35   7  39  29  28   0
                                                     *                         ******
345  25  25  25  25  35  35  10  10  17  17  28  32  32  11  11  11  11  11  35  35  39* 39  39  28  28  83  55
                                                    *                                      *******
346   0   0  25   0  10  10  10  17  17  17  32  32* 32  11  11  11  11  35  35  39  39  39  39  83* 83  83  55
    ****                                          *                                                  *  ********
347   0   0   0   7   7  17  17  17  17  21  21  32  32   0  11  35  49  35  39  39  89  70 101  83  83 121 117
          ****                                  *                                                   *
348   0   0   7* 29  29  14  17  17  10  21  21* 21  24  49  35  49  49  49  39  39  70  46 101 139*139 117 117
                 *****                        *                                                    *
349   0   7  29  29  29* 29  17  17  21  21  21  24  49  49  49  49  49  53  53  70  77 139 139 135 117 117 117
                         *****              *  *****                                               *
350  29  29  29  29  22  29  29*  7  21  24* 24  24  49* 49  49  49 250  53  53  84  77 145 135 135 117 117 117
                                 *****    *              *****                                    *
351  29  29  29   7   7   7   7   7   7*  0   0   0  49  49  49* 49  53  53  84  77 121 141 135 169 117 117  54
                                        *                        ********                          *
352   7   7   7   7   7   7   7   7   8   0   0   0   0  25  46  46  53  84*103 117 141 141 135*117 117  62  62
                                       *                                     *******            *
353   7   7   7   7   7   7   7   7   8   1   0   0   0  21  21  46  21  72  86 117 141*141 117  62  62  62  62
                                     *                                                   *******
354   7   7   7   7   7   7   7   7   8   7   0  22  21  21  21  21  65  65  99   0 123 123  62  62  62  62  62
                                   *                                                         *
355   7   7   7   7  29  29  29   7   7  22  22  22  43  43  21  21  21  44  44  44  68  24  62  62  62  38  38
                                 *                                                             *
356  29  29  29  29  29  29  29  22* 22   0  22  22  43  21  21  21  21   0  44  44   0   0   0   0   0  38   0
                                     ****                                                     *
357  22  29  29  29  29  22  22  22  22  22* 22   0  43  21  21  21  21   0   0   0   0   0   0   0   0   0   0
                                             *******                                         *
358  18  18  29  22  22  22  22  22  47  22   0   0  21* 21  21  21  21   0   0   0   0   0*  0   0   0   0   0
                                                         ******                             *
359  18  18  18  18  22  22  47  47  47  22   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  25
                                                                   *****                ****
360  18  18  18   0  22  47  47  47  47  25   0   0   0   0   0   0   0   0   0   0   0*  0   0*  0   0   0  25
   ***** MANHATTAN                                                       *****          *          ********
361*  9* 18  18  18   0   0   0  25  25   0   0   0   0   0   0   0   0   0   0*  0*  0   0   0   0   0   0* 25
   *****                                                                            ***
362*  0* 18  18  18   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0  25
   ***** AKRON
```

Figure 6-11:

Sample computer printout map of rainfall (in mm x 10) for the period 00-24 GMT, 30 June 1975 produced by Subprogram METRUN, as explained in text. Circled values are actual rainfall reports for the same period.

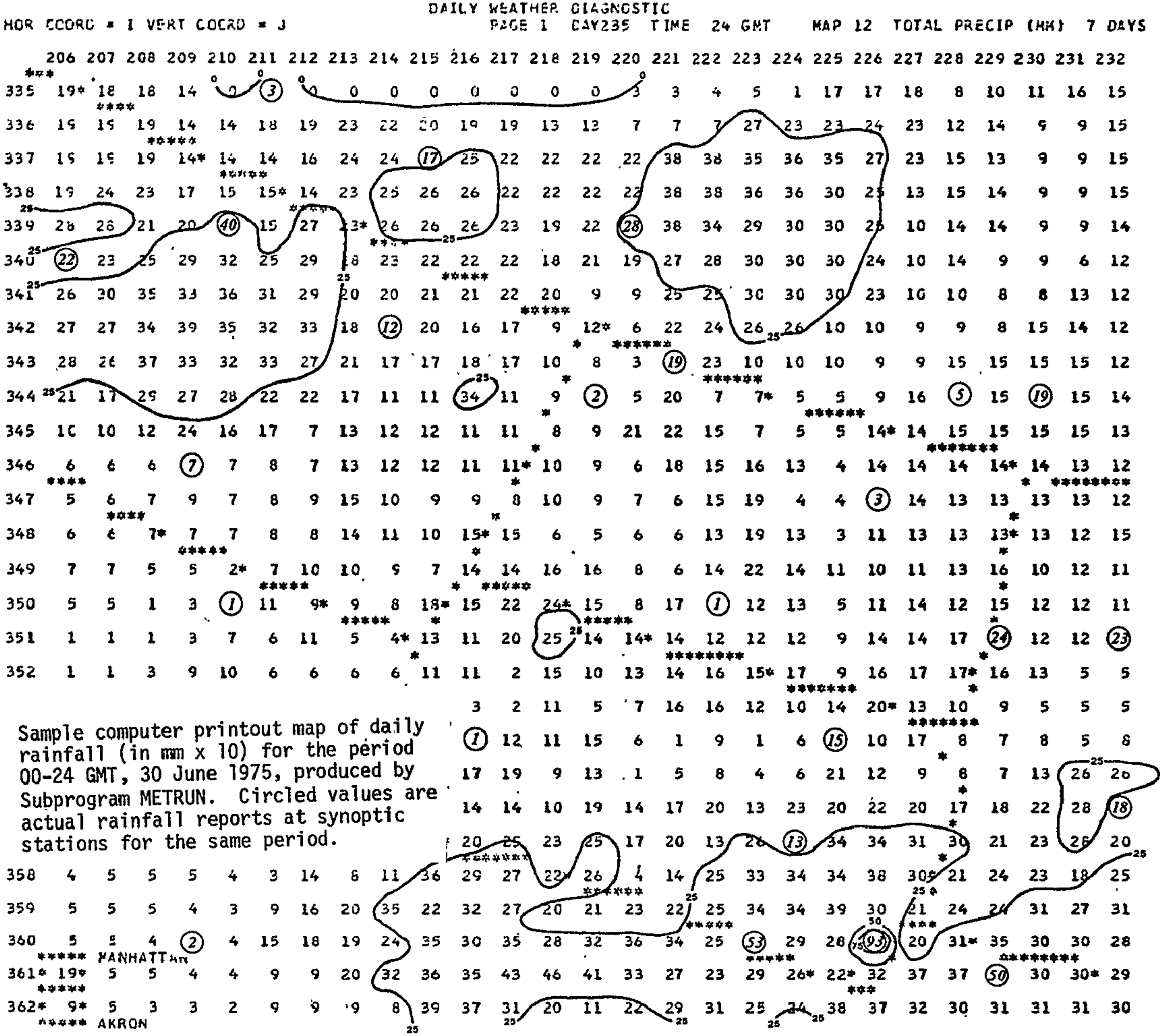


```
         HOR COORD=I,  VERT COORD=J            DAILY CELLULAR PRECIP(MM*10) ENDING AT 24Z               DAY=181

       206  207  208  209  210  211  212  213  214  215  216  217  218  219  220  221  222  223  224  225  226  227  228  229  230  231  232
 335     0   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
 336     0    0    0   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
 337     0    0    0    0   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
 338    14    0   19   -1    0   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
 339     0    0   -1    0    0    0    0   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
 340    -1   -1   93   -1   -1   32   -1    0    0   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
 341     0  114    7   76   -1   13    0   -1   28   -1    3   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
 342     3   81  251   -1   15   25    0  317    0   -1   -1    0    0   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
 343     0   10    3   -1    0    0    0   -1    0   -1  216   -1    0    0    0   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
 344     0    6    0   -1    0    0   -1    0   -1   -1   -1   -1   -1    0   -1    0   -1   11   -1   -1   -1   -1   -1   -1   -1   -1   -1
 345     0    0    0    0   -1    0    0    0    0    0    0   -1   -1   -1   -1   -1    3   -1   -1    8   36  135   -1   -1   -1   -1   -1
 346    -1    0    0    0   -1    0   -1   -1   -1    0   -1    0   -1    0    0    0   -1    4   -1  114   -1  107   -1   -1   -1   -1   -1
 347    -1    0    0   -1    0   -1    0   -1    0    0   -1    0   15    0   -1   -1   -1  102   61   -1   -1  226  196  160  224   -1  102
 348    -1   -1   -1    0    0    0    0   -1    3   74  216   -1   -1   -1   -1  122   31  077   -1  170   -1   -1   -1   -1   -1  145   89
 349    -1   -1   -1   -1    0    0    0   -1  140   -1   -1   -1   51   -1   -1   -1  323   -1  523  873   -1  287   -1  147  145   -1  450
 350    -1   -1   -1   -1   -1    0   -1   -1   -1  123  114   86   55   -1   -1   66   -1  306  470   -1   -1  345  161   -1   -1  100   -1
 351    -1   -1   -1   -1   -1   -1   -1   -1   -1    0   -1   -1    0    3    0   -1   17   -1   -1   -1  654   -1   -1  251  226   76   -1
 352    -1   -1   -1   -1   -1   -1   -1   -1   -1    0   -1    0    0    0    0   -1   -1    0  741   30  211  203   -1   -1   -1   -1   63
 353    -1   -1   -1   -1   -1   -1   -1   -1    0    0   -1    0    0    0    0   -1   -1    0    0    0   -1   -1   -1   38   15   -1   -1
 354    -1   -1   -1   -1   -1   -1   -1   -1    0    0   -1    0    0    0   -1    0   -1    0    4   -1    0    0   -1    0   -1   -1    0
 355    -1   -1   -1   -1   -1   -1   -1   -1   -1   10    0   -1   -1    0    0    0    0   -1    0   -1   -1    0   -1   -1   -1   -1    0
 356    -1   -1   -1   -1   -1   -1   -1   -1    0   -1   -1    0   -1    0    0   -1    0   -1    0    0   -1   -1   -1   -1   -1   -1   -1
 357    -1   -1   -1   -1   -1   -1   -1   -1   -1   -1    0    0    0    0    0    0   -1    0   -1    0    0    0    0   -1   -1    0    0
 358    -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1    0    0    0   -1    0    0   -1    0    0   -1   -1   -1    0    0    0
                                                                        -1    0    0    0    0    0    0   -1   -1    0   -1   -1   -1    5
                                                                        -1   -1   -1   -1    0    0   -1    0   -1   -1    0    0   -1   -1
                                                                        -1   -1   -1   -1   -1   -1    0   -1   -1   -1   -1   -1   -1   87
                                                                        -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1   -1
```

Figure 6-12: Computer printout map of cooperative stations reported rainfall (in mm x 10) averaged for each I,J cell having at least one observation at 5 to 6 p.m. local time, for 30 June 1975. -1 indicates no observation available.

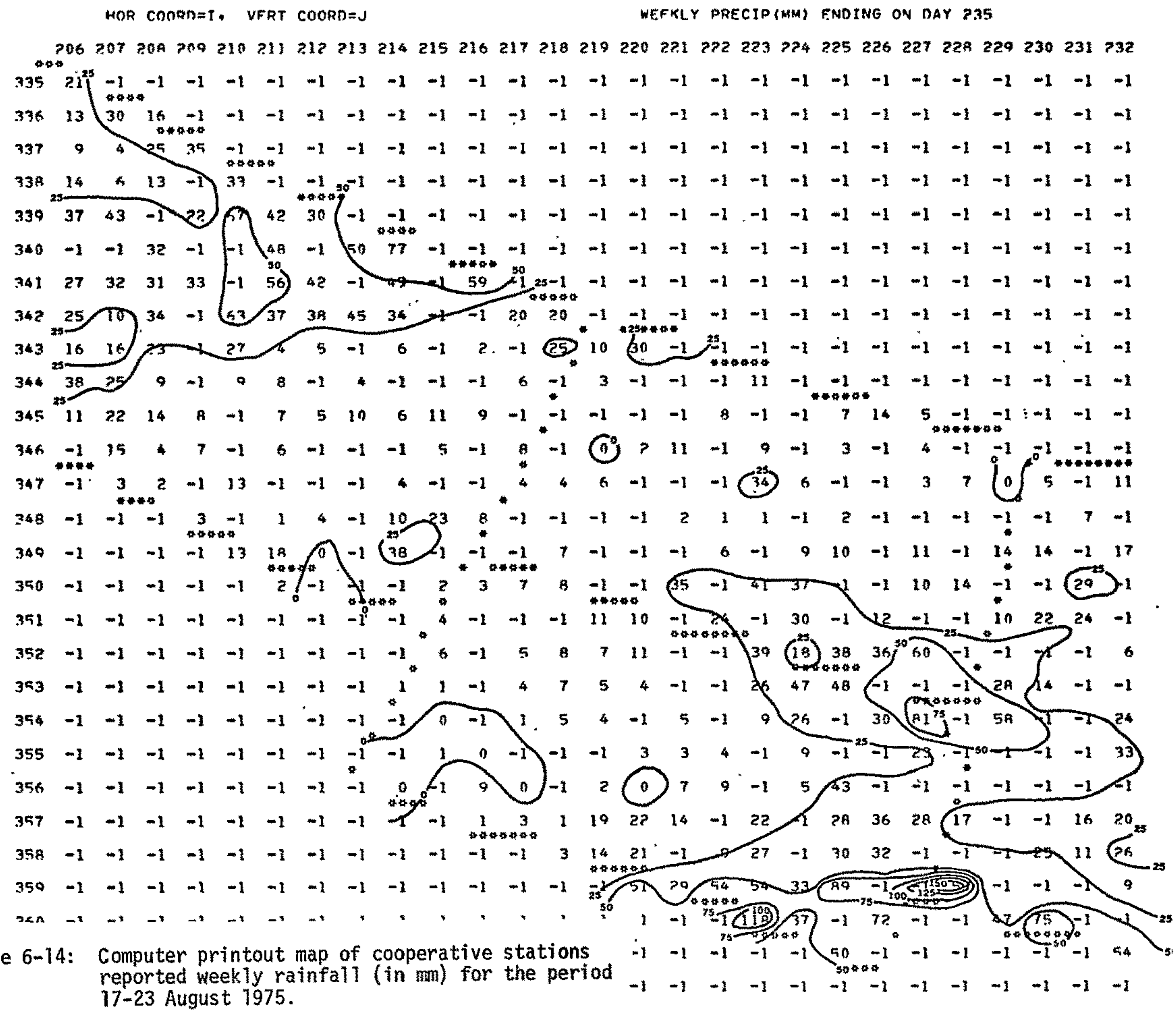
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR



```
                                         DAILY WEATHER DIAGNOSTIC
HOR CCORD = I VERT COCRD = J                  PAGE 1  CAY235  TIME  24 GMT    MAP 12  TOTAL PRECIP (MM)  7 DAYS

      206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232
335   19*  18  18  14   0   ③   0   0   0   0   0   0   0   0   3   3   4   5   1  17  17  18   8  10  11  16  15
336    19  19  19  14  14  18  19  23  22  20  19  19  13  13   7   7   7  27  23  23  24  23  12  14   9   9  15
337    19  19  19 14*  14  14  16  24  24   ⑰  25  22  22  22  22  38  38  35  36  35  27  23  15  13   9   9  15
338    19  24  23  17  15 15*  14  23  25  26  26  22  22  22  22  38  38  36  36  30  25  13  15  14   9   9  15
339    28  26  21  20   ㊵  15  27 23*  26  26  26  23  19  22   ㉘  38  34  29  30  30  25  10  14  14   9   9  14
340     ㉒  23  25  29  32  25  29  18  23  22  22  22  18  21  19  27  28  30  30  30  24  10  14   9   9   6  12
341    26  30  35  33  36  31  29  20  20  21  21  22  20   9   9  25  25  30  30  30  23  10  10   8   8  13  12
342    27  27  34  39  35  32  33  18   ⑫  20  16  17   9 12*   6  22  24  26  26  10  10   9   9   8  15  14  12
343    28  26  37  33  32  33  27  21  17  17  18  17  10   8   3   ⑲  23  10  10  10   9   9  15  15  15  15  12
344    21  17  29  27  28  22  22  17  11  11  34  11   9   ②   5  20   7  7*   5   5   9  16   ⑤  15   ⑲  15  14
345    10  10  12  24  16  17   7  13  12  12  11  11   8   9  21  22  15   7   5   5 14*  14  15  15  15  15  13
346     6   6   6   ⑦   7   8   7  13  12  12  11 11*  10   9   6  18  15  16  13   4  14  14  14 14*  14  13  12
347     5   6   7   9   7   8   9  15  10   9   9   8  10   9   7   6  15  19   4   4   ③  14  13  13  13  13  12
348     6   6  7*   7   7   8   8  14  11  10 15*  15   6   5   6   6  13  19  13   3  11  13  13 13*  13  12  15
349     7   7   5   5  2*   7  10  10   9   7  14  14  16  16   8   6  14  22  14  11  10  11  13  16  10  12  11
350     5   5   1   3   ①  11  9*   9   8 18*  15  22 24*  15   8  17   ①  12  13   5  11  14  12  15  12  12  11
351     1   1   1   3   7   6  11   5  4*  13  11  20  25  14 14*  14  12  12  12   9  14  14  17   ㉔  12  12   ㉓
352     1   1   3   9  10   6   6   6   6  11  11   2  15  10  13  14  16 15*  17   9  16  17 17*  16  13   5   5
                                                3   2  11   5   7  16  16  12  10  14 20*  13  10   9   5   5   5
                                                ①  12  11  15   6   1   9   1   6   ⑮  10  17   8   7   8   5   8
                                               17  19   9  13   1   5   8   4   6  21  12   9   8   7  13  26  26
                                               14  14  10  19  14  17  20  13  23  20  22  20  17  18  22  28   ⑱
                                               20  25  23  25  17  20  13  26   ⑬  34  34  31  30  21  23  26  20
358     4   5   5   5   4   3  14   6  11  36  29  27 22*  26   4  14  25  33  34  34  38 30*  21  24  23  18  25
359     5   5   5   4   3   9  16  20  35  22  32  27  20  21  23  22  25  34  34  39  30  21  24  24  31  27  31
360     5   5   4   ②   4  15  18  19  24  35  30  35  28  32  36  34  25 (53)  29  28 (93)  20 31*  35  30  30  28
   ***** MANHATTAN
361*  19*   5   5   4   4   9   9  20  32  36  35  43  46  41  33  27  23  29 26* 22*  32  37  37   ㊿  30 30*  29
362*   9*   5   3   3   2   9   9   9   8  39  37  31  20  11  22  29  31  25  24  38  37  32  30  31  31  31  30
   ***** AKRON
```

Figure 6-13: Sample computer printout map of daily rainfall (in mm x 10) for the period 00-24 GMT, 30 June 1975, produced by Subprogram METRUN. Circled values are actual rainfall reports at synoptic stations for the same period.



```
          HOR COORD=I,  VERT COORD=J                               WEEKLY PRECIP(MM) ENDING ON DAY 235

      206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232
 335   21  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 336   13  30  16  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 337    9   4  25  35  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 338   14   6  13  -1  33  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 339   37  43  -1  22  67  42  30  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 340   -1  -1  32  -1  -1  48  -1  50  77  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 341   27  32  31  33  -1  56  42  -1  49  -1  59  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 342   25  10  34  -1  63  37  38  45  34  -1  -1  20  20  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 343   16  16  23  -1  27   4   5  -1   6  -1   2. -1  25  10  30  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
 344   38  25   9  -1   9   8  -1   4  -1  -1  -1   6  -1   3  -1  -1  -1  11  -1  -1  -1  -1  -1  -1  -1  -1  -1
 345   11  22  14   8  -1   7   5  10   6  11   9  -1  -1  -1  -1  -1   8  -1  -1   7  14   5  -1  -1  -1  -1  -1
 346   -1  15   4   7  -1   6  -1  -1  -1   5  -1   8  -1   0   2  11  -1   9  -1   3  -1   4  -1  -1  -1  -1  -1
 347   -1   3   2  -1  13  -1  -1  -1   4  -1  -1   4   4   6  -1  -1  -1  34   6  -1  -1   3   7   0   5  -1  11
 348   -1  -1  -1   3  -1   1   4  -1  10  23   8  -1  -1  -1  -1   2   1   1  -1   2  -1  -1  -1  -1  -1   7  -1
 349   -1  -1  -1  -1  13  18   0  -1  38  -1  -1  -1   7  -1  -1  -1   6  -1   9  10  -1  11  -1  14  14  -1  17
 350   -1  -1  -1  -1  -1   2  -1  -1  -1   2   3   7   8  -1  -1  35  -1  41  37  -1  -1  10  14  -1  -1  29  -1
 351   -1  -1  -1  -1  -1  -1  -1  -1  -1   4  -1  -1  -1  11  10  -1  24  -1  30  -1  12  -1  -1  10  22  24  -1
 352   -1  -1  -1  -1  -1  -1  -1  -1  -1   6  -1   5   8   7  11  -1  -1  39  18  38  36  60  -1  -1  -1  -1   6
 353   -1  -1  -1  -1  -1  -1  -1  -1   1   1  -1   4   7   5   4  -1  -1  26  47  48  -1  -1  -1  28  14  -1  -1
 354   -1  -1  -1  -1  -1  -1  -1  -1  -1   0  -1   1   5   4  -1   5  -1   9  26  -1  30  81  -1  58  -1  -1  24
 355   -1  -1  -1  -1  -1  -1  -1  -1  -1   1   0  -1  -1  -1   3   3   4  -1   9  -1  -1  23  -1  -1  -1  -1  33
 356   -1  -1  -1  -1  -1  -1  -1  -1   0  -1   9   0  -1   2   0   7   9  -1   5  43  -1  -1  -1  -1  -1  -1  -1
 357   -1  -1  -1  -1  -1  -1  -1  -1  -1  -1   1   3   1  19  22  14  -1  22  -1  28  36  28  17  -1  -1  16  20
 358   -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1   3  14  21  -1   9  27  -1  30  32  -1  -1  -1  25  11  26
 359   -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  51  29  54  54  33  89  -1 [illegible] [illegible]  -1  -1  -1   9
 360   -1  -1  -1  -1  -1  -1  -1                               1  -1  -1 119  37  -1  72  -1  -1  47  75  -1  -1
                                                               -1  -1  -1  -1  -1  50  -1  -1  -1  -1  -1  -1  54
                                                               -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
```

Figure 6-14: Computer printout map of cooperative stations reported weekly rainfall (in mm) for the period 17-23 August 1975.

designated by -1. The reason for the many cells with no reports is that only those stations reporting at 5-6 p.m. local time were considered. Isohyets were drawn on Figures 6-12 and 6-14 (somewhat subjectively because of missing data) to permit a visual comparison with METRUN. The comparison of daily coop-precipitation maps with METRUN maps shows that, 1) spatial patterns of major rain areas correspond fairly well, 2) METRUN tends to spread out the major rain areas, 3) METRUN, as already stated, underestimates rainfall above 1/2", and overestimates low rain fall, and 4) METRUN smooths out the rainfall daily spatial variability. The comparison of weekly maps shows a better fit of spatial patterns and absolute rainfall amounts.

6.2.2 Crop Reporting District Rainfall Analysis

Since the AGMET system uses daily precipitation amounts on a cell basis for the calculation of stress accumulation, we have concentrated our efforts on determining the precipitation errors on a cell and on a daily basis. We have, nevertheless, conducted some additional error analyses for weekly periods for Crop Reporting District (CRD) areas. These error analyses consisted in comparing the average METRUN precipitation with that obtained from all reporting cooperative observers stations in the Crop Reporting District.

Before comparing the METRUN estimates to the cooperative stations estimates we proceeded to determine an estimate of the errors involved in the cooperative stations averages by the following technique. We used the daily June-August precipitation observations in one representative Crop Reporting District, NW North Dakota, to construct precipitation frequency distributions for light, medium, and heavy precipitation as shown in Figure 6-15. Daily rainfall events were arbitrarily assigned to light, medium, or heavy rain distributions if the 21 stations in the district reported a daily cumulative total of .05" or less, .05 to 2.0", and greater than 2", respectively. The number of rainfall events in each class was scaled up or down to give 1,000 events total for each of the three distributions. We then proceeded to randomly sample the distributions t times with n sample sizes, each time comparing the average of the random sample with the "true" average of the distribution (1,000 events average), and then calculated the mean percent deviation for each sample size. We set t = 1,000 for n = 2, 10, and t = 50 for n = 50, 100, 500, 700. The results are presented in Figure 6-16. The lack of smoothness of the graphs is due to the relatively low number of times (t) n samples were selected, especially in the small sample range (n < 50). The graphs are, nevertheless, indicative of the range of precipitation errors due to sampling in a typical agricultural district. For example, the graphs show that for the NW N. Dakota district with 21 stations the mean percent deviation between the true and the estimated daily area precipitation for light, medium, and heavy rains are 80%, 38%, and 25% of the totals, respectively. These translate to mean deviations of 0.10 mm, 0.48 mm, and 2.23 mm. By multiplying the mean deviations by 1.25 we obtain the values of the standard deviations of the estimated means;

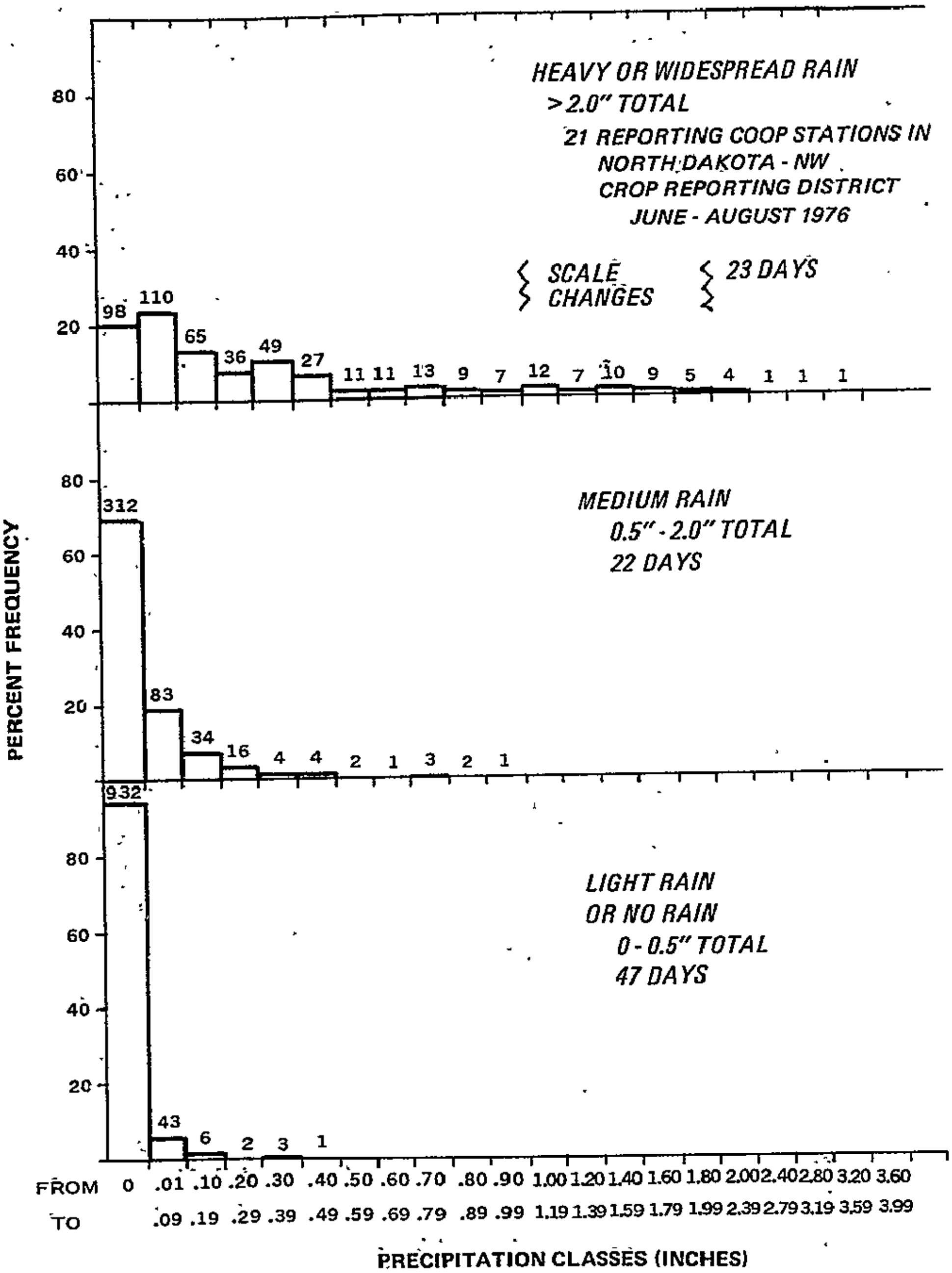


Figure 6-15: Frequency distributions for light, medium, and heavy precipitation for the N.W. North Dakota Crop Reporting District during the summer of 1975. Daily rainfall events were arbitrarily assigned to light, medium, or heavy rain distributions if the 21 stations in the District reported a daily cumulative total of 0.5" or less, 0.5" to 2.0", and greater and 2", respectively.

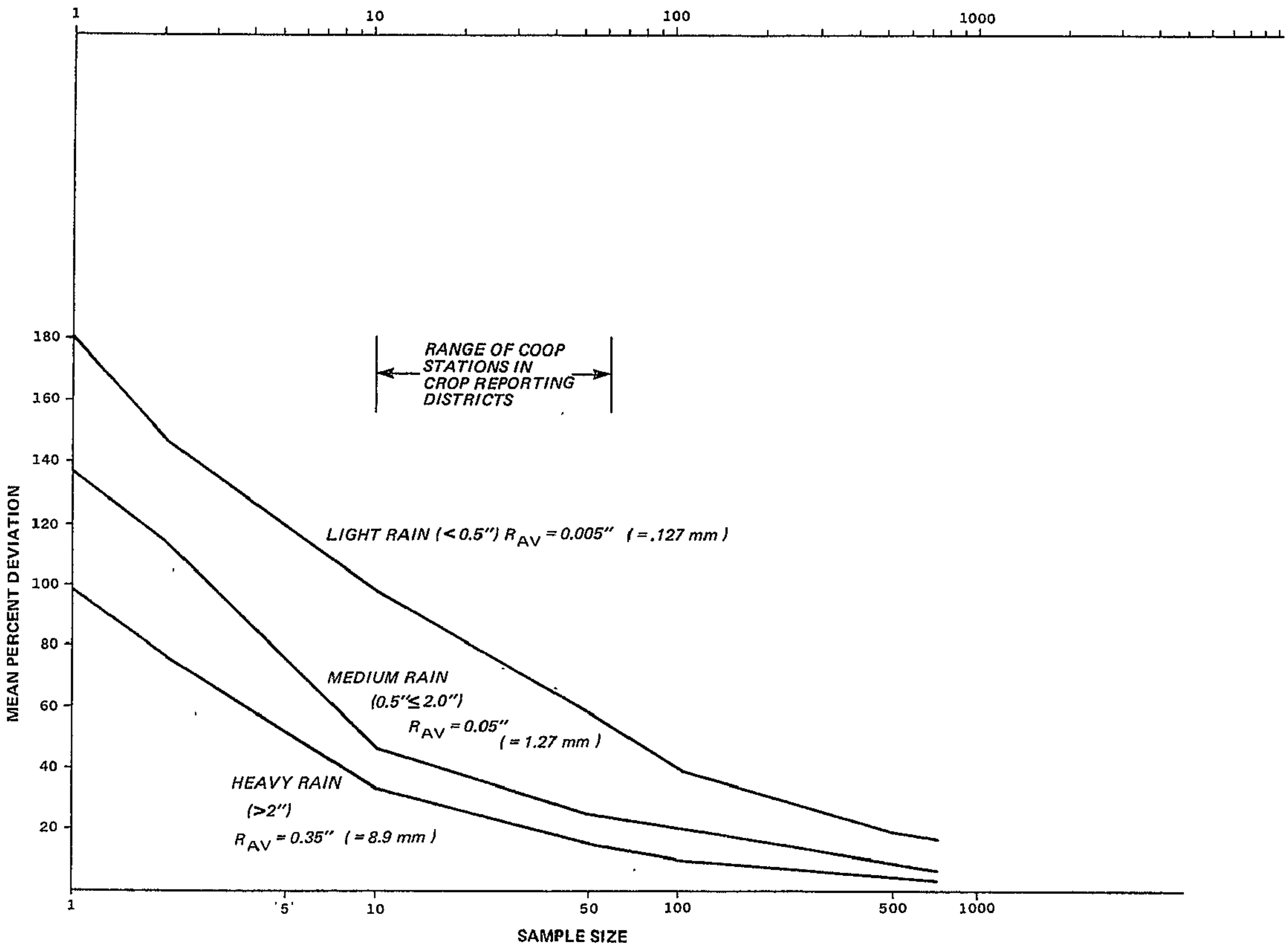


Figure 6-16: Mean percent deviation between "true" averages of the daily precipitation distributions presented in Figure 6-15 and averages calculated with n sample size.

0.125, 0.60, and 2.79 mm for light, medium, and heavy rain. Approximately 2/3 of the times the estimated daily area precipitation will be within these limits.

An estimate of the errors on a weekly basis can be obtained by taking the root-mean-square errors of the daily precipitation events. Assuming that light, medium, or heavy raindays are distributed during one week on the average with the same frequency as during the season (47, 22, 23), and using the values of the standard deviations derived above as the errors of the mean we obtained errors of about 4 mm per week, 8 mm per month, and 13 mm for the entire season; or respectively, 25, 11, and 6% of the total precipitation. These are the errors implicit in the cooperative stations averages which we use as "ground truth."

We are now ready to consider comparisons of CRD METRUN averages and cooperative station averages on a weekly basis. Such comparison is shown in the verification table of Figure 6-17 and graphically in Figure 6-18. A total of 338 weekly averages from 26 crop reporting districts were used. The verification table in Figure 6-17 does not bring out any clear cut tendency for METRUN to overestimate or underestimate, although METRUN does show less occurrences of weekly precipitation below 6 mm (66 versus 110 for the cooperative averages) and less occurrences above 49 mm (18 versus 26). Figure 6-18 shows the percent of METRUN and synoptic stations estimates within a certain departure (in mm) from the cooperative stations average. Only those districts with at least one synoptic station were used in the comparison. Synoptic stations never

METRUN ESTIMATE (mm)

COOPERATIVE STATION AVERAGE (mm)	0	1-6	7-12	13-18	19-24	25-30	31-36	37-42	43-48	49-54	55-60	61-66	67-72	73-78	78-84	85-90	90	COOPERATIVE STATION TOTALS
0		11	4	1														16
1-6		39	34	17	4													94
7-12		14	30	20	9		2	2										77
13-18		2	9	16	8	3	7						1					46
19-24			11	5	3	5	5	3	2		1							35
25-30			2	5		3		3		1								14
31-36				2	4	1	3	1	4									15
37-42				2	1	1		1	2	1								,8
42-48							1	1	2	2		1	1					7
49-54				2					1	2								5
55-60								3	1	1						1	1	7
61-66								1	1	1	1	1						4
67-72							1			1								2
73-78								2	1									3
79-84					1					1								2
85-90										1	1							2
90								1										1
METRUN TOTALS	0	66	90	70	30	13	19	18	14	10	2	2	2	0	0	1	1	338

Figure 6-17: Verification table of weekly METRUN precipitation averages for Crop Reporting Districts in the test area versus cooperative stations' averages for June, July, August 1975.

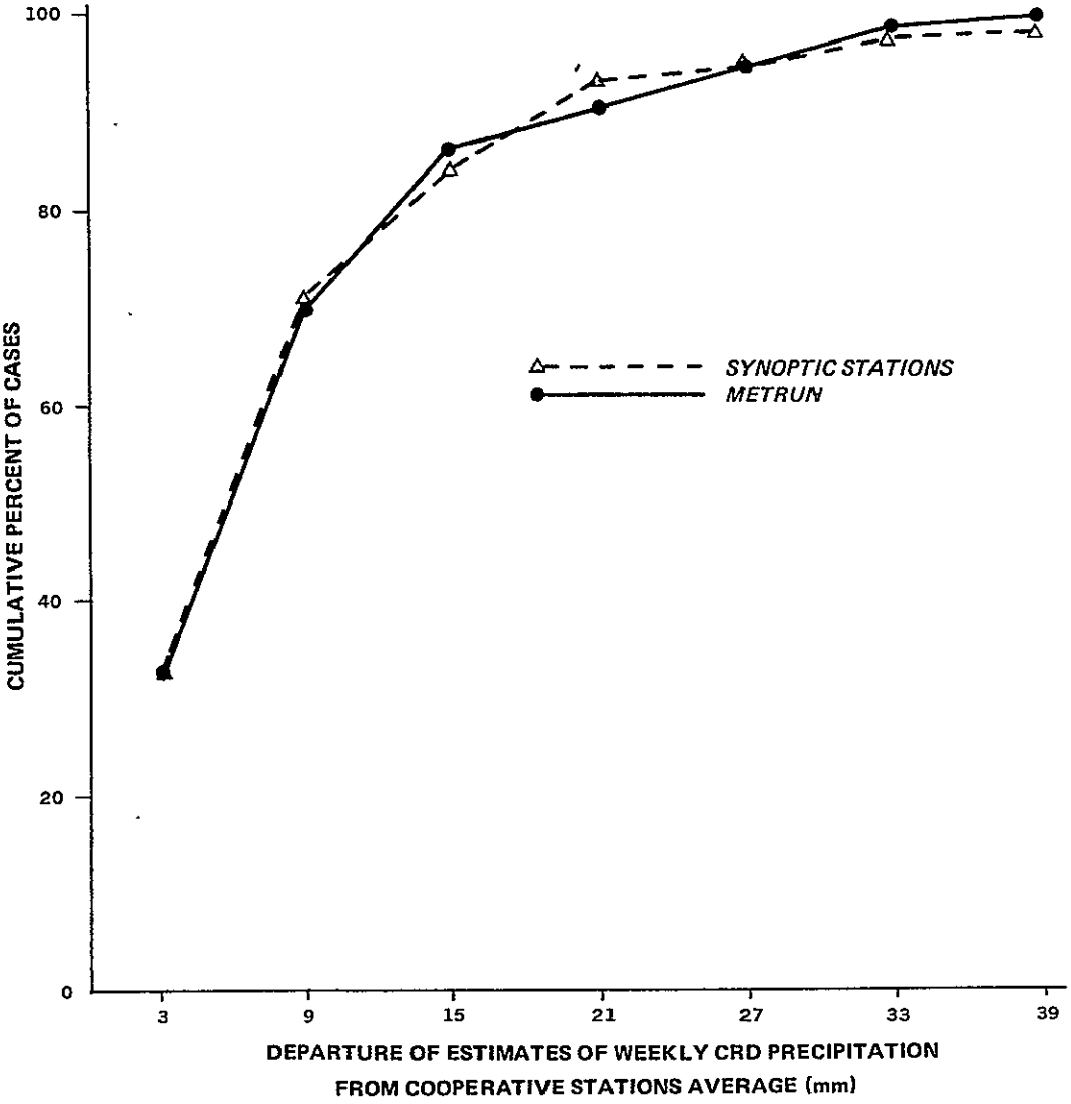


Figure 6-18: Percent of METRUN cell daily rainfall estimates which depart by less than a certain amount from the cooperativ station average.

numbered more than two per district. Figure 6-18 shows that on a weekly basis the METRUN averages are equal in accuracy to synoptic station averages, but does not show the fact that the synoptic stations tend to underestimate the total weekly precipitation. This is brought out in the sequence of plots in Figure 6-19, which present the running sums of weekly precipitation as determined by the cooperative stations, METRUN, and synoptic stations. Table 6-4 shows the totals for the entire season. On the basis of Figure 6-19 and Table 6-4 we conclude that the METRUN season totals of precipitation are closer to the cooperative stations totals than the synoptic station, although on a weekly basis METRUN seems to equal to the synoptic stations.

6.3 Potential Evapotranspiration (ETP)

Evapotranspiration is the combined processes by which water is transferred from the earth's surface the atmosphere; evaporation of liquid or solid water plus transpiration from plants. Potential evapotranspiration (ETP) is the amount of moisture which, if available, would be removed from a given land area by evapotranspiration, expressed in units of water depth.

ETP is a function of temperature, humidity, wind, and net radiation. From values of ETP one can obtain values of actual evapotranspiration, ET, which when combined with precipitation, runoff, soil and plant types, yields soil moisture.

A reliable method of calculating ETP from readily available meteorological information is needed. The Penman method which includes the effects of temperature, wind, relative humidity, and

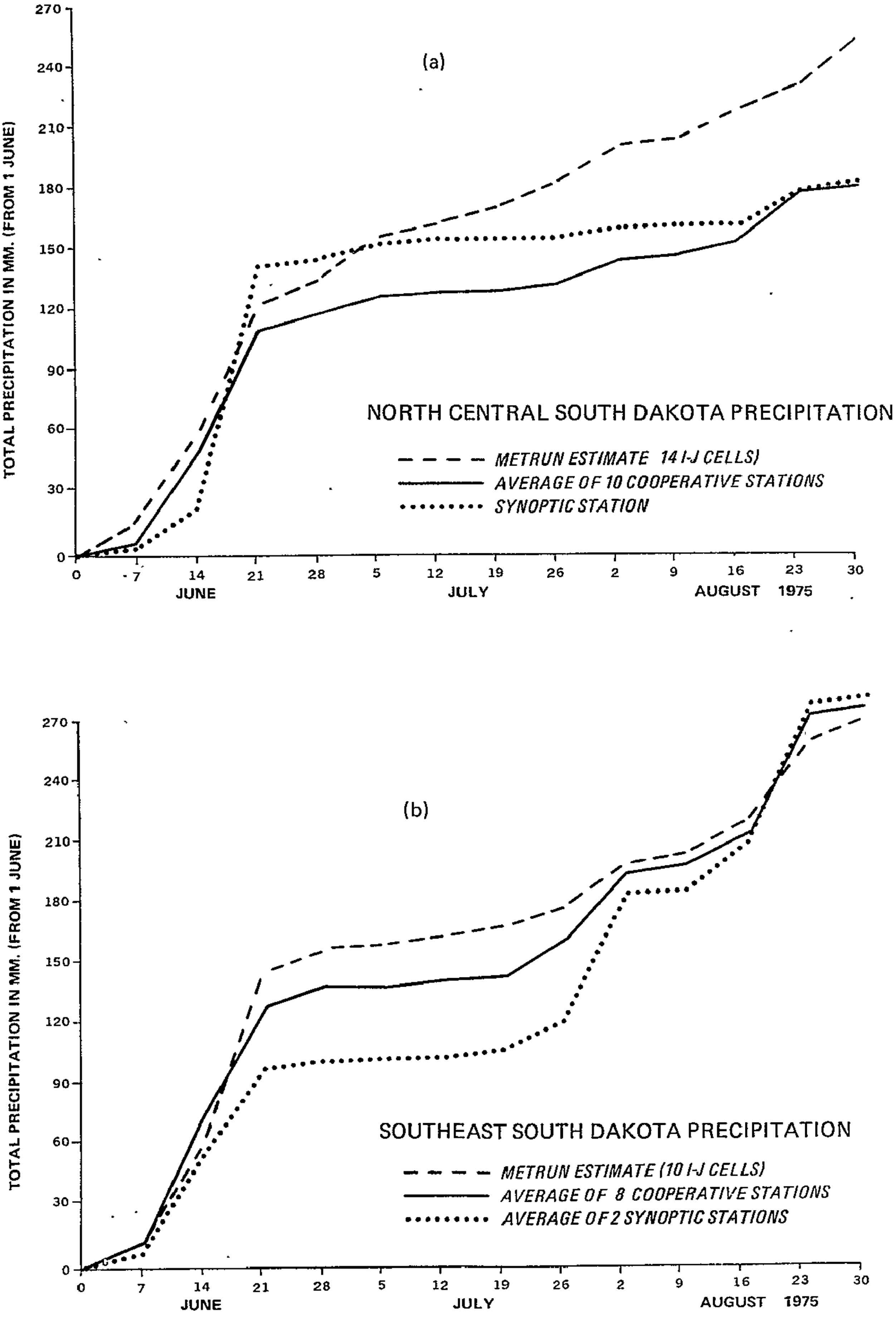


Figure 6-19: Cumulative weekly precipitation for all Crop Reporting Districts having at least one synoptic station, estimated by METRUN, synoptic stations, and cooperative stations. Period of 1 June to 30 August 1975.

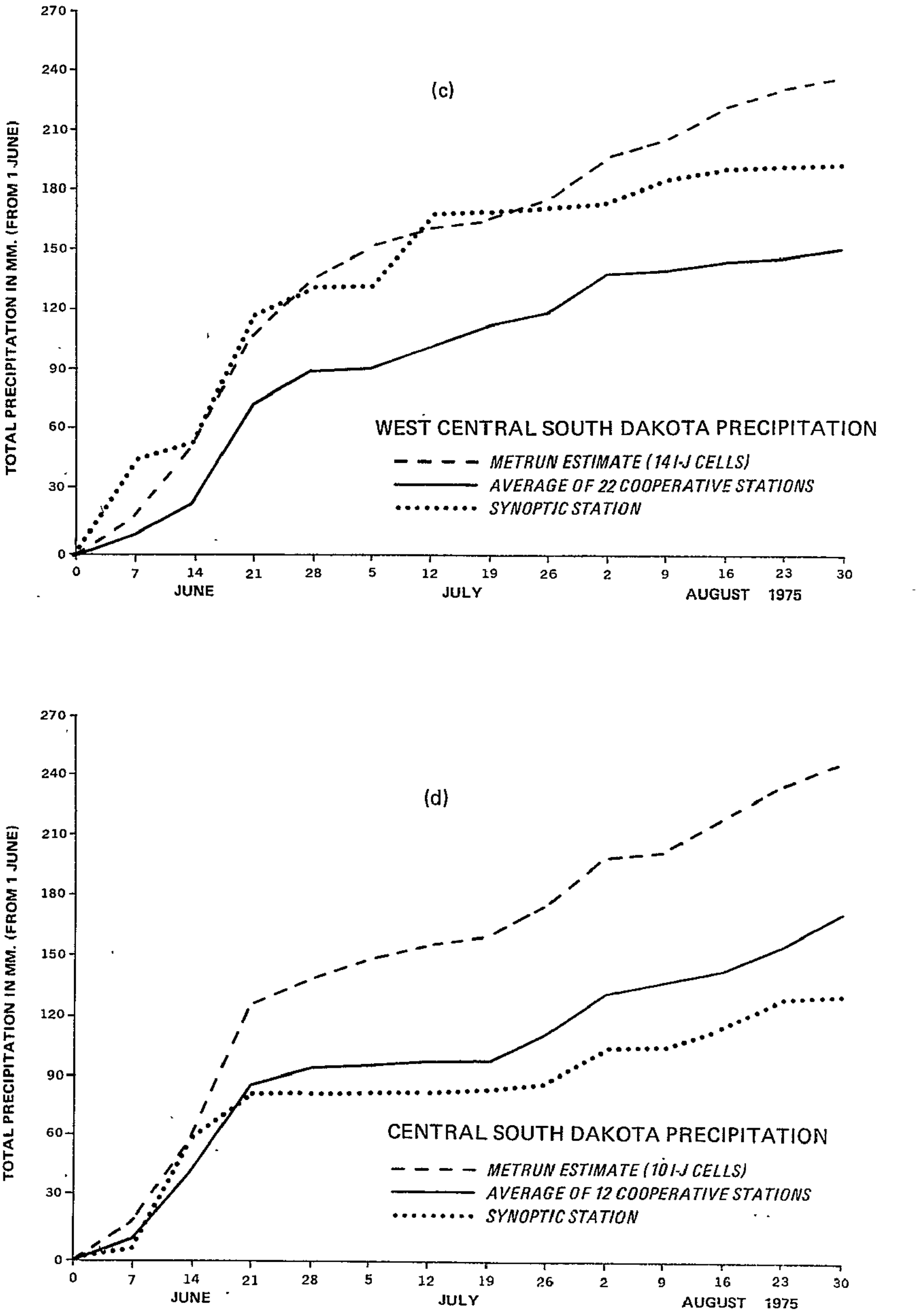
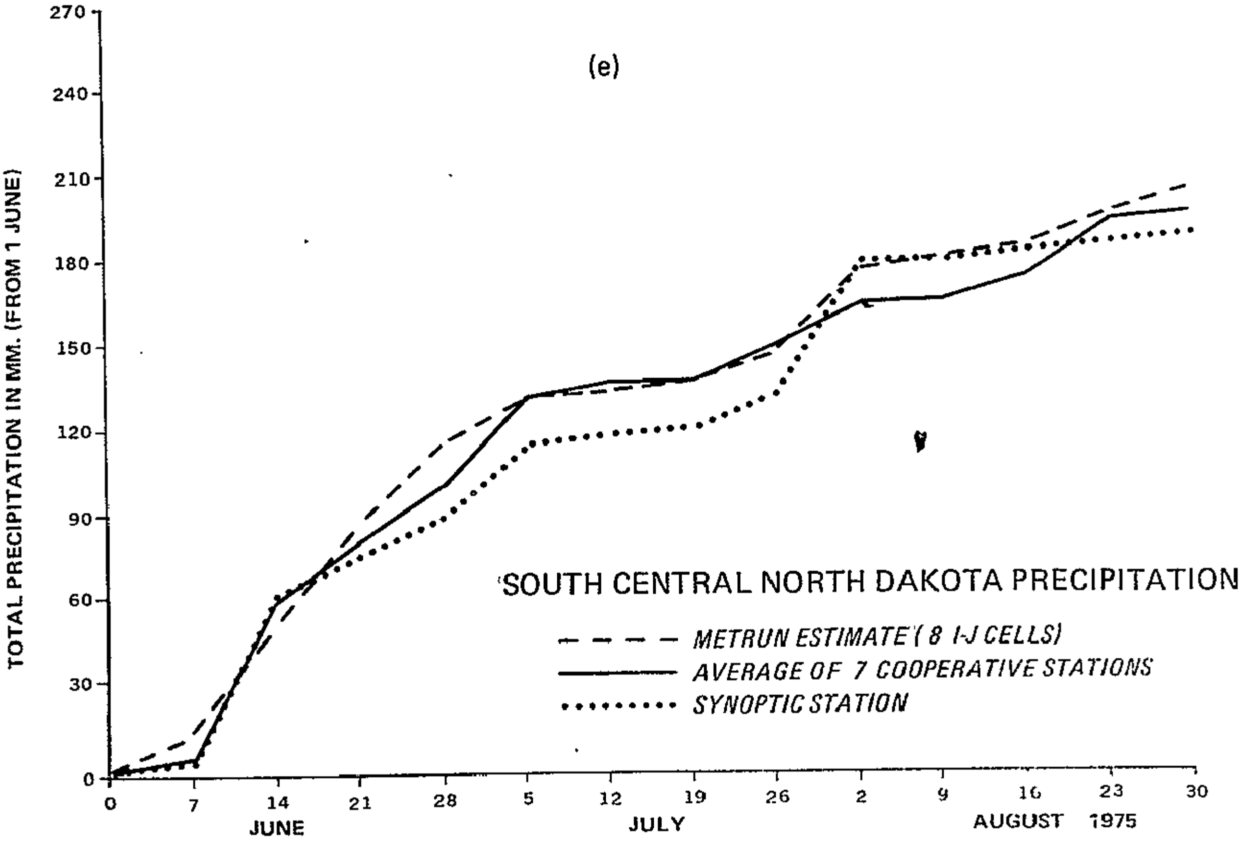


Figure 6-19: Continued



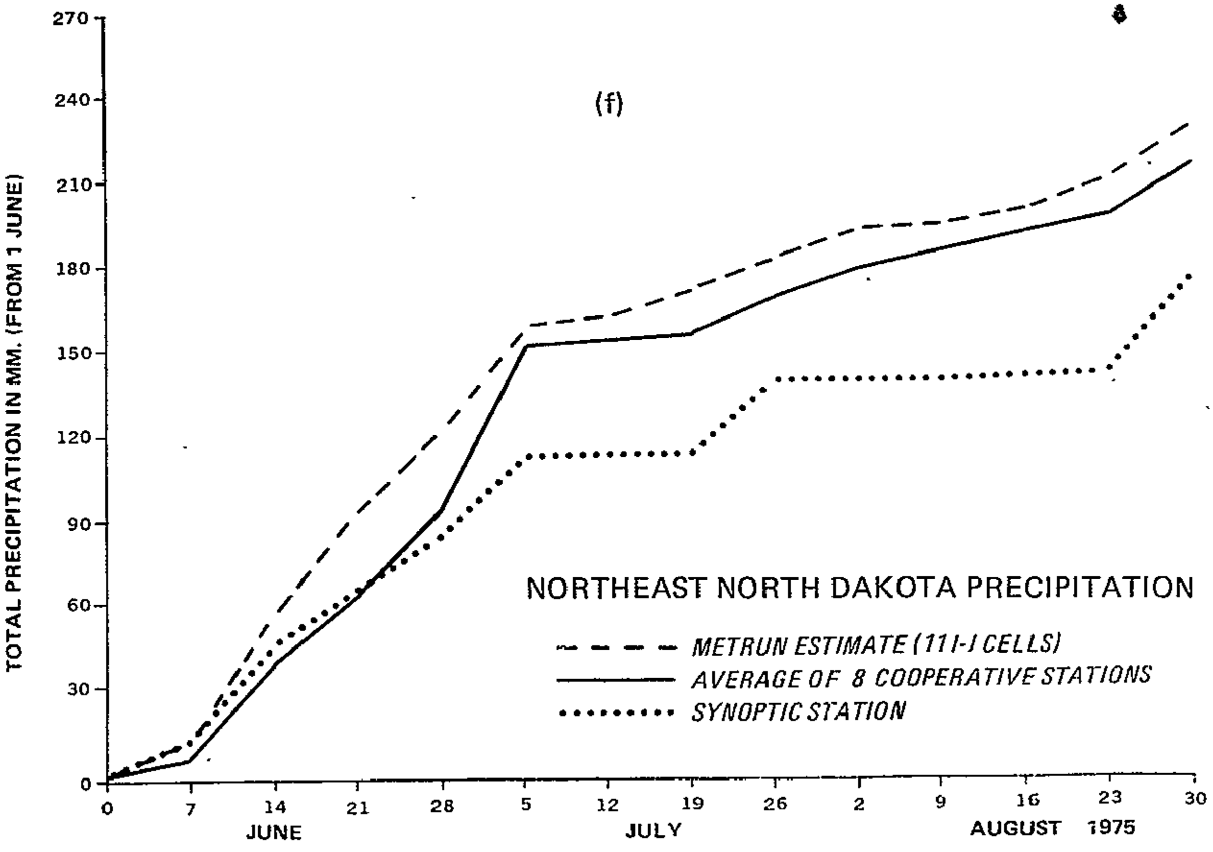


Figure 6-19: Continued

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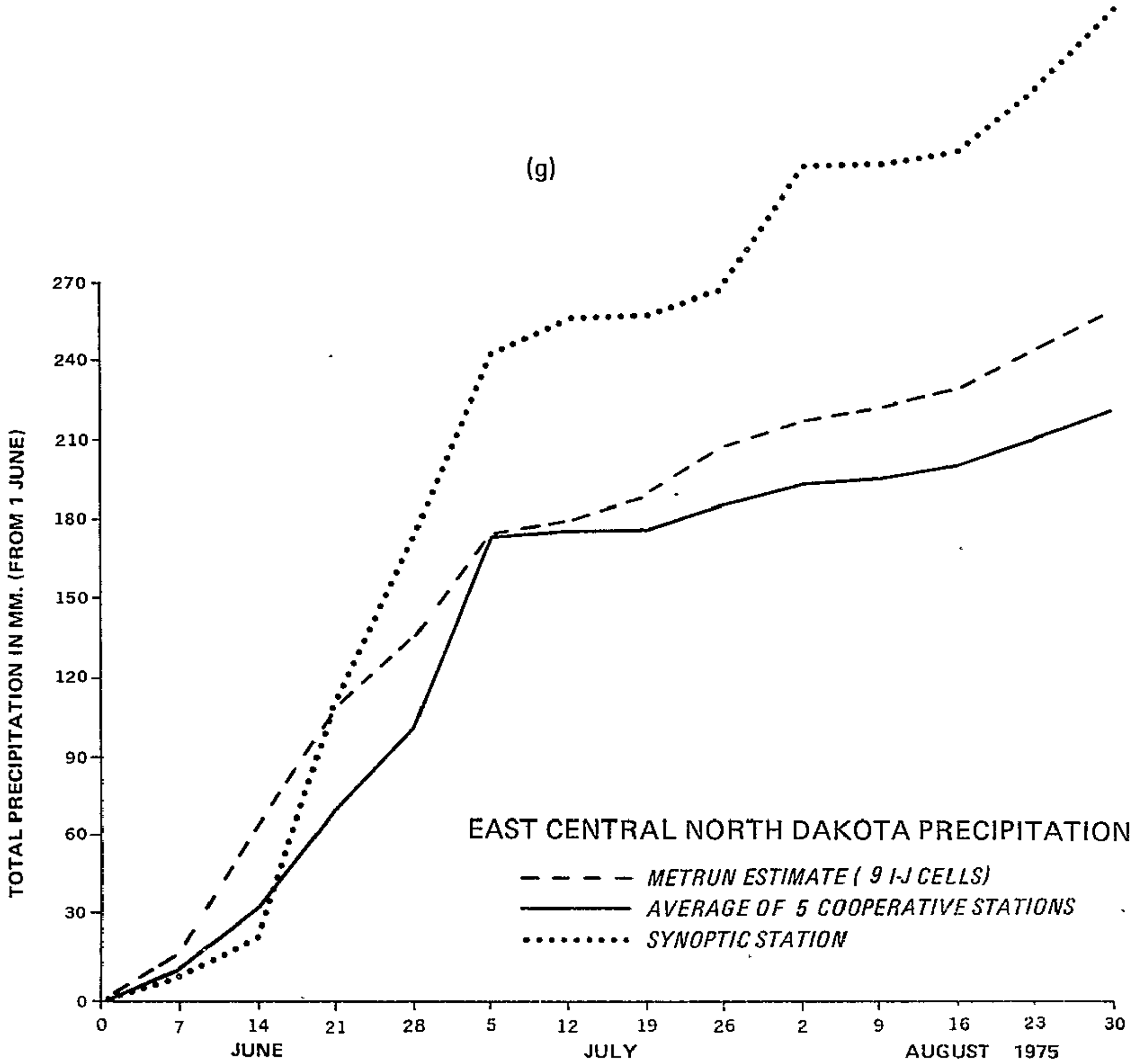


Figure 6-19: Continued

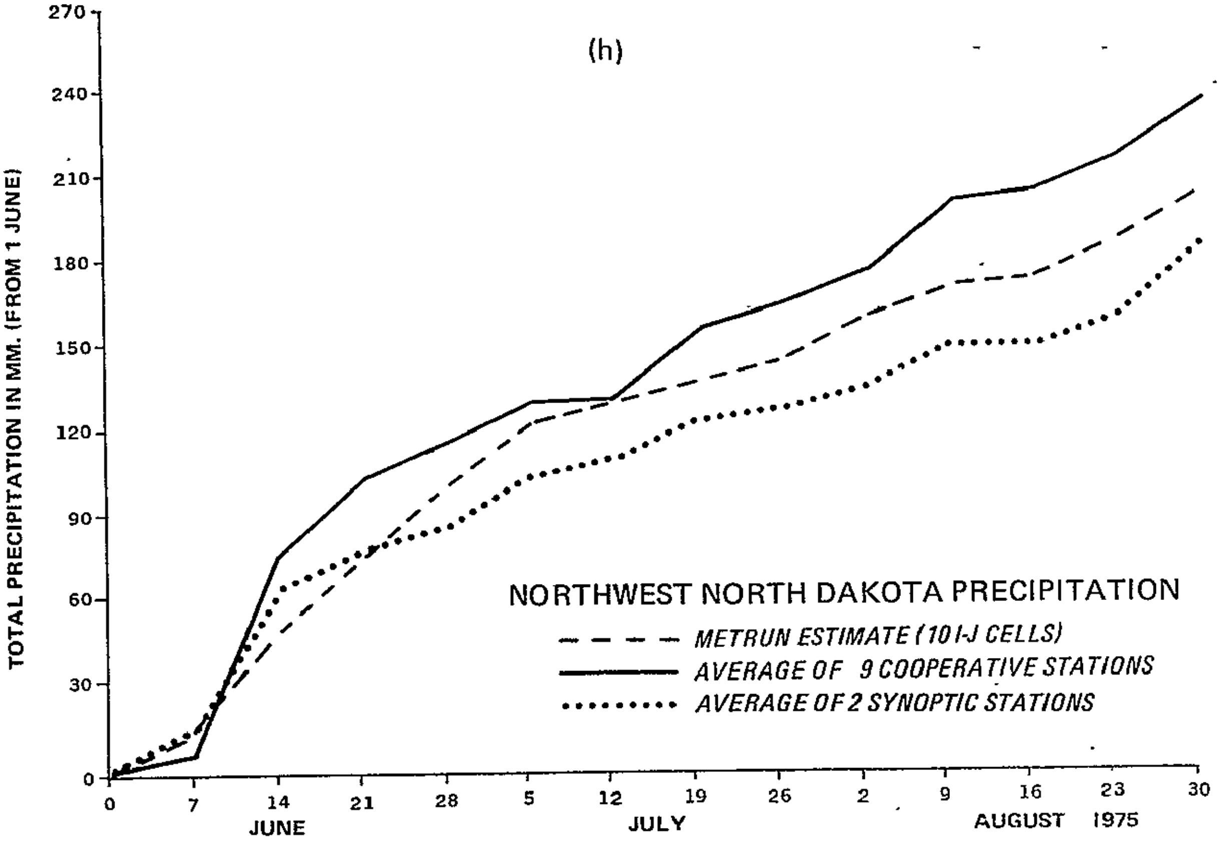
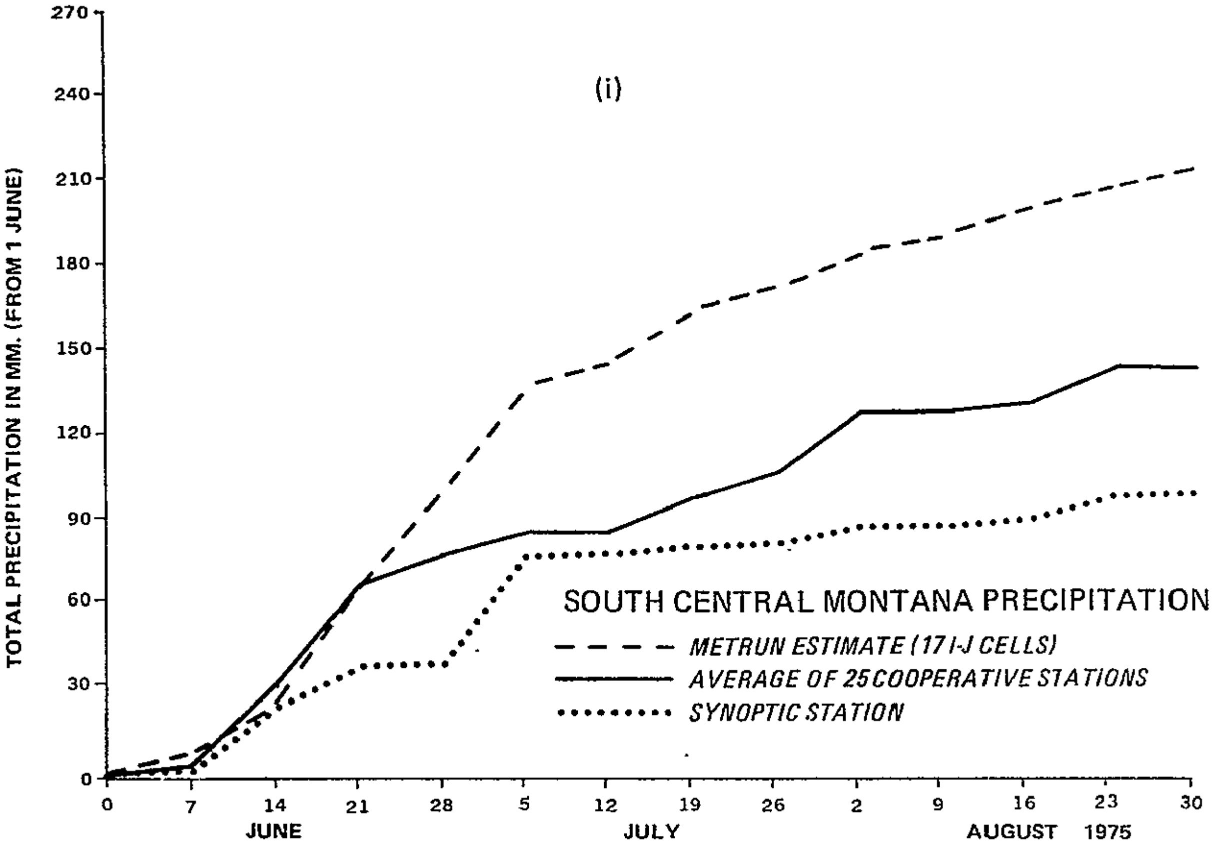


Figure 6-19: Continued



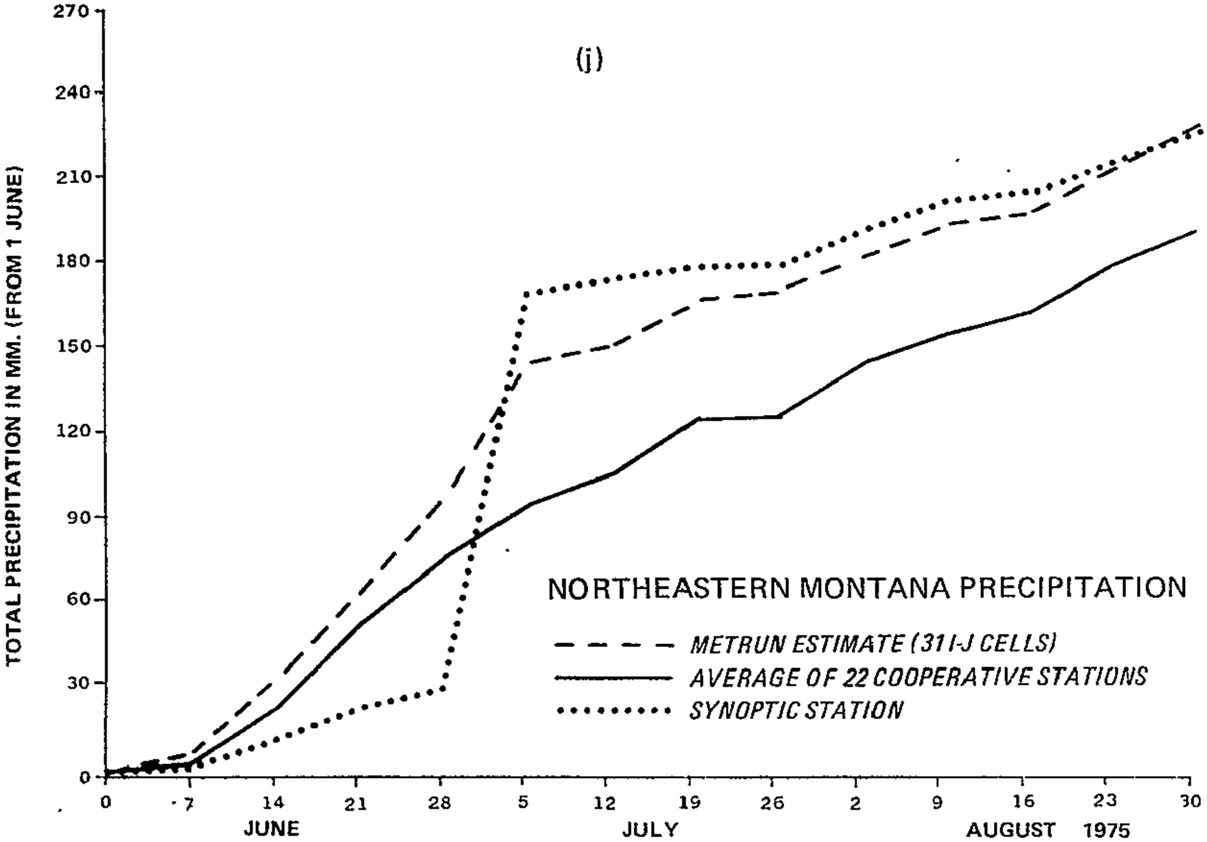
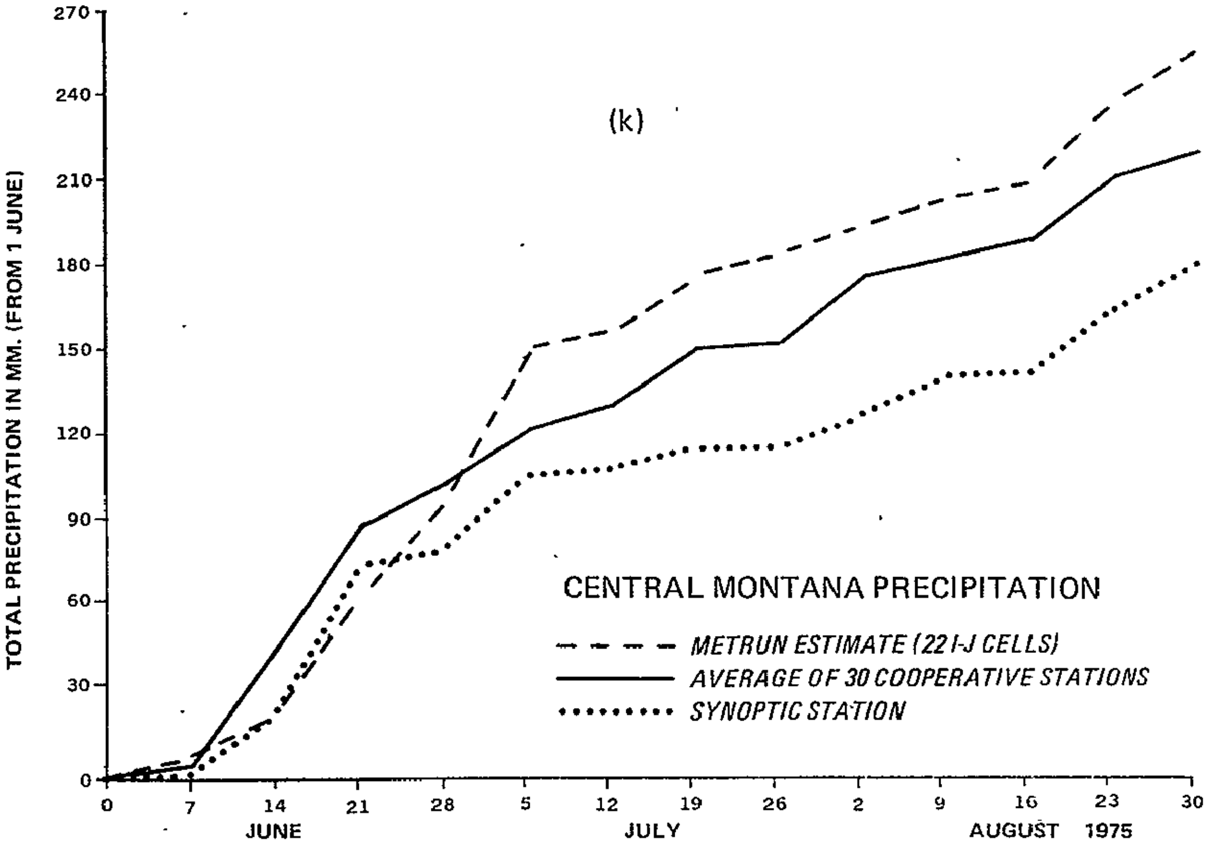


Figure 6-19: Continued



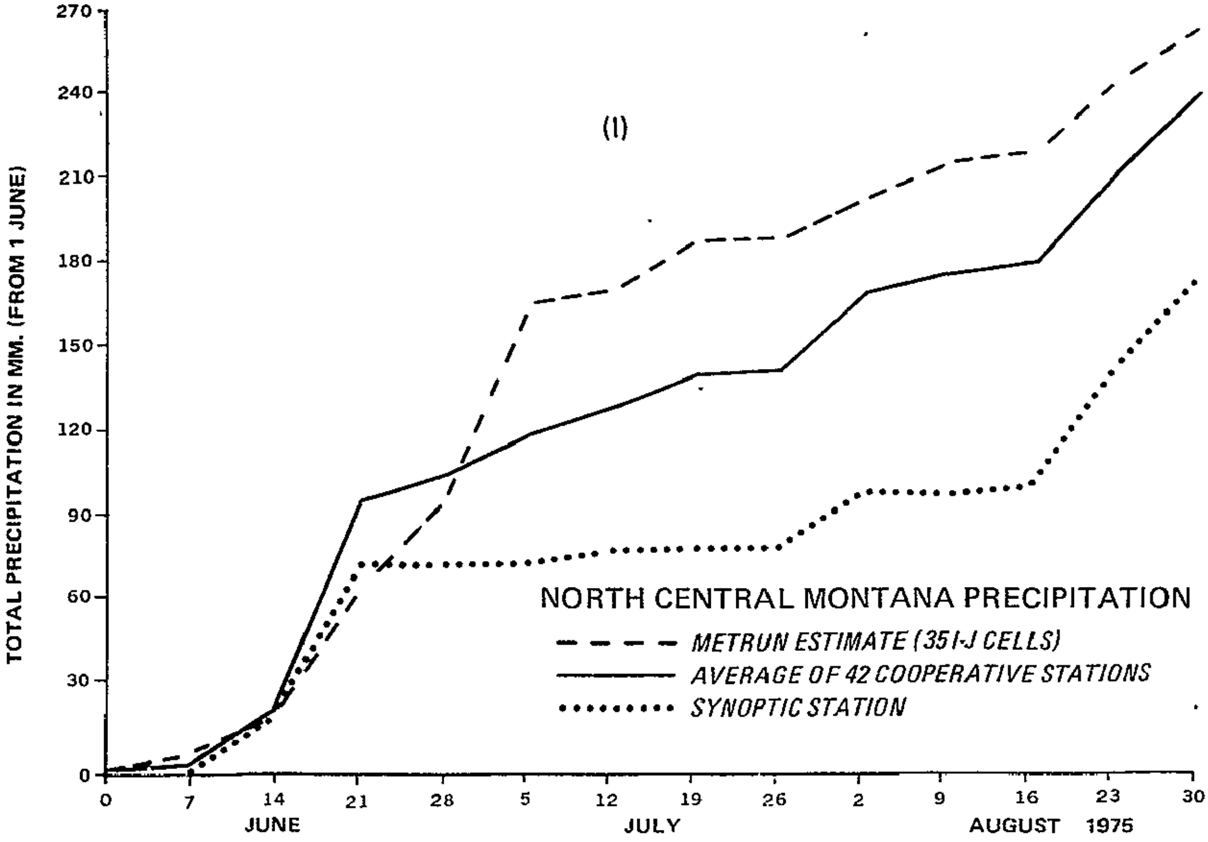


Figure 6-19: Continued

TABLE 6-4

Total June-August 1975 Precipitation for Agricultural Districts Determined by Cooperative Stations Reports, METRUN, and Synoptic Stations.

		Total Precipitation (mm)				
Agricultural District		Cooperative Stations	METRUN		Synoptic Stations	
Mont	C	223	260	(+43)*	184	(-39)
	NC	241	265	(+24)	177	(-64)
	SC	147	219	(+72)	103	(-44)
	NE	193	230	(+37)	229	(+36)
SD	SE	281	277	(-4)	288	(+7)
	C	177	253	(+76)	135	(-42)
	NC	190	258	(+68)	188	(-2)
	WC	155	242	(+87)	197	(+42)
ND	SC	204	212	(+8)	193	(-11)
	NE	219	234	(+15)	179	(-40)
	EC	226	263	(+37)	378	(-152)
	NW	238	206	(-32)	188	(-50)

*Departure from Cooperative Stations Average net radiation has demonstrated the necessary accuracy (WMO, 1971). The following is a description of how the EarthSat "System" agrometeorological software calculates the ETP utilizing both ground observations and satellite cloud cover.

The Penman equation for potential evapotranspiration is (Penman, 1948):

$$\text{ETP (mm/time)} = \frac{\Delta R_{NET} + 0.64 f(w)(e_s - e_a)}{\Delta + 0.64} \qquad [6\text{-}8]$$

where

R_{NET} is net radiation in cal/cm^2 per time interval,

Δ is slope of saturation vapor pressure versus temperature curve (mb °K^{-1})

e_s is saturation vapor pressure at air temperature (mb)

e_a is vapor pressure at air temperature (mb)

$f(w)$ is the wind effect, a function of the horizontal wind velocity.

The wind effect $f(w)$ is given by Penman (1956) as

$$f(w) = 0.35\ (0.5 + w/100) \qquad [6\text{-}9]$$

where w is wind movement in miles per 24 hours

In the EarthSat "System" the ETP calculations are performed for six-hour intervals at each I, J in the area. Daily ETP is obtained by summing up four six-hour calculations. For six-hour calculations the wind function becomes:

$$f(w) = 0.35\ (0.5 + 0.27618\ w)/4 \qquad [6\text{-}10]$$

where w is a surface wind measurement, in knots, made during the six-hour interval.

e_s, e_a and Δ are calculated from six-hourly temperatures and dew point observations by means of psychometric equations presented in the Smithsonian Meteorological Tables (1966) (See pp. 350 and 372).

Temperature, dew point, and wind are interpolated for each I, J cell coordinate from the 34 meteorological stations observations (see Section 4.1) by means of an inverse-distance weight function. The interpolated value at I, J, X_{ij}, is

$$X_{ij} = \sum_{1}^{n} \frac{x_n}{d_n} \sum_{1}^{n} \frac{1}{d_n} \qquad [6\text{-}11]$$

where x_n represents the value of a parameter observed at station n at a distance d_n from the cell coordinates I, J. Only the nearest three stations (of a total of eight) are considered. A preliminary discussion of the accuracy of this interpolation scheme and the overall error effects on ETP is presented in a following subsection.

Net radiation (R_{NET}) is the net energy gained by the surface through the processes of insolation and terrestrial radiation losses to space. R_{NET} is a measure of how much energy is available for heating the ground, and most importantly, for evaporation. R_{NET} is estimated by means of a combination of surface reports of temperature and dew point and cloud cover and type determined at six-hourly interval from SMS satellite imagery (see Section 4.2). R_{NET} is calculated in cal/cm^2 per six-hours, as will be described, and is changed into mm of evaporation using the conversion factor of 58.6 cal/cm^2 to evaporate one mm of water.

The net radiation at the surface, R_{NET} (cal/cm^2), is the difference between the net solar radiation, R_{SN}, and the net long wave or terrestrial radiation, R_{LN}:

$$R_{NET} = R_{SN} - R_{LN} \qquad [6\text{-}12]$$

Net solar radiation, R_{SN}, is that portion of the total incoming clear-sky solar radiation, $R_{sc}\downarrow$, not attenuated by clouds and not reflected by the earth's surface:

$$R_{SN} = (1 - A)\ F_s R_{sc}\downarrow \qquad [6\text{-}13]$$

where A is surface albedo expressed as a decimal from 0 to 1.

F_s is a solar radiation cloud factor which is a function of cloud type and amount.

$R_{sc}\downarrow$ is the total incoming clear-sky solar radiation which is the sum of direct clear-sky solar radiation at the earth's surface, $R_s\downarrow$, and the diffuse solar radiation, R_d: $R_{sc}\downarrow = R_s\downarrow + R_d\downarrow$

Following is a presentation of the equations used in calculating the various components of the net solar radiation.

Surface albedo is calculated as a function of the stage of growth of the wheat crop expressed in terms of Biometeorological Time, BMT. The equations used are:

$A = 0.10$ for bare ground ($BMT \leq 0$)

$A = 0.10 + 0.47BMT$ for the period between emergence and heading ($0 < BMT \leq 3.0$)

$A = 0.24$ for the period between heading and soft dough ($3 < BMT \leq 4$)

$A = 0.24 - 0.14(BMT-1)$ for the period between soft dough and ripe (< 4 $BMT \leq 5$)

The above equations represent linear interpolations between average albedo values of 0.10 for bare ground and 0.24 for the heading to soft dough stages, and back to .10 from soft dough to ripe. Figure 6-20 schematically illustrates wheat field albedo as a function of BMT. The solar radiation cloud factors, F_s, were estimated with the aid of values of transmission of solar radiation through clouds (overcast) presented in the Smithsonian Meteorological Tables (1966), p. 441. Table 6-5 presents the cloud factors for overcast conditions adapted from SMT.

The formula used to estimate cloud factor for any given cloud conditions is:

$$F_s = \Sigma n_t \cdot F_t + 1.0 - \Sigma n_t \qquad [6\text{-}14]$$

where n_t is fraction of given cloud types, and F_t is overcast cloud factor for given cloud types as shown in Table 6-1.

The direct clear-sky solar radiation at the earth's surface is:

$$R\downarrow_s = \int J_o \cos z \, \tau^{\sec z} \, dt \qquad [6\text{-}15]$$

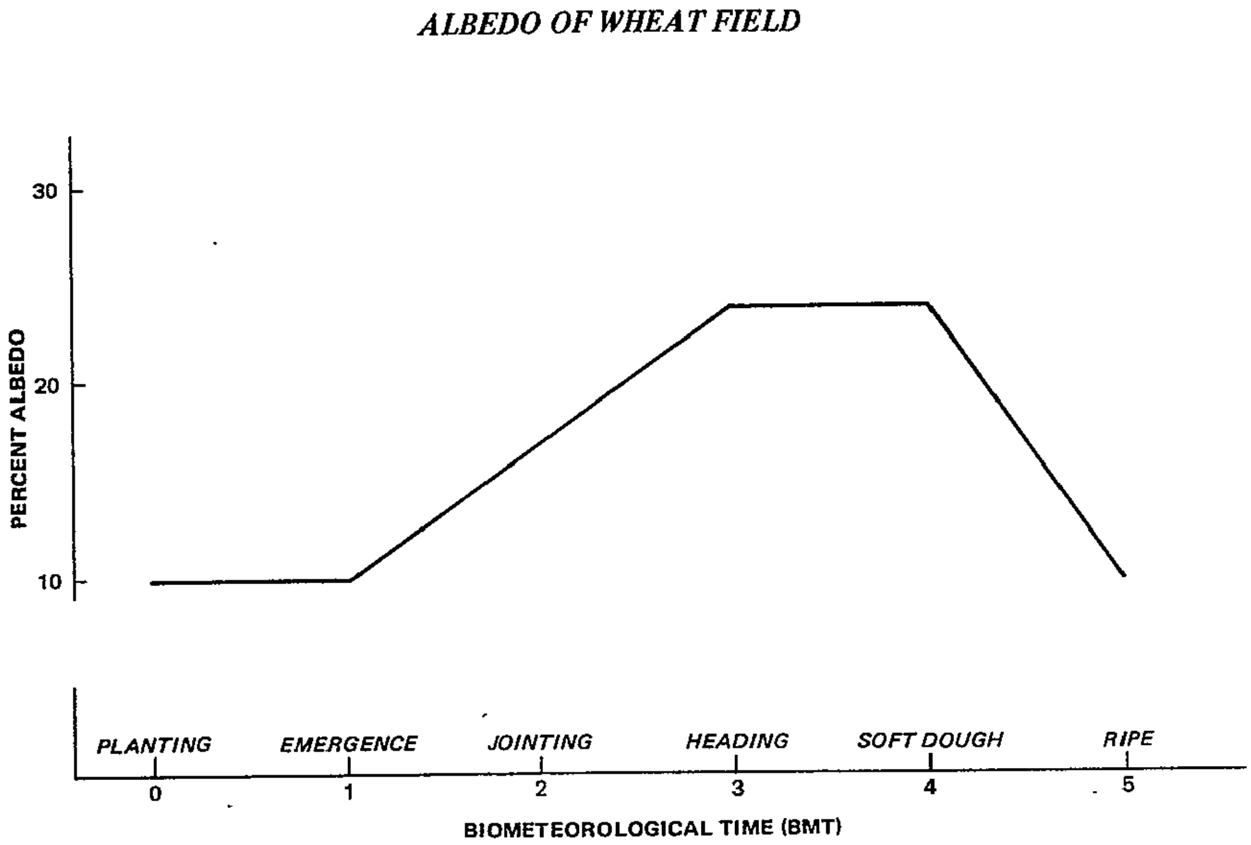


Figure 6-20: Albedo of wheat field as a function of Biometeorological Time.

TABLE 6-5

Solar Radiation Cloud Factors For Overcast Conditions
(Adapted from the Smithsonian Meteorological Tables, 1966)

Cloud Type	Cloud Factor, F_+
Ci	0.84
Cs	0.81
Ac	0.51
As	0.41
Sc	0.34
St	0.25
Ns	0.15
Fog	0.17

where J_0 = solar constant (2 $cal/cm^2/min$). z = solar zenith angle, τ = atmospheric transmission coefficient, and t = time.

The solar zenith angle is calculated by the following expression (SMT, p. 417):

$$\cos Z = \sin \Phi \sin \delta + \cos \Phi \cos \delta \cos h \qquad [6\text{-}16]$$

where Φ is latitude, δ is the sun's declination, h is the hour angle of the sun (angular distance of the sun from the meridian of the observer) and is expressed in degrees by:

$$h = 15t + \theta - 180 \qquad [6\text{-}17]$$

where t is Greenwhich Mean Time

θ is Longitude

The sun's declination is well approximated by:

$$\delta = 23.5 \sin (2\pi (D - 80)/365) \qquad [6\text{-}18]$$

where D is day of year

The atmospheric transmission coefficient, τ, is calculated using the relationship developed by McDonald (1960) and corrected for depletion due to dust:

$$\tau = 0.95 - 0.077\ u^{0.3} \qquad [6\text{-}19]$$

where the atmospheric water vapor, u (cm. of precipitable water), is estimated from the surface vapor pressure, e_a, by (McDonald, 1960):

$$\log_{10} u = -0.579 + 0.247\sqrt{e_a} \qquad [6\text{-}20]$$

The direct solar radiation for six hours is obtained by substituting h in terms of t in equation [6-16] and integrating equation [6-15] in steps of half hour intervals for the six-hour period.

The diffuse solar radiation at the earth's surface, R_d, is estimated by (SMT, p. 240):

$$R\downarrow_d = \frac{0.91\ R_o + R\downarrow_s}{2} \qquad [6\text{-}21]$$

where R_o is the incoming solar radiation at the top of the atmosphere and is calculated by:

$$R_o = \int J_o \cos z\ dt \qquad [6\text{-}22]$$

where all the symbols are as previously defined, and the integration is done for a six-hour period.

The net long wave radiation, R_{LN} (cal/cm^2), is that portion of the long wave radiation that is lost to space:

$$R_{LN} = R_{LC}\uparrow - F_L\ (\sigma\ T_a^4 - R_{LC}\uparrow) \qquad [6\text{-}23]$$

where $R_{LC}\uparrow$ is the clear sky long wave radiation and is calculated by Geiger's method (1972):

$$R_{LC}\uparrow = [\sigma\ T_a^4\ (.18 + .25 \times 10^{-065e}) - 0.007\ (T_a - T_g)] \qquad [6\text{-}24]$$

where T_a is air temperature

T_g is ground temperature ($T_g = T_a$ in our calculations)

$\sigma = 8.132 \times 10^{-11}$ cal/cm^2/min/deg^4

e is vapor pressure at air temperature

F_L is the long wave radiation cloud factor calculated for a combination of cloud cover and type by:

$$F_L = (\Sigma \sqrt{k_t}\ W_t)^2 \qquad [6\text{-}25]$$

The above equation is a variant of the long wave cloud factor, kw^2, presented by Geiger (1972), p. 26, which considers only one cloud type at a time. W_t is fraction of given cloud type, and k_t is a constant which depends on the cloud type. Values of k_t are as follows (Geiger, 1972): Ci, 0.04; Cs, 0.08; Ac, 0.17; As, 0.20; Cu, 0.20; St, 0.24.

SMS images such as shown in Section 4 Figures 4-4 and 4-5 are used to determine cloud cover and type necessary for net radiation calculations. Cloud cover and type are readily determined from the visible images. When only infrared images are available the two brightness levels analyzed on the infrared images are arbitrarily changed into probable cloud types for purposes of estimating the cloud factors, F_L and F_s. The amount of brightest (whitest or coldest) area measured is equally divided among the three cloud types Cb, Ns, and Cc, which are most likely to appear coldest in the infrared. The amount of bright (gray-white) area measured is changed into 2/3 stratus and 1/3 cumulus.

Figure 6-21 summarizes schematically all the parameters involved in the calculation of ETP. Following are examples of mapped solar, net radiation, and ETP calculation performed daily by METRUN.

Figure 6-22 is an example of solar radiation maps produced daily as an output of METRUN. The map presents values of total incoming solar radiation received at the surface for June 30, 1975 (day 181). Two SMS images for this same day are shown in Figure 4-4 and 4-5. These solar radiation values will be directly compared with pyranometer measurements of total solar radiation for sites in the study area.

The solar radiation values range from about 130-150 ly/day in the area of eastern North Dakota - northwestern Minnesota, which the 23:45 GMT (approximately 7:15 PM local solar time) SMS image shows covered by thick cumulonimbus clouds, to values in the 800's ly/day in cloud-free areas.

Figure 6-23 is an example of net radiation maps produced daily as an output of METRUN. This map also is for June 30, 1975 (day 181). Net radiation is also strongly correlated to cloud cover, with low values (less than 100 ly/day) occurring in areas of thick clouds and high values (greater than 500 ly/day) occurring in cloud-free areas.

6.3.1 ETP Error Analysis

An estimation of the errors involved in the calculation of ETP by the Penman equation requires an estimation of the

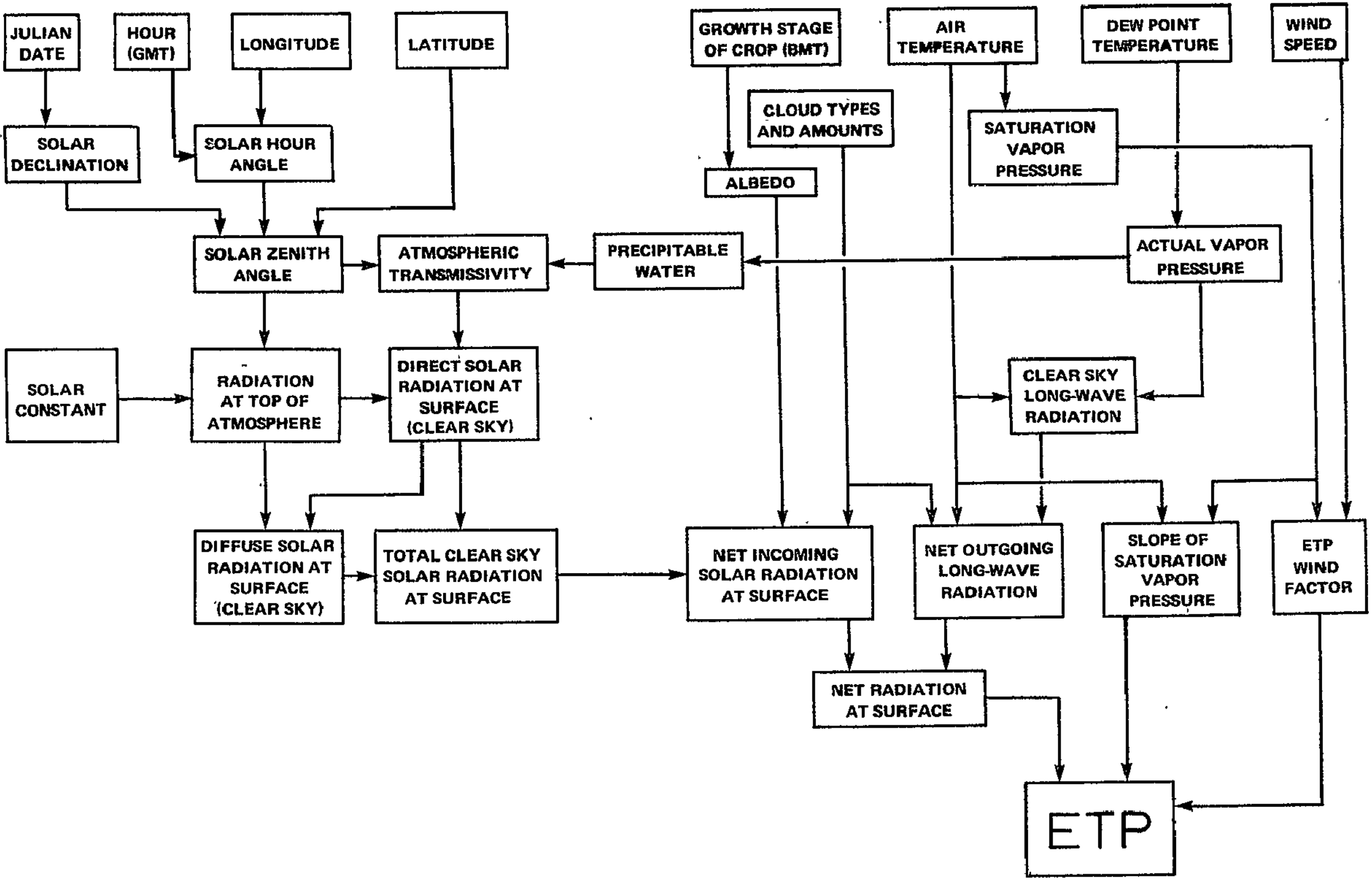


Figure 6-21 Parameters involved in the calculation of Potential Evapotranspiration (ETP).

```
                                                  EARTHSAT
                                          DAILY WEATHER DIAGNOSTIC
HOR COORD = I VERT COORD = J                    PAGE 1  DAY181  TIME  24 GMT    MAP 11  00-24 GMT SOLAR RAD LY/DAY

    206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232
  ***
335 702*702 702 733 889 888 887 887 886 887 886 885 883 882 881 880 880 880 879 873 873 868 867 866 764 761 865
         ****
336 703 703 704 704 705 705 738 762 764 765 766 765 883 807 805 802 880 880 876 876 873 869 869 767 764 762 861
              *****
337 701 703 704 705*705 706 763 764 765 767 634 661 704 807 805 882 882 881 876 876 875 870 770 768 765 564 667
                     *****
338 703 702 704 735 735 762*762 632 632 633 634 589 703 701 699 777 776 879 878 876 780 578 576 572 566 564 669
                            *****
339 732 733 734 736 735 627 629 630*632 633 635 590 589 702 699 776 775 775 772 679 580 577 574 569 566 564 669
                                    ****
340 734 734 735 604 603 627 574 695 684 686 614 641 637 700 776 776 776 775 681 586 579 577 571 569 566 563 668
                                           *****
341 733 734 735 736 605 551 695 695 693 615 614 639 703 700 777 776 775 685 681 582 578 574 572 569 566 563 669
                                                   *****
342 885 886 689 688 697 696 694 694 692 691 613 704 702 734*735 776 688 686 681 581 575 573 571 569 567 563 669
                                                        *   ******
343 689 688 688 687 698 696 694 694 692 690 677 709 707 665 735 736*736 683 584 581 576 573 571 569 551 548 635
                                                       *             ******
344 689 689 688 687 633 632 828 828 827 825 818 816 773 843 737 735 734 643*545 542 575 572 557 553 514 513 669
                                                     *                         ******
345 687 687 687 686 830 829 827 826 827 826 819 817 774 843 843 842 661 660 564 562 523*522 556 517 515 274 429
                                                    *                                      *******
346 884 885 734 733 830 829 827 825 826 824 819 817*772 844 842 661 660 566 563 547 544 521 519 278*275 274 428
    ****                                          *                                                 *  ********
347 885 886 734 689 688 676 674 673 825 819 819 773 773 843 660 573 568 565 549 546 353 388 314 312 310 132 147
          ****                                  *                                                  *
348 886 885 689*688 636 686 675 673 672 665 817*774 761 759 756 569 566 602 584 582 389 758 312 132*132 147 147
                 *****                        *                                                   *
349 886 843 687 635 634*632 672 670 662 815 772 759 758 796 794 607 604 587 584 391 388 132 131 146.146 147 148
                         *****              *  *****                                              *
350 845 841 636 634 633 633 632*630 815 803*797 799 798*795 792 593 590 587 583 391 388 128 146 146 146 148 148
                                 *****    *              *****                                   *
351 848 846 687 634 633 633 632 784 784*878 878 880 797 790 594*592 577-586 391 389 201 143 147 146 147 148 148
                                        *                        ********                       *
352 849 847 686 684 683 633 632 785 530 831 877 717 680 679 605 604 728 394*201 215 142 143 147*146 147 472 473
                                       *                                     *******           *
353 850 849 692 689 687 685 635 788 532 624 715 520 521 606 605 754 752 533 547 215 142*143 146 472 473 473 473
                                     *                                                   *******
354 851 850 691 689 688 686 683 837 530 829 521 522 452 452 604 755 561 561 215 214 142 143 472 472 473 473 472
                                   *                                                        *
355 855 853 847 690 688 686 684 837 834 718 718 522 452 452 756 754 752 683 686 687 594 773 598 473 473 579 706
                                 *                                                            *
356 856 855 854 848 847 688 686 861*886 884 722 523 452 605 757 753 796 873 688 690 872 872 872 744 680 705 707
                                     ****                                                    *
357 899 856 855 764 762 808 869 705 859 858*882 680 454 607 757 754 796 873 689 873 874 873 872 745 806 807 807
                                             *******                                        *
358 900 900 765 811 810 872 870 863 733 859 855 680 761*608 758 798 797 875 874 874 873 874*874 872 808 808 808
                                                         ******                            *
359 901 900 812 811 902 873 739 735 733 860 883 878 878 834 877 875 873 874 873 874 875 875 874 874 808 809 810
                                                                   *****                ****
360 901 811 812 904 877 740 739 739 735 763 889 884 879 876 876 875 874 874 874 873 873*874 874*874 811 811 872
   ***** MANHATTAN                                                       *****         *          ********
361*736*901 901 877 875 822 819 739 764 891 889 881 881 877 877 876 874 873 873*873*873 874 875 875 811 875*874
   *****                                                                           ***
362*799*901 875 875 874 822 821 816 814 889 887 881 881 878 877 875 874 872 874 872 871 873 875 876 812 873 873
   ***** AKRON
```

Figure 6-22:

Sample computer printout map of solar radiation (langleys/day) produced by Subprogram METRUN. The map is for 30 June 1975 (day 181). Two SMS images for this same day are shown in Figure 4-4 and 4-5. Solar radiation is calculated at each I, J cell location. Values for Manhattan, Kansas and Akron, Colorado, the two lysimeter sites outside of the area, are shown on the lower left hand corner. Figure 4-2 is an overlay to this printout

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                                                  EARTHSAT
                                          DAILY WEATHER DIAGNOSTIC
HOR COORD = I VERT COORD = J                    PAGE 1  DAY181  TIME  24 GMT    MAP  6  00-24 GMT NET RAD LY/DAY

    206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232
  ***
335 443*448 447 463 570 571 570 571 568 571 570 569 568 559 557 557 556 555 555 544 543 538 538 538 484 481 535
         ****
336 444 444 447 447 448 448 468 485 486 485 485 488 564 525 523 521 557 556 546 545 543 539 568 518 484 482 527
              *****
337 442 442 444 445*447 448 483 485 488 488 384 404 447 528 527 562 561 558 546 546 544 570 520 518 517 370 422
                     *****
338 442 442 442 459 459 477*484 385 384 385 385 371 445 446 444 480 479 556 548 546 529 384 381 378 371 370 422
                            *****
339 458 458 458 460 458 374 375 376*382 383 384 370 370 446 444 476 475 471 466 420 385 382 379 375 371 370 424
                                    ****
340 458 459 461 359 358 373 349 431 409 410 383 402 398 442 476 475 471 471 423 390 383 381 376 375 372 370 425
                                           *****
341 486 487 486 487 387 363 431 430 428 377 379 394 441 439 472 500 470 427 422 386 383 379 376 375 373 371 394
                                                   *****
342 589 588 441 440 461 459 458 429 428 425 374 438 436 467*469 499 457 455 422 386 380 379 377 375 373 340 394
                                                        *   ******
343 441 441 440 439 461 460 460 458 426 424 421 450 463 435 470 470*470 453 386 376 371 379 377 375 370 337 369
                                                       *             ******
344 442 441 439 439 413 414 563 530 528 541 537 534 520 555 471 468 468 423*349 348 371 370 367 364 313 312 396
                                                     *                         ******
345 441 440 439 438 564 560 528 530 541 541 536 549 516 550 553 552 418 409 361 360 341*340 366 314 313 148 231
                                                    *                                      *******
346 566 564 478 477 534 532 529 541 541 542 551 554*515 549 549 414 418 362 358 356 352 339 338 147*144 148 230
    ****                                          *                                                 *  ********
347 570 565 453 425 424 433 432 431 541 521 520 519 519 519 414 374 373 362 356 355 221 246 208 170 168  73  76
          ****                                  *                                                  *
348 570 570 432*456 416 435 431 430 415 410 522*490 488 517 507 375 372 399 384 382 247 520 207 105*105  76  76
                 *****                        *                                                   *
349 571 551 460 420 415*413 429 428 407 517 488 487 516 543 538 399 397 392 391 250 257 106 106 107  74  74  76
                         *****              *  *****                                              *
350 577 573 420 418 418 410 410*378 519 516*512 512 541*544 534 386 395 389 390 259 257 103 108 106  74  75  77
                                 *****    *              *****                                   *
351 579 578 458 388 388 387 386 496 489*547 545 546 541 534 387*384 382 388 254 253 150 106 108 107  74  75  77
                                        *                        ********                       *
352 550 549 427 427 425 386 384 496 305 510 544 449 392 424 388 383 472 246*117 150 104 105 106* 75  74 298 300
                                       *                                     *******           *
353 551 551 433 430 428 426 387 500 288 342 428 284 299 357 355 493 441 336 367 146 101*105  74 291 292 292 299
                                     *                                                   *******
354 551 551 432 430 428 426 424 536 287 499 309 308 253 253 335 432 339 337 113 113  68  69 288 289 293 291 289
                                   *                                                        *
355 554 553 547 429 459 458 454 514 511 460 450 308 275 274 438 428 427 399 409 410 370 463 375 290 289 340 427
                                 *                                                            *
356 585 583 583 578 576 458 456 556*569 533 458 312 278 351 431 428 459 494 403 411 502 502 502 419 382 426 428
                                     ****                                                    *
357 606 585 583 510 508 531 583 459 573 548*557 375 270 353 430 426 459 494 405 496 497 502 504 419 466 466 466
                                             *******                                        *
358 600 599 511 535 535 587 585 578 489 573 533 375 436*353 430 459 459 494 498 496 497 496*496 498 466 467 466
                                                         ******                            *
359 600 598 528 530 608 589 496 491 490 574 551 546 546 500 495 495 493 493 493 498 497 497 496 498 458 459 492
                                                                   *****                ****
360 598 528 529 603 593 499 498 496 491 477 560 551 546 535 533 539 536 492 493 493 493*496 498*498 459 459 530
   ***** MANHATTAN                                                       *****         *          ********
361*455*599 599 583 560 518 516 465 479 557 555 543 541 536 533 537 535 533 493*494*494 534 532 532 460 497*530
   *****                                                                           ***
362*478*591 575 581 556 516 516 510 509 556 553 545 544 546 540 538 537 533 534 533 494 531 532 532 492 536 567
   ***** AKRON
```

Figure 6-23:

Sample computer printout map of net radiation (langleys/day) produced by Subprogram METRUN. The map is for 30 June 1975 (day 181).

errors in each of the parameters in the equation. We will, therefore, first present a discussion of the errors in temperature, dew point, wind, and solar radiation, the major components of the Penman Equation.

6.3.1.1 Error Discussion - Temperature, Dew Point and Wind

As was discussed in section 6.2, the available synoptic stations data are used to assign a temperature, wind speed, and dew point to each I, J cell. These quantities are calculated by means of an inverse-distance weight function (equation 6-11).

To evaluate the error in this technique each week of synoptic data was examined. For the 24 cells in the study area that contain a synoptic station, estimated values of temperature, dew point, and wind speed were calculated. These quantities were obtained by eliminating the station within the cell and using the three closest stations around the cell. The weighting formula (equation 6-11) was applied, and estimated quantities of temperature, dew point, and wind speed were obtained.

The values of the station within the cell are assumed to be actual cell values. These actual values were compared to the estimated values. Statistical analysis software was applied to calculate frequency distributions for each time period and for each station. An example of the results is presented in Figure 6-24.

```
                                          ERROR ANALYSIS FOR TEMPERATURES(C)      DAYS 159 THRU 165

                             FREQUENCY DISTRIBUTION FOR (DELTAT=TTACTUAL-TTESTIMATE)          TIME  24 GMT
           STATION                                   CLASS INTERVAL
                      GE 3      2.9T01.0     .9T00.0    -.1T0-1.0  -1.1T0-3.0     LT -3.0        AVG DEV    VARIANCE      ST DEV
          ABERDEEN       1           3           2           1           0           0             1.4         2.9          1.7
         ST. CLOUD       0           1           0           4           2           0             1.0         1.6          1.2
        RAPID CITY       0           2           2           3           0           0             0.8         1.4          1.2
             HURON       0           0           3           2           1           0             0.5         0.7          0.8
         PICKSTOWN       0           1           1           2           3           0             1.2         1.9          1.4
       SIOUX FALLS       0           0           2           2           3           0             1.3         2.4          1.5
           SPENCER       0           1           2           1           3           0             1.3         2.6          1.6
       GREAT FALLS       0           2           1           0           4           0             1.8         3.9          2.0
             HAVRE       0           4           2           1           0           0             1.2         1.8          1.3
           GLASGOW       2           3           0           0           1           0             2.8         8.9          3.0
         WILLISTON       0           2           2           1           1           0             1.2         2.1          1.5
          BISMARCK       0           2           1           2           2           0             1.2         2.3          1.5
       DEVILS LAKE       1           1           2           1           1           1             2.2         7.5          2.7
             FARGO       0           2           0           4           1           0             1.1         1.9          1.4
           BEMIDJI       0           2           2           3           0           0             0.7         0.9          0.9
          BILLINGS       0           1           3           1           1           1             0.9         1.9          1.4
          SHERIDAN       0           1           1           1           2           2             2.0         6.9          2.6
PORTAGE LA PRAIRIE       0           1           3           1           1           1             1.6         4.4          2.1
          WINNIPEG       0           1           5           0           1           0             0.9         1.5          1.2
           ESTEVAN       0           0           2           1           3           1             1.5         4.3          2.1
            REGINA       1           4           0           1           1           0             2.0         5.9          2.4
     SWIFT CURRENT       0           1           0           1           4           1             2.1         5.6          2.4
      MEDICINE HAT       0           0           2           2           3           0             1.0         2.0          1.4
          CHEYENNE       0           0           0           0           4           3             3.3        15.1          3.9


                                FREQUENCY ANALYSIS FOR ALL STATIONS AT TIME  24 GMT
                     .030        .212        .230        .212        .255        .061              1.5         3.8          1.9
```

Figure 6-24: Sample computer printout of temperature error analysis program.

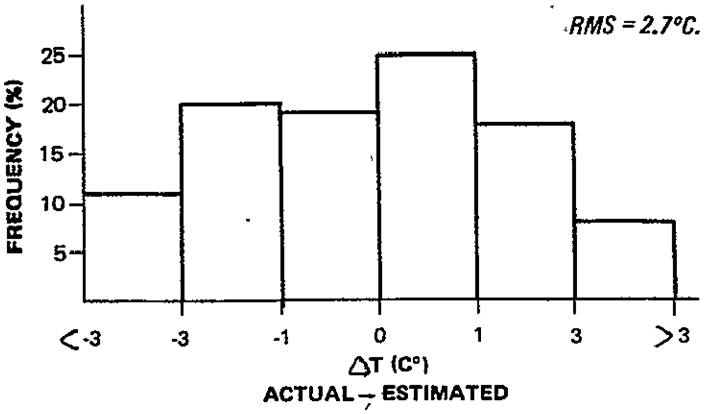
Results show that the distance weighting technique described above is acceptable in most cases. For the weekly periods in June to August the root-mean-square error (rms) for temperature and dew points ranges between 2 and 3°C, averaging 2.3°C for temperature and 2.6°C for dew point. The rms for wind speeds range from 3.5 to 5.0 knots, averaging 4.2 knots. A representative example of the frequency distribution of the differences between actual and estimated values is displayed in Figure 6-25.

Noticeable discrepancies between the actual quantity and the estimated quantity occur when: 1) the distances between the stations become larger than 150 kilometers, 2) the three closest stations are all upstream or downstream from the I, J cell, 3) topographical variations between stations are abrupt, 4) frontal situations produce strong gradients, and 5) mesoscale events such as valley fog or air-mass thunderstorms are present in the study area.

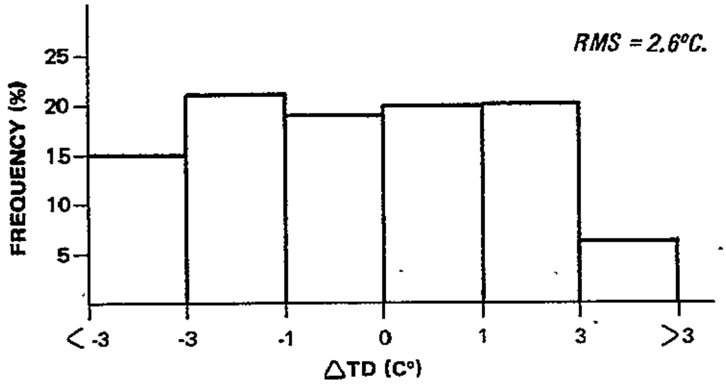
6.3.1.2 Analysis of Solar Radiation Estimation by METRUN

Solar radiation is one of the more important components of the METRUN calculations. It comes into play in the net radiation term of the Penman equation, and will be a major input to any physiological plant model. Since no daily measurements of net radiation are available in our area of interest for comparison to

TEMPERATURE



DEW POINT



WIND SPEED

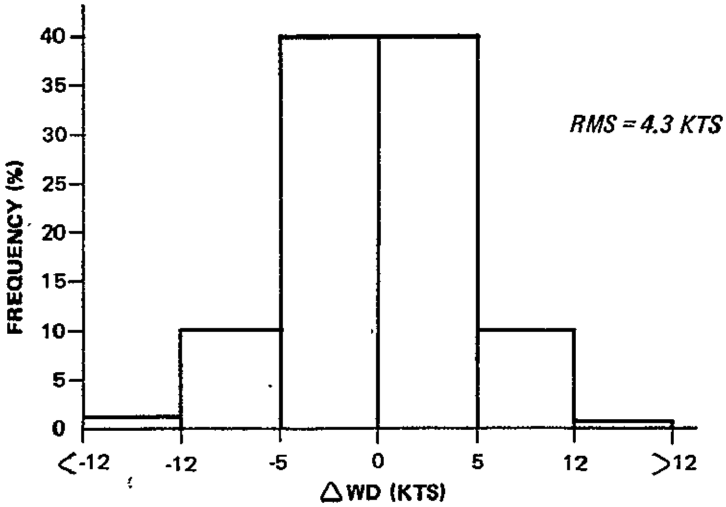


Figure 6-25: Frequency distributions of errors (actual minus estimated values) in temperature, dew point, and wind caused by the distance interpolation scheme, for June 8-14, 1975. Values shown are typical for the entire period (1 June to 30 August 1975)

our net radiation estimates, we are limited to a comparison of the METRUN daily solar radiation estimates against solar radiation measured at various stations in the area. Four stations with hemispheric solar radiation measurements are located within our areas: these are 1) Laramie, Wyoming; 2) Brookings, South Dakota; 3) Manhattan, Kansas; and 4) Bismarck, North Dakota. Daily solar radiation for June-July-August 1975 for these four stations were obtained from NOAA National Climatic Center, Asheville, North Carolina. The data were received with the following disclaimer:

> "The National Weather Service considers the accuracy of previously published solar radiation data questionable; the accuracy of data being collected currently but not published is also considered questionable."

In conversation with NOAA officials at the National Weather Service, we were told that the main problems with the pyranometers were their loss of calibration and deterioration of sensitivity with time.

To obtain a rough check on any gross deterioration that might have occurred in the instruments employed at the four stations we compared the average observed solar radiation on clear days in June-July with values calculated with the aid of tables in the Smithsonian Meteorological Tables (List 1966, Tables 135, 150). The comparisons, together with the METRUN calculations for the same clear days, are shown in Table 6-6.

TABLE 6-6

Comparison of Clear-Sky Solar Radiation (ly/day) Observed by ground stations, calculated by METRUN, and with the Smithsonian Meteorological Tables (SMT, Tables 135, 150)

	Observed Average of Clear days in June-July Average	Range	Calculated by SMT*	Calculated by METRUN
Manhattan, KA	731	762-703	786	871
Brookings, S.D.	570	634-513	787	859
Laramie, WY	739	768-709	796	878
Bismark, N.D.	715	726-691	784	864

*Calculations assume an atmospheric transmissivity of 0.8.

The immediate conclusion apparent from Table 6-6 is that the Brookings observations are too low, even if we allowed for a lower atmospheric transmissivity and for some cloud contamination. We, therefore, decided to omit the Brookings observation from our analysis. Another conclusion is that METRUN overestimates clear sky solar radiation by as much as 20%.

Figures 6-26a, b, and c show scatter diagrams of observed versus METRUN calculated solar radiation for Manhattan, Bismarck, and Laramie for all sky conditions during June-August. Table 6-7 summarizes the average daily solar radiation measured and calculated by METRUN for these three stations. Figure 6-26 and Table 6-7 show that the METRUN values are, on an overall average, 10% higher than the observations. For the purpose of the Penman equation sensitivity and error analyses we will consider this a systematic error of 10%, or about 55 ly/day for average cloud conditions, although it is apparent from the scatter diagrams in Figure 6-19 that the error is greater at higher values (clear to mostly clear conditions) and lower at overcast conditions. We will, additionally, consider the presence of a random root-mean-square error which, after subtraction of the systematic error, we have calculated to be 80 ly/day for the three stations. Some of this random error is due to the inherent difficulty of comparing a point observation to an area estimate. The satellite cloud cover information used

TABLE 6-7

Average Daily Solar Radiation Measured and Calculated by METRUN during June-July-August 1975

	MANHATTAN, KA		BISMARCK, ND		LARAMIE, WY	
	MEASURED	METRUN	MEASURED	METRUN	MEASURED	METRUN
JUNE	546	687 (+26%)	555	601 (+8%)	567	538 (-5%)
JULY	639	738 (+15%)	604	686 (+14%)	600	656 (+9%)
AUGUST	506	547 (+8%)	428	430 (+0.5%)	524	593 (+13%)

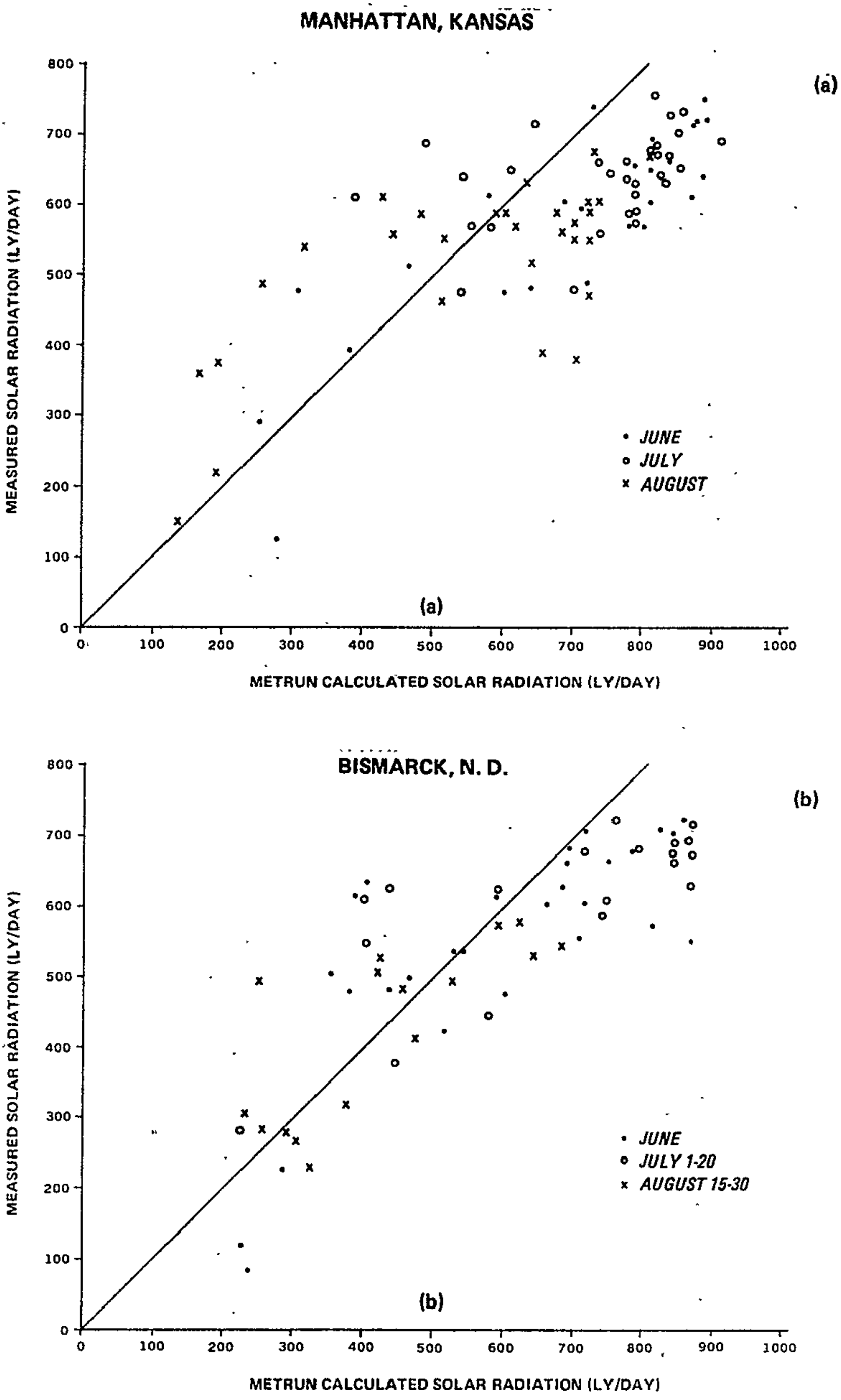


Figure 6-26: Comparison of pyranometer observations of daily solar radiation and METRUN calculated daily solar radiation during June, July, August 1975. No pyranometer data was available at Bismarck from 21 June to 14 August because of instrument malfunction.

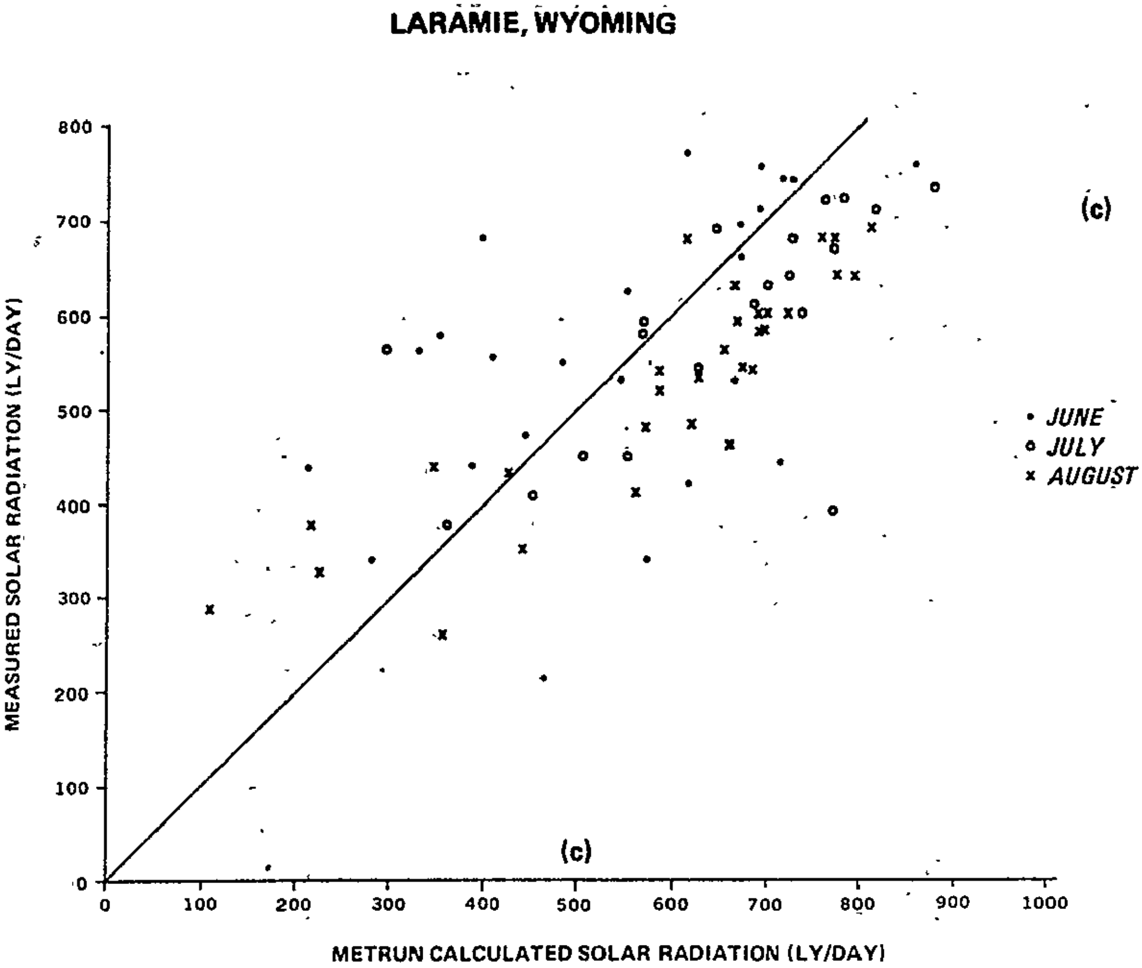


Figure 6-26: Continued

in the METRUN calculations covers a fairly large area defined by the cloud polygon which may be tens of thousands of square miles, while the observations are only affected by the local cloud cover. Part of the random error is also due the analysts subjectivity in determining cloud cover on the satellite images. To estimate this random error we had one week of satellite data independently analyzed by three technicians. A comparison of the solar radiation values obtained from the three analysis yielded a root-mean-square error of 30 ly/day. We may safely conclude, therefore, that about 14% of the variance in the solar radiation $((30/80)^2 = .14)$ can be explained by the analyst subjectivity in determining cloud cover.

Although instrument deterioration may account at the most for 2-5% of the systematic difference (personal communication with Michael Riches, NWS solar radiation specialist), we believe that the main cause for the difference is the high values of clear-sky atmospheric transmission used by METRUN. Figure 6-27 is a plot of transmission versus total atmospheric water vapor used by METRUN. We also believe that the cloud transmission factors in METRUN are too low, and partially compensate for the high atmospheric transmission.

A method developed by Klein (1948) and based on Kimball's charts of transmission of solar radiation (SMT, Table 147) was then employed to estimate clear-

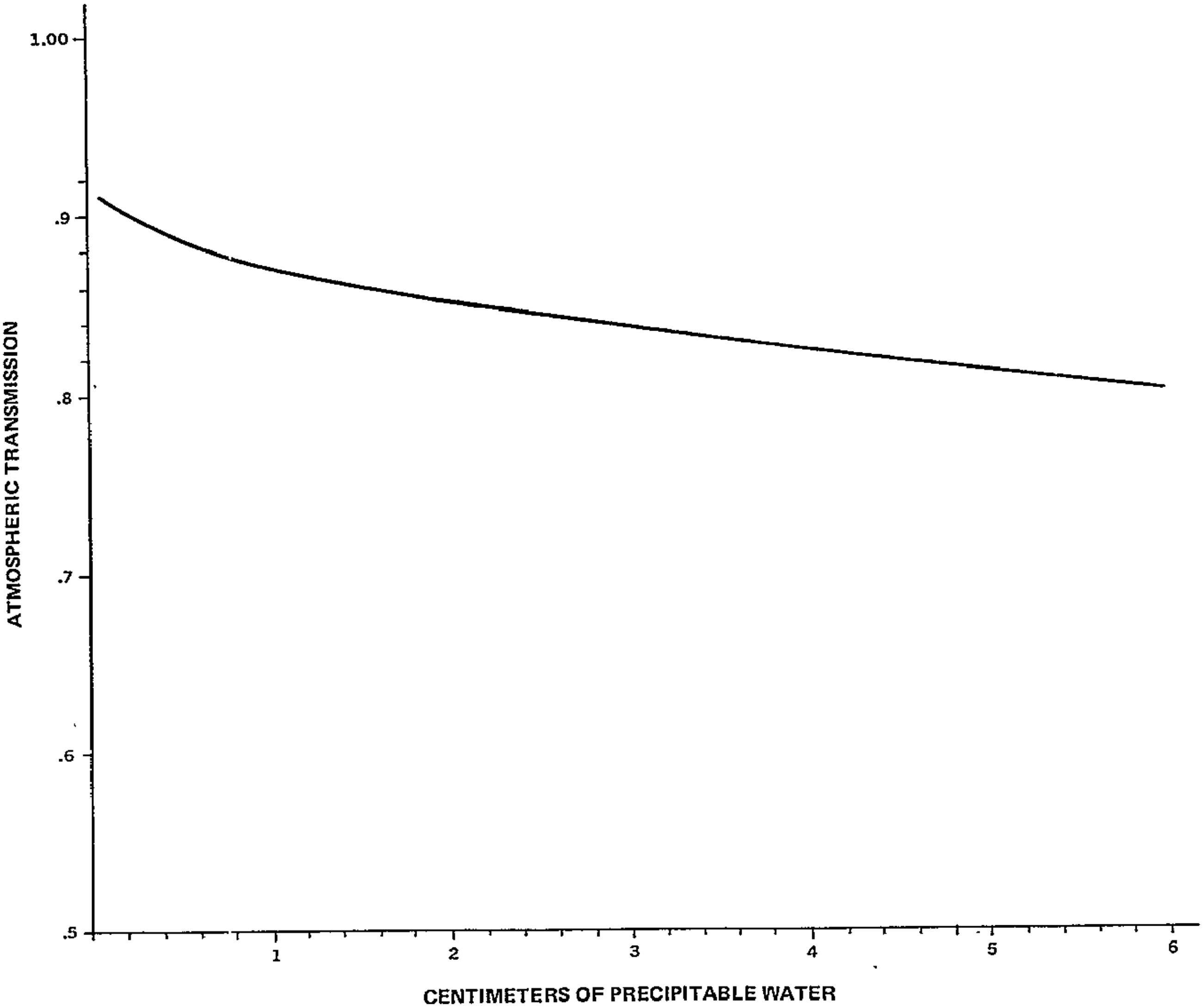


Figure 6-27: Vertical atmospheric transmission function used by METRUN.

sky solar radiation for seven cloudless days at Bismarck during June-July. Figure 6-28 shows the hour-by-hour calculations of solar radiation using the Klein formulas compared with METRUN and with observations during a clear day at Bismarck (24 June 1975). The Klein method shows a marked improvement, bringing the clear day solar radiation to within 2% of that observed in this example. Such improvement was found for all the seven cloudless days considered. The recalculated solar radiation averaged 738 ly/day, only 3% higher than the observed 715 ly/day.

Figure 6-29 is a scatter diagram of observed versus calculated solar radiation for Bismarck, using the Klein method. The calculation compares better with the observations (see Figure 6-26b for comparison) at higher values (> 650 ly/day), but on the average the METRUN with the Klein correction underestimates solar radiation for cloudy conditions. We tentatively conclude that the cloud transmission factors in our model are too low by approximately 5-10% per cent, and that most of the random error is due to: 1) point versus areas cloud cover differences, 2) differences of cloud thicknesses causing variations from any average cloud transmission factors used, 3) cirrus clouds undetected by the satellite image, 4) local pollution not considered by our solar radiation model, and 5) analysts subjectivity in satellite cloud cover determination.

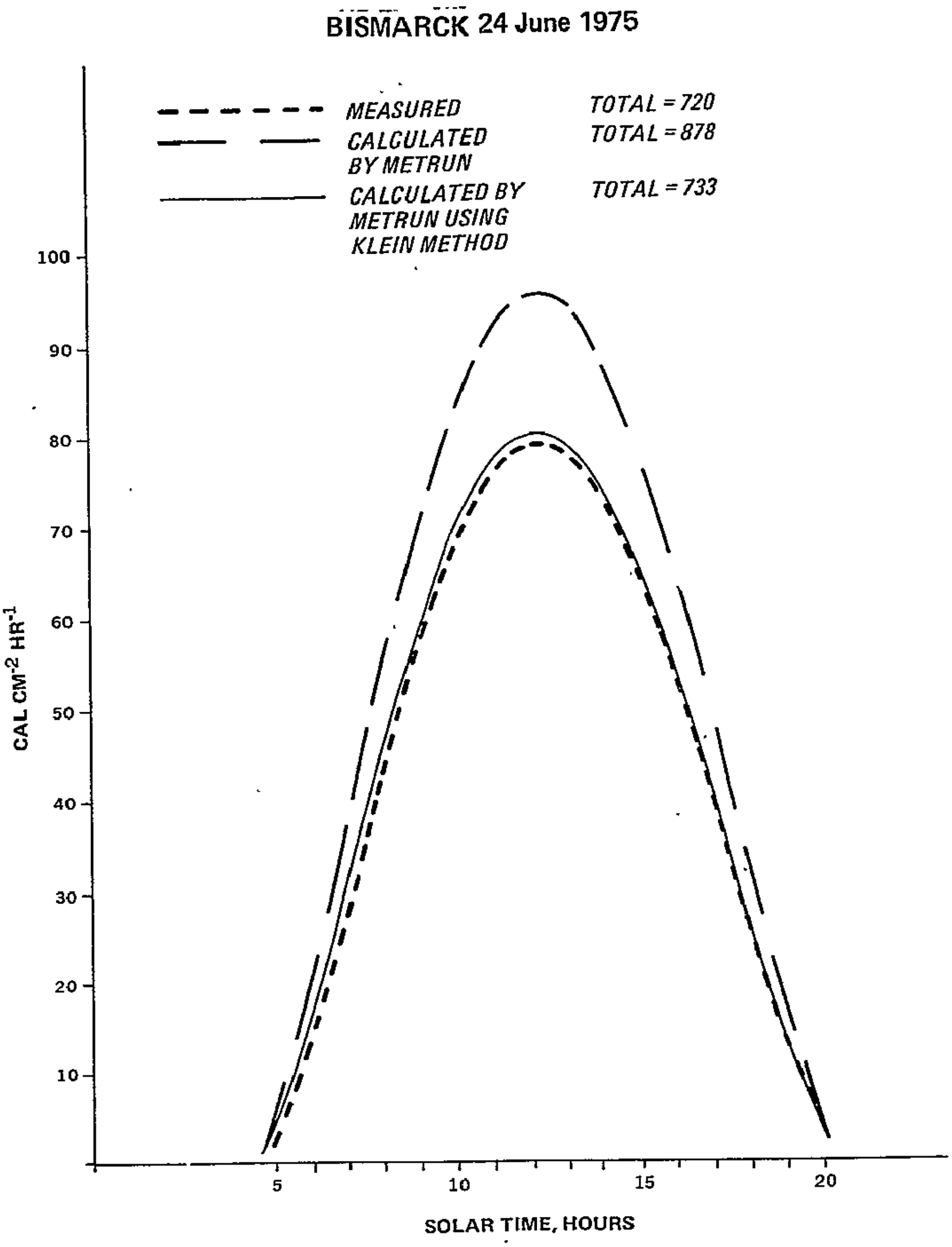


Figure 6-28: Comparison of hourly solar radiation measured at Bismarck during a cloudless day (June 24 1975) and solar radiation calculated by METRUN with the transmission function shown in Figure 6-27, and with the transmission function of the Klein method.

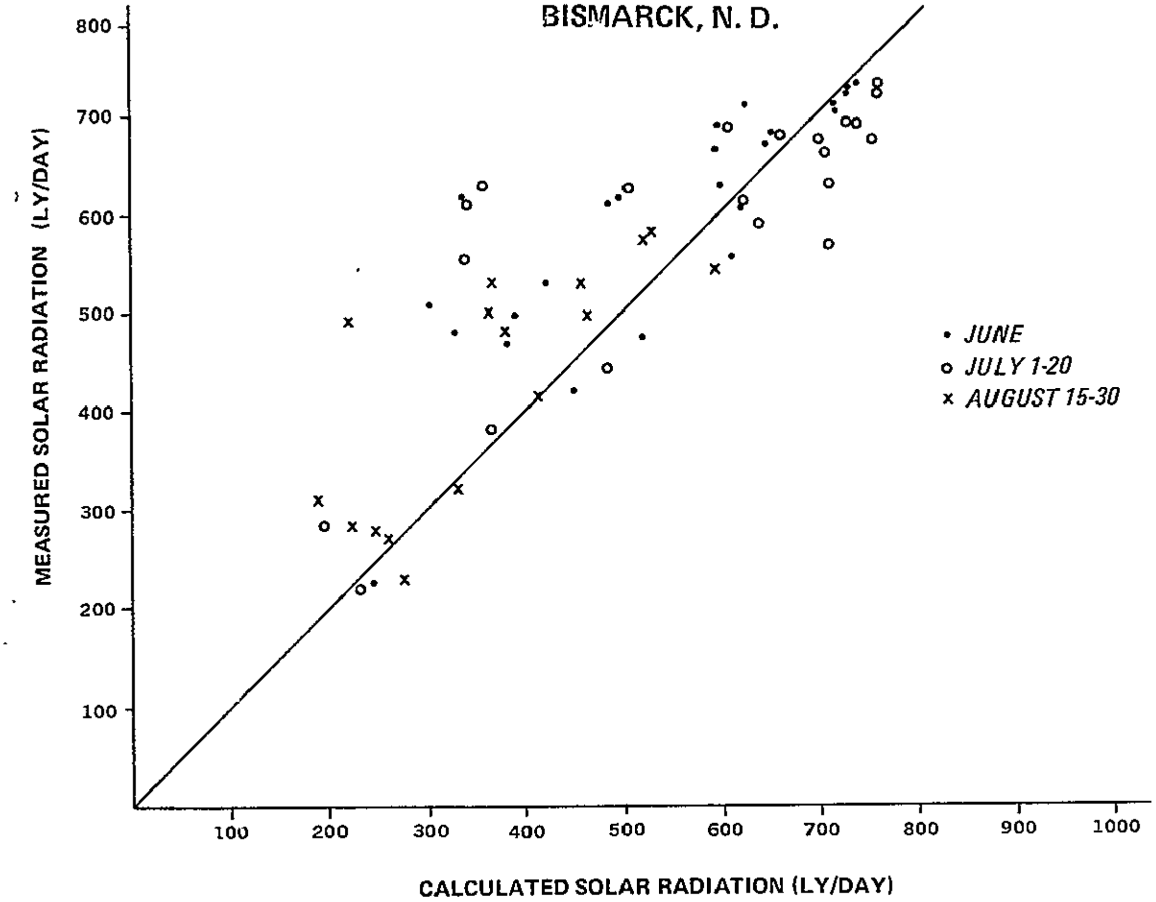


Figure 6-29: Comparison of observed daily solar radiation and METRUN calculated daily solar radiation using the Klein method.

An attempt to determine new cloud transmission factors from available satellite cloud data and the observed hourly solar radiation met with only limited success because of the limited amounts of hourly solar data available to us (only Bismarck and Manhattan had hourly data for most of June and part of July). It was nevertheless evident that in most cases when overcast-to-broken cloud conditions were observed on the satellite image, the ground stations reported higher solar radiation values than those calculated by METRUN with the Klein method. It is evident from our error analysis that estimations of solar radiation can be improved considerably by using the Klein method which would eliminate a systematic error of 55 ly/day for average cloud conditions, and by deriving improved cloud transmission coefficients from satellite cloud information and solar radiation observations.

6.3.1.3 Sensitivity and Error Analysis - The Penman ETP Equation

Having established the errors on temperature T_A, dew point temperature T_D, and wind W, we can now determine their effects on the accuracy of the Penman ETP calculations. Additionally, we will also consider effects of errors in cloud cover, surface albedo, and solar radiation which control the net radiation term of the Penman ETP equation. The scope of our analysis is, 1) to determine the sensitivity of the Penman ETP to the many variables involved in its calculation, 2) to calculate the total error in ETP, by assuming reasonable errors in these variables, and 3) to compare the Penman ETP to actual pan evaporation.

The first two tasks can rightly be called part of a sensitivity analysis of the Penman ETP equation. The third task is the closest one can come to an error analysis of ETP, since such comparison would not only include measurement and/or estimation errors in those parameters that affect ETP, but would test the validity of the Penman equation in our area of interest.

To perform a sensitivity analysis on an equation involving many variables, one would simply find the partial differentials with respect to each of the variables and then evaluate these partial differentials for given conditions. In the case of the Penman equation, temperature and dew point appear in a fairly complex way in the calculations of vapor pressures and radiation terms, and therefore it was found more expeditious to calculate the partial differentials with respect to temperature and dew point, graphically from plots of ETP at given conditions. On the other hand, the partial differential with respect to net radiation is very simply:

$$\Delta ETP_{R_{NET}} = \gamma/(\gamma + 0.64)\ \Delta R_{NET} \qquad [6\text{-}26]$$

where γ is slope of the saturation vapor pressure versus temperature curve (mb/°K), and can be obtained from the SMT. Equation is evaluated as:

$$\Delta ETP_{R_{NET}} = 0.5623 \ \Delta R_{NET} \quad \text{at } T_A = 10°C$$
$$\Delta ETP_{R_{NET}} = 0.6935 \ \Delta R_{NET} \quad \text{at } T_A = 20°C$$
$$\Delta ETP_{R_{NET}} = 0.7919 \ \Delta R_{NET} \quad \text{at } T_A = 30°C$$

The available ETP subroutine permitted us to perform ETP calculations for various combinations of air temperature T_A, dew point temperature T_D, wind W, albedo A, and cloud cover. From the results, we constructed graphs showing the effects of various meteorological parameters on ETP, which allowed us to estimate reasonable rates of change of ETP. June 21 and 45° N - 105° W were chosen as a representative date and latitude longitude for our calculations. Calculations were done for each 6-hour interval, starting at 00 GMT ± 3 hours, to correspond with the time intervals of the METRUN calculations.

Figures 6-30 to 6-34 show the results of our ETP calculations for the normal range of summer conditions present in our area of interest. From these graphs, we estimated the differentials given in Table 6-8. Since the R_{NET} errors have a systematic and random components, and are available to us only on a daily basis, we shall treat their effects on ETP separately after we have evaluated the total 24-hour errors

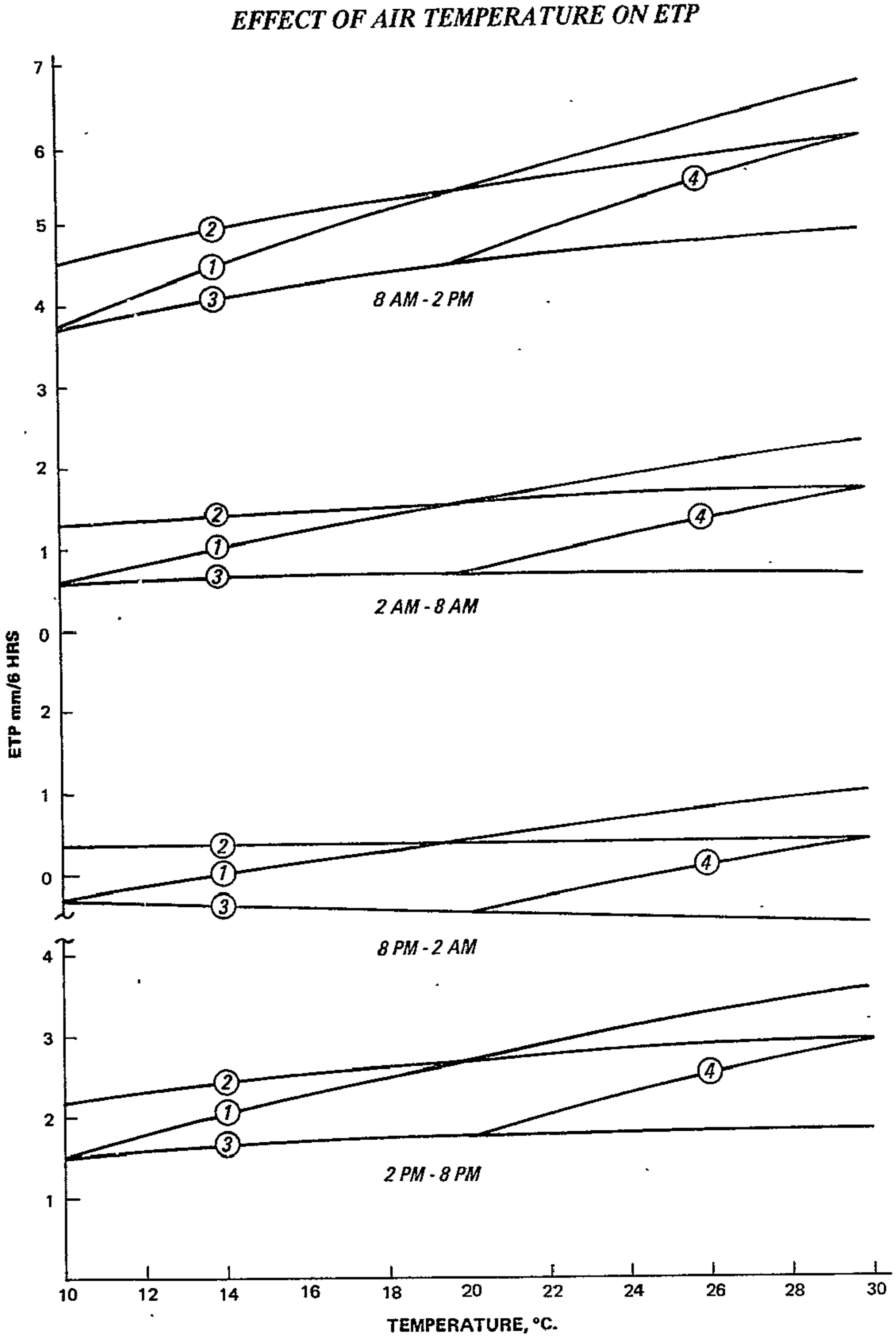


Figure 6-30: Potential Evapotranspiration (mm/6 hours) as a function of air temperature, calculated by the Penman method, for clear skies, and the sun-earth geometry of June 21 and 45N-105W. Curve 1 is for a dew point temperature of 10°C; curve 2 is for a dew point 10°C lower than the air temperature; curve 3 is for saturated conditions (dew point equal air temperature); curve 4 is for a dew point of 20°C. Surface albedo and wind are kept constant at 20% and 10 knots respectively.

EFFECT OF DEW POINT TEMPERATURE ON ETP

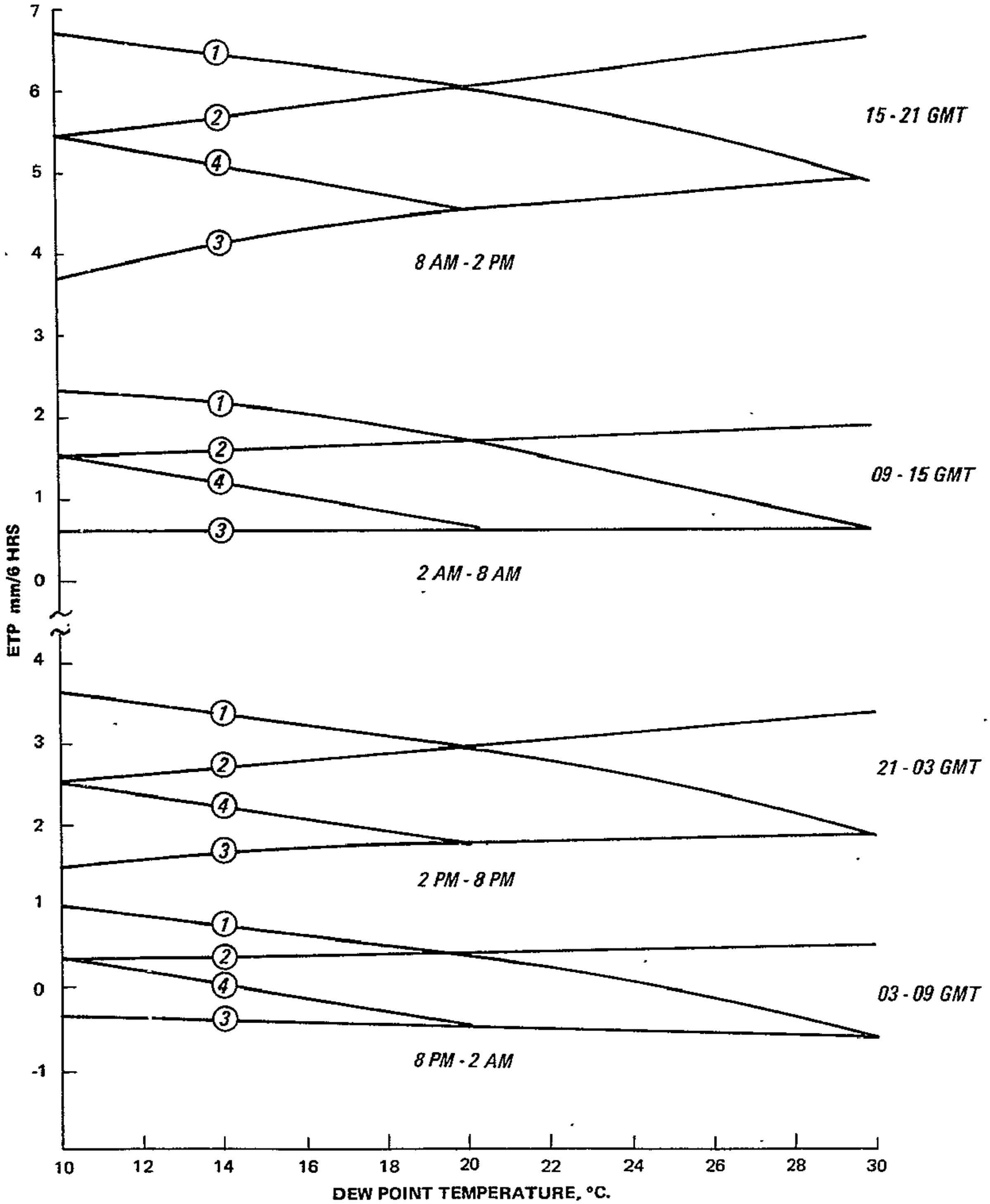


Figure 6-31: Potential evapotranspiration (mm/6 hours) as a function of dew point temperature calculated by the Penman method, for clear skies, and the sun-earth geometry of June 21 and 45N-105W. Curve 1 is for an air temperature of 30°C; curve 2 is for an air temperature 10°C higher than dew point; curve 3 is for saturated conditions (dew point equal air temperature); curve 4 is for an air temperature of 20°C. Surface albedo and wind are kept constant at 20% and 10 knots respectively.

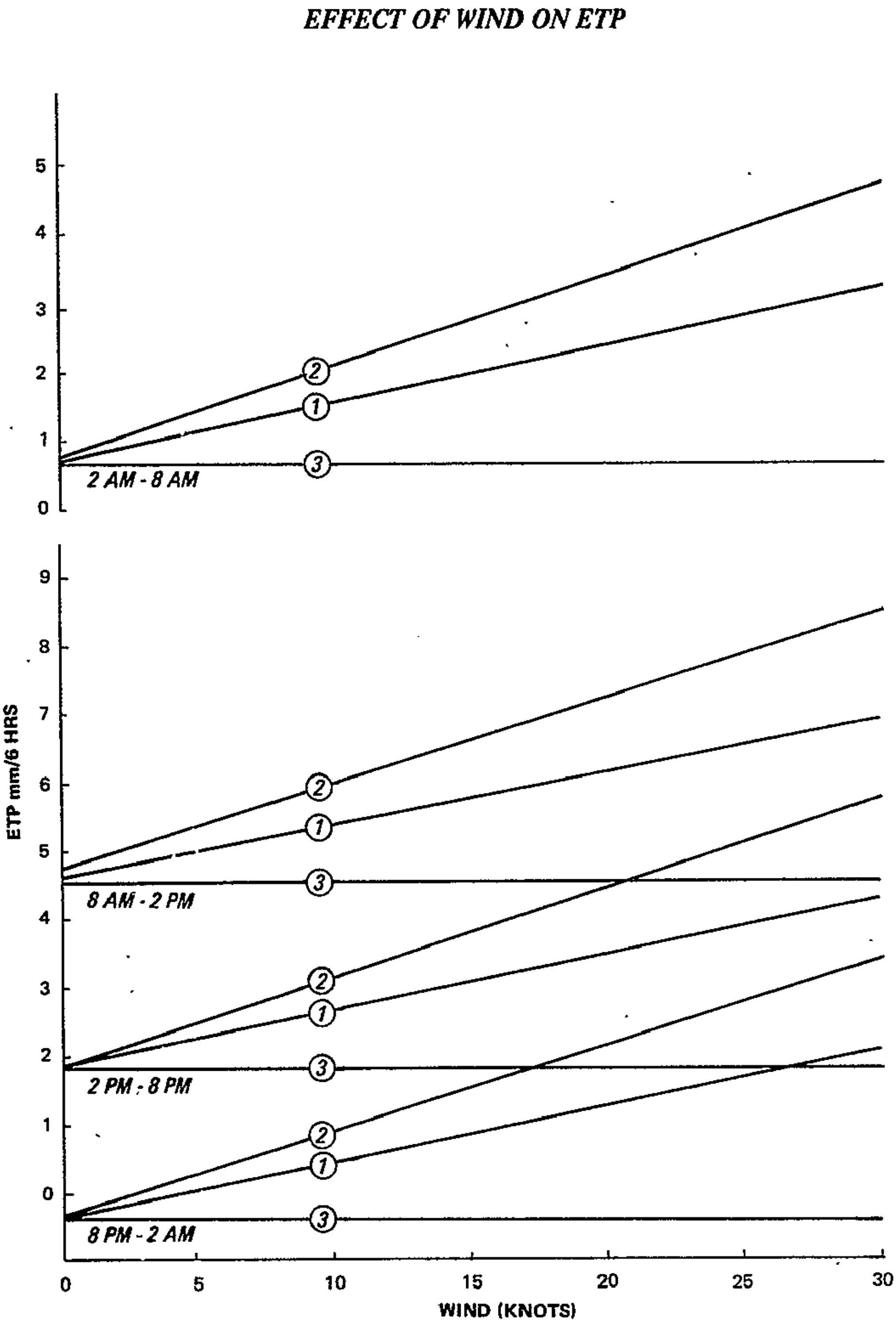


Figure 6-32: Potential evapotranspiration (mm/6 hours) as a function of wind calculated by the Penman method, for clear skies, and the sun-earth geometry of June 21 and 45N-105W. Curves 1, 2, and 3 are for dew point temperatures of 10°C, 0°C, and 20°C respectively. Albedo and air temperature are kept constant at 20% and 20°C.

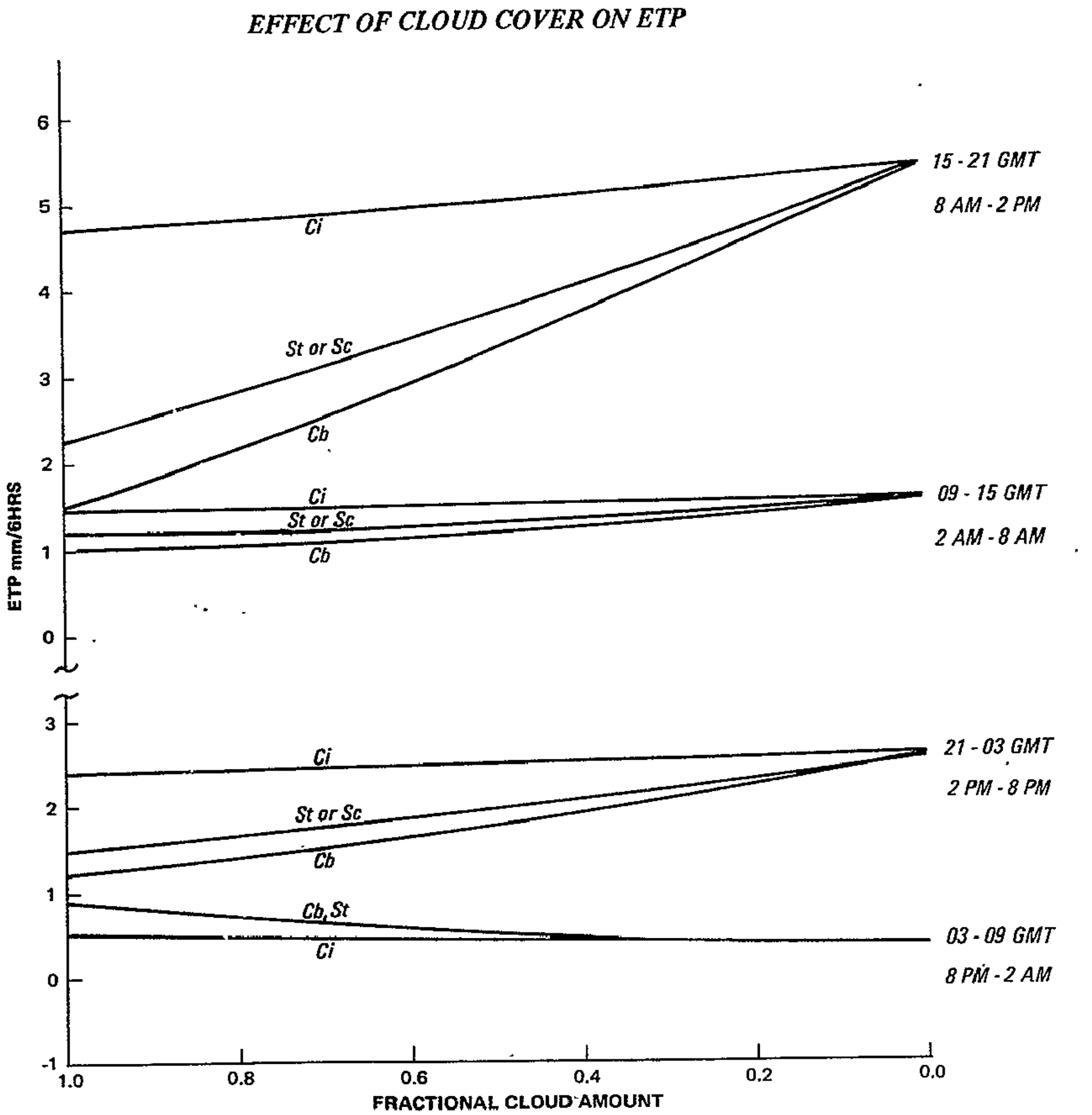


Figure 6-33: Potential evapotranspiration (mm/6 hours) as a function of cloud cover amounts calculated by the Penman method for the sun-earth geometry of June 21 and 45N-105W. Cumulonimbus (Cb), stratus or stratocumulus (St or Sc), and cirrus (ci) clouds attenuation factors are used in the calculations. Air temperature, dew point, wind and albedo are kept constant at 20°C, 10°C, 10 knots, and 20% respectively.

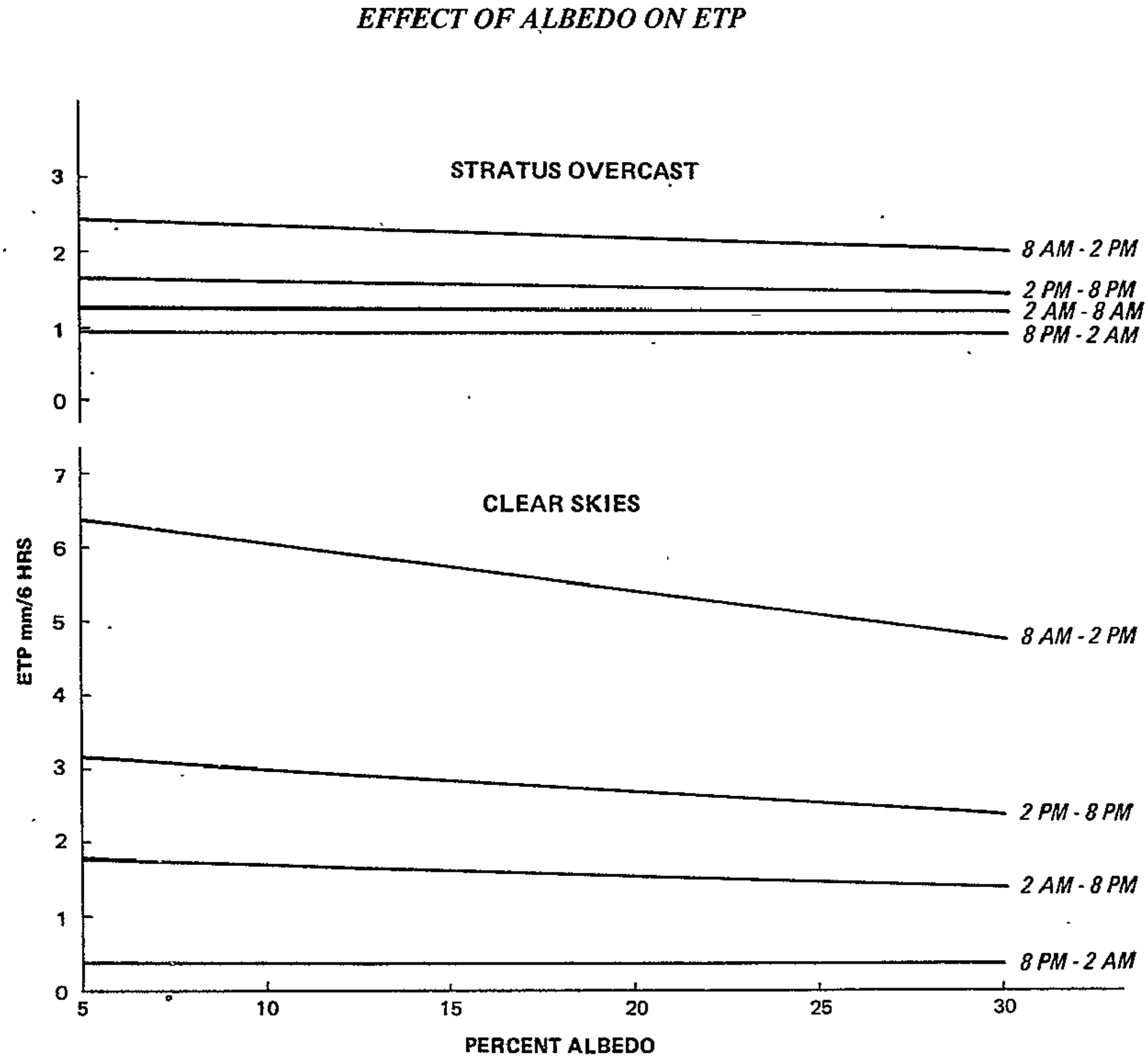


Figure 6-34: Potential evapotranspiration (mm/6 hours) as a function of surface albedo, calculated by the Penman method for clear and stratus overcast conditions, and for the sun-earth geometry of June 21 and 45N-105W. Air temperature, dew point, and wind are kept constant at 20°C, 10°C and 10 knots.

TABLE 6-8

Sensitivity of Penman ETP to changes in meteorological parameters.

TIME INTERVAL AT 105 W	$\frac{\Delta ETP}{\Delta T_{air}}$ mm - 6hr^{-1}C^{-1}	$\frac{\Delta ETP}{\Delta T_{dew}}$ mm - 6hr^{-1}C^{-1}	$\frac{\Delta ETP}{\Delta Wind}$ mm - 6hr^{-1}Kn^{-1}	$\frac{\Delta ETP}{\Delta Albedo}$ mm - 6hr^{-1}P$_c$$^{-1}$	$\frac{\Delta ETP}{\Delta Cloud}$ mm - 6hr^{-1}P$_c$$^{-1}$		
					Ci	St or Sc	Cb
03 - 09 GMT 8PM - 2AM	0.065	0.080	.083	0.0	0.0	.005	.005
09 - 15 GMT 2AM - 8AM	0.085	0.085	0.083	0.015	0.0	.004	.006
15 - 21 GMT 8AM - 2PM	0.150	0.090	0.083	0.067	.007	.032	.039
21 - 03 GMT 2PM - 8PM	0.105	0.090	0.083	0.029	.002	.011	.014
CONDITIONS	Clear Skies $10 \leq T_d \leq 20$ A = 20% W = 10 Knots	Clear Skies $10 \leq T_a \leq 30$ A = 20% W = 10 Knots	Clear Skies $T_a = 20$ $T_d = 10$ A = 20%	Clear Skies $T_a = 20$ $T_d = 10$ W = 10 Knots	A = 20% $T_a = 20$ $T_d = 10$ W = 10 Knots		

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due to T_{AIR}, T_{DEW}, wind, and albedo. For each six-hour period the total error on ETP, excluding effects of R_{NET} errors is:

$$\Delta ETP_t = \pm\sqrt{(\Delta ETP)^2_{ta} + (\Delta ETP)^2_{td} + (\Delta ETP)^2_{w} + (\Delta ETP)^2_{a}} \quad [6\text{-}27]$$

where $(\Delta ETP)_{ta}$, is error caused by an error in air temperature

$(\Delta ETP)_{td}$, is error caused by an error in dew point

$(\Delta ETP)_{w}$, is error caused by an error in wind

$(\Delta ETP)_{a}$, is error caused by an error in albedo

To evaluate the above equation we have used the values of the differentials given in Table 6-7 and the rms errors obtained in the error analysis of T_a, T_{dew}, and W. Additionally, we assumed a 5% Albedo error. The errors for each 6-hour interval are shown in Table 6-9. The total 24-hour ETP error, excluding effect of R_{NET} errors is:

$$\Delta ETP = \pm\sqrt{(ETP)^2_{9} + (\Delta ETP)^2_{15} + (\Delta ETP)^2_{21} + (\Delta ETP)^2_{03}} \quad [6\text{-}28]$$

$$= \pm\ 1.03 \text{ mm/day.}$$

To this ± 1.03 mm/day we now must add errors caused by errors in R_{NET} which essentially include cloud cover determination errors, atmospheric water vapor errors,

TABLE 6- 9

ETP ERRORS FOR 6-HOUR PERIODS (in mm- $6hr^{-1}$)

CLOUDLESS AVERAGE CONDITIONS

ERRORS IN METEOR. PARAMETERS	ERRORS IN ETP FOR 6 - HOUR PERIOD ENDING AT:				
		09 GMT	15 GMT	21 GMT	03 GMT
$\Delta T_A = 2.3$ °C	$(\Delta ETP)_{TA} =$	0.150	0.195	0.345	0.241
$\Delta T_D = 2.6$ °C	$(\Delta ETP)_{TD} =$	0.208	0.221	0.234	0.229
$\Delta W = 4.2$ Kts	$(\Delta ETP)_W =$	0.350	0.350	0.350	0.350
$\Delta A = 5\%$	$(\Delta ETP)_A =$	0.0	0.073	0.335	0.145
Total Δ ETP for 6-hour period (mm $6hr^{-1}$)		0.43	0.46	0.64	0.50

and systematic and random errors of cloud and atmospheric transmissivities. We shall assume that R_{NET} errors are caused only by solar radiation errors and neglect (because of lack of observations) errors in terrestrial radiation which may add or substract to the R_{NET} errors. From our previous analysis of solar radiation, we determined that solar radiation errors, and therefore net radiation errors, for average conditions in our area consisted of a systematic component of +55 ly/day due to our overestimation of atmospheric transmissivities, and a random component of ± 80 ly/day. At 20°C these errors translate to + 0.65 mm/day and ± 0.94 mm/day in ETP errors respectively. The random component of the error can be added as a squared term under the radical in equation [6-28], giving a total random error of ± 1.38 mm/day. The systematic error of 0.65 mm/day has the net effect of shifting the total root-mean-square error of ETP to a range of -0.73 to 2.03 mm/day.

The ETP error range of -0.73 to 2.03 mm/day is the result of our sensitivity analysis of the Penman equation to average conditions in the area of interest and to the range of METRUN errors in its component parameters. If the Penman ETP were the true potential evaporation this range would represent true errors in potential evaporation. But of course the Penman ETP does have errors because of its simplifying assumptions and its semiempirical nature. These errors could be determined if we had available concurrent potential evaporation measurement which, within acceptable errors, could be taken as "ground truth." The only measurements we have to compare with our ETP are NOAA class A pan daily evaporations which can not be strictly equated to ETP. It is generally recognized that the pan evaporation measurements (E_{pan}) alone are not sufficient for the estimation of evapotranspiration from a vegetated surface. The main reasons are:

(1) the pan is located six feet above the surface

(2) the heat exchange between the pan and surroundings does not represent the actual heat exchanges of the surface

(3) the wind speed at pan level differs from that at the surface.

The range of errors associated with these problems vary widely among the sites and a standard range is indeterminable. In spite of these shortcomings, several researchers have used CLASS A pan readings summed over monthly periods to compare with ETP from lysimeter measurements. Stanhill (1958) found that <u>monthly</u> ETP for an alfalfa plot compared to E_{PAN} by $ETP = 70E_{PAN} + .47$ ($r = .96$). Pruitt and Angus (1961) found that for monthly averages over rye grass $ETP = .79\ E_{PAN} + .08$ ($r = .95$) for January through May and $ETP = .76\ E_{PAN} - .02$ ($r = .91$) for July through December. However, it must be noted that the <u>daily</u> ETP versus E_{PAN} relationship using the same data showed a large amount of scatter. An extensive study (Kohler and others, 1955) of pan evaporation errors conducted jointly by the Geological Survey, Bureau of Reclamation, Navy, and Weather Bureau at Lake Hefner, Okla., during 1950 - 1951 showed that appreciable errors arose when using the customary conversion $ETP_{lake} = 0.7\ E_{PAN}$, which does not take in consideration heat transfer through the pan. The potential evaporation we seek is of course not over a lake but over a vegetated surface, nevertheless we can safely assume that at least similar errors would be involved if we would straightforwardly convert E_{PAN} to ETP. The same Lake Hefner study attempted to develop a universal relation for computing pan evaporation from meteorological parameters. ETP was calculated by the Penman equation for 100 days for 20 U.S. stations and compared to the Pan Evaporation. The aerodynamic term of the Penman equation which in our treatment of the Penman equation is $0.35(0.5 + w/100)(e_s - e_a)$, was modified in their analysis to $(.37 + .004w)(e_s - e_a)^{0.88}$ to best fit lake evaporation data. With the modified Penman equation they achieved correlation coefficients with pan evaporation ranging from 0.57 to 0.96.

In the METRUN study area, there are over thirty stations with daily class A pan evaporation. Observation time is not uniform, approximately half of the stations take observations at 5 PM, the rest at various times in the morning. Our initial correlation of E_{PAN} to ETP was conducted using first order Weather Bureau stations which needed no interpolation of meteorological parameters. The three stations available were Fargo, ND; Sious Falls, SD; and Pickstown, SD.

The pan evaporation observations are made at 6 AM (approximately 1300 GMT) at Fargo and Pickstown, and at midnight (approximately 0700 GMT) at Sioux Falls, while the daily METRUN ETP calculations terminate at 03 GMT (8 PM local time at 105°W). However, this time misalignment should not cause any problems because it occurs at night when evaporation is negligible. Figures 6-35 a, b, c present the comparisons as scatter diagrams. Approximately 2/3 of the METRUN ETP's are within ±2 mm of the measured pan evaporation. Correlation coefficients for Fargo (0.74), Sioux Falls (0.66), and Pickstown (0.57) are in line with the correlations obtained in the Lake Hefner study, considering that no effort was made in our ETP method to best-fit the coefficients of the aerodynamic term of the Penman equation. Other reasons for the relatively low correlations are:

(1) large random errors due to small samples (90 days)

(2) non-standard siting and operating of pans can lead to significant effects on evaporation

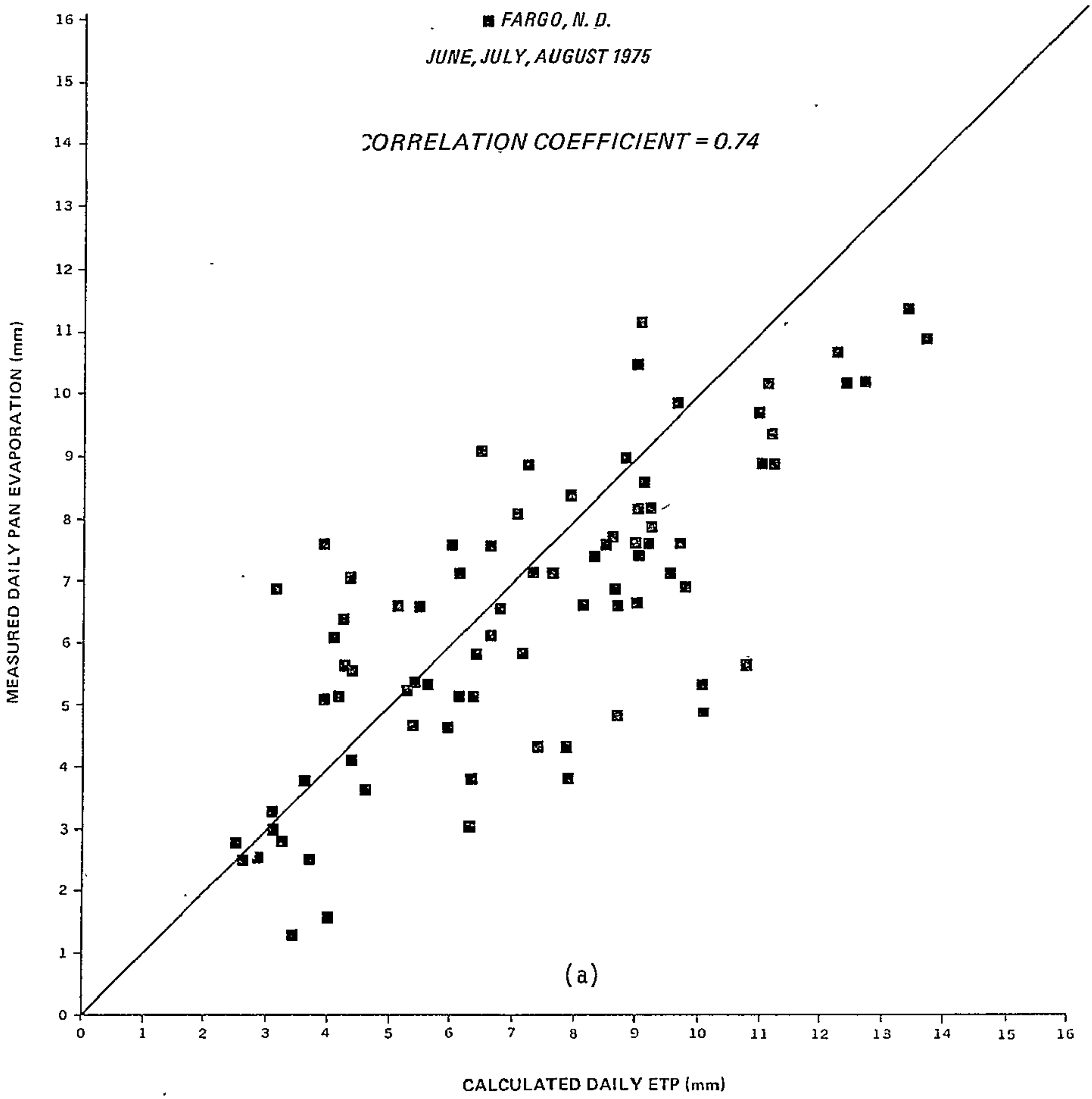
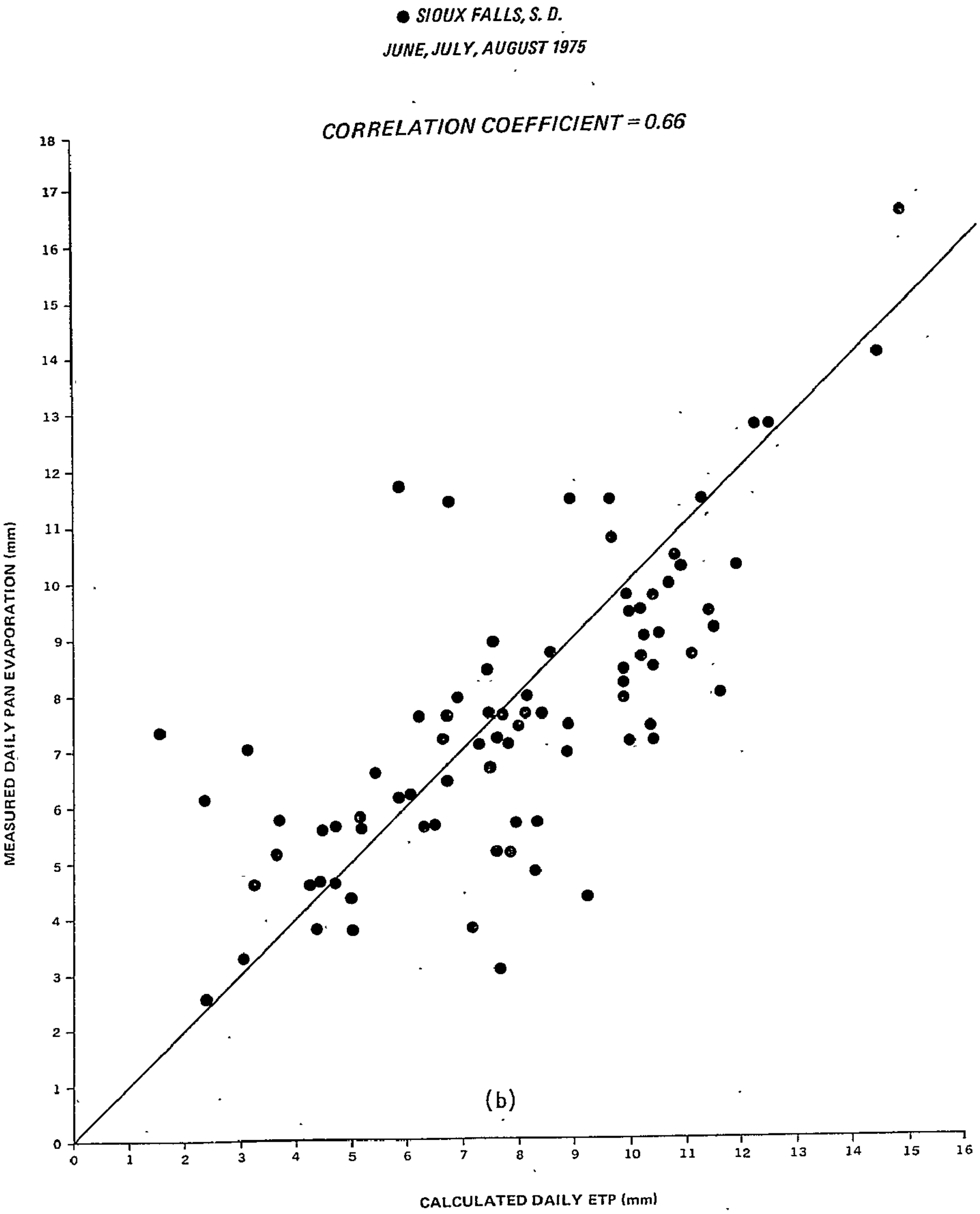


Figure 6-35: Comparison of measured daily pan evaporation and ETP calculated by METRUN during June, July, and August 1975 at a) Fargo, N. Dakota, b) Sioux Falls, S. Dakota, and c) Pickstown, S. Dakota.



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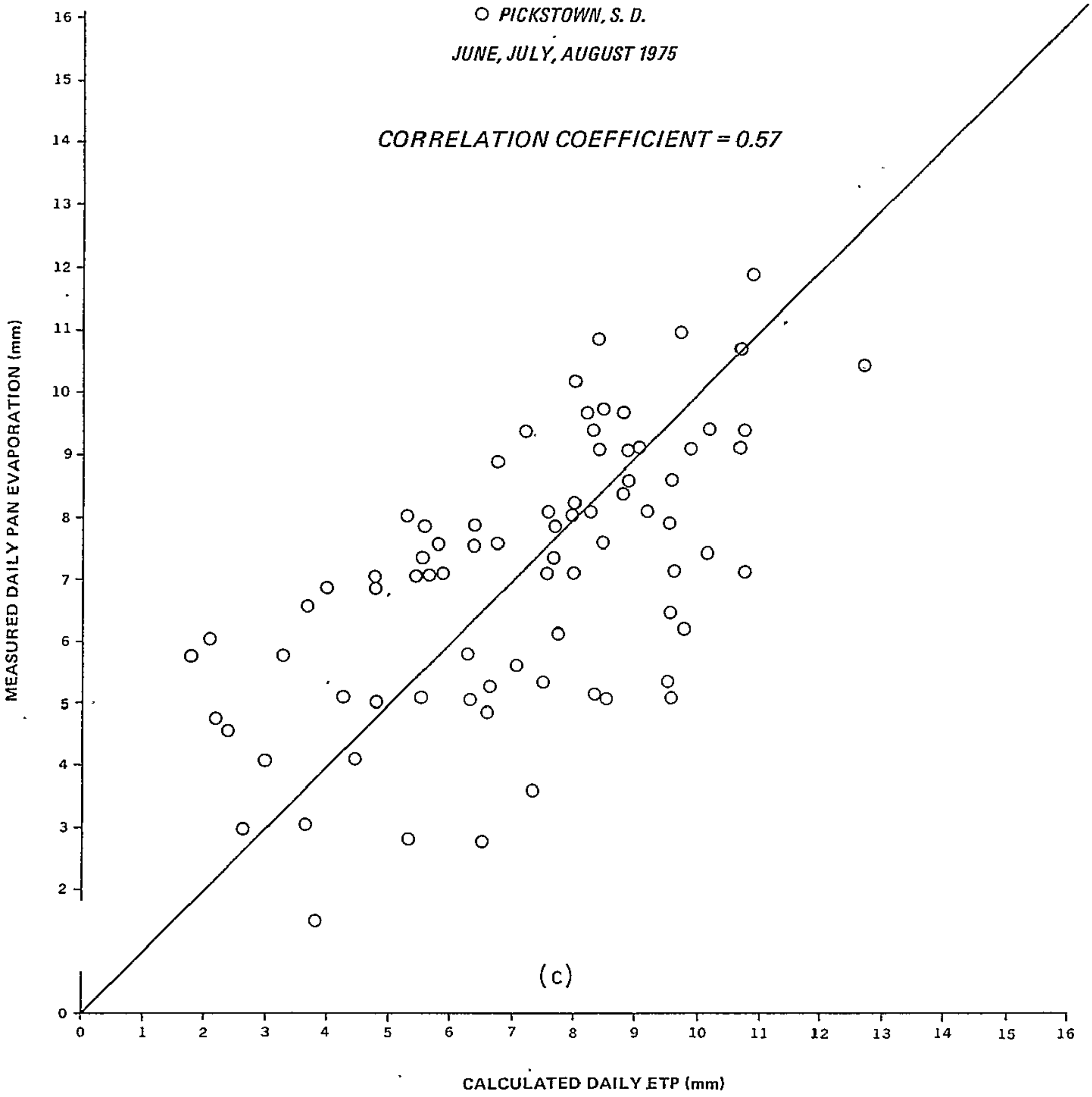

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(3) pan evaporation is influenced by the local cloud cover, while the METRUN ETP is calculated using the satellite "polygon cloud cover" which may span tens of thousands square miles.

When weekly and monthly pan evaporations are compared to METRUN ETP, there's a corresponding improvement in the correlation. Table 6-10 and Figure 6-36 present such comparisons. A correlation coefficient of 0.89 is achieved in the weekly comparisons. Evident in the weekly comparisons of Figure 6-35 is a tendency for METRUN to overestimate ETP by about 2 mm per week. Approximately 2/3 of the weekly METRUN ETP estimates are within 6.7 mm of the pan measurements.

Correlation analyses of METRUN ETP versus pan evaporation were also conducted for July for the thirty stations which required interpolation of meterological parameters. The majority of the correlations were between 0.5 to 0.6, slightly lower than the correlations obtained for the synoptic stations. The lower correlations may be explained by the smaller samples (30 days versus 90 days), interpolation of meteorological parameters, and inaccurate observation times at the second order climatological stations.

We then compared the Crop Reporting District average ETP to the average of E_{PAN}, selecting one Crop Reporting District from each of the four states. The four Districts selected were Northeast Montana, West

TABLE 6-10

Comparison of weekly and monthly pan evaporation and METRUN ETP (in mm) for the period 1 June - 30 August 1975 (Days 152-242).

	FARGO, ND		SIOUX FALLS, SD		PICKSTOWN, SD	
JULIAN DAYS	PAN	METRUN	PAN	METRUN	PAN	METRUN
152-158	39	49	52	57	47	48
159-165	24	35	36	36	32	35
166-172	40	38	43	47	46	36
173-179	42	42	49	63	56	64
180-186	*	*	67*	61*	62	67
187-193	43	61	58	63	53	55
194-200	60	75	83	83	70	66
201-207	49	49	60	64	57	54
208-214	63	70	63	66	58	59
215-221	55	61	56	65	58	58
222-228	44	53	45	41	42	35
229-235	28	34	37	33	30*	22*
236-242	44	46	42	39	45	40
JUNE	144	163(+13%)	204	225(+10%)	199	203(+2%)
JULY	231	266(+15%)	308	304(-1%)	276	271(-2%)
AUG	184	206(+12%)	191	188(-2%)	182	164(-10%)
TOTAL	559	635(+14%)	703	717(+2%)	657	638(-3%)

*Week incomplete because of missing pan reports

Because of missing data the following number of days in each month (June, July, August) were used for each station:

FARGO (27, 30, 30), SIOUX FALLS (30, 30, 30), PICKSTOWN (30, 31, 29)

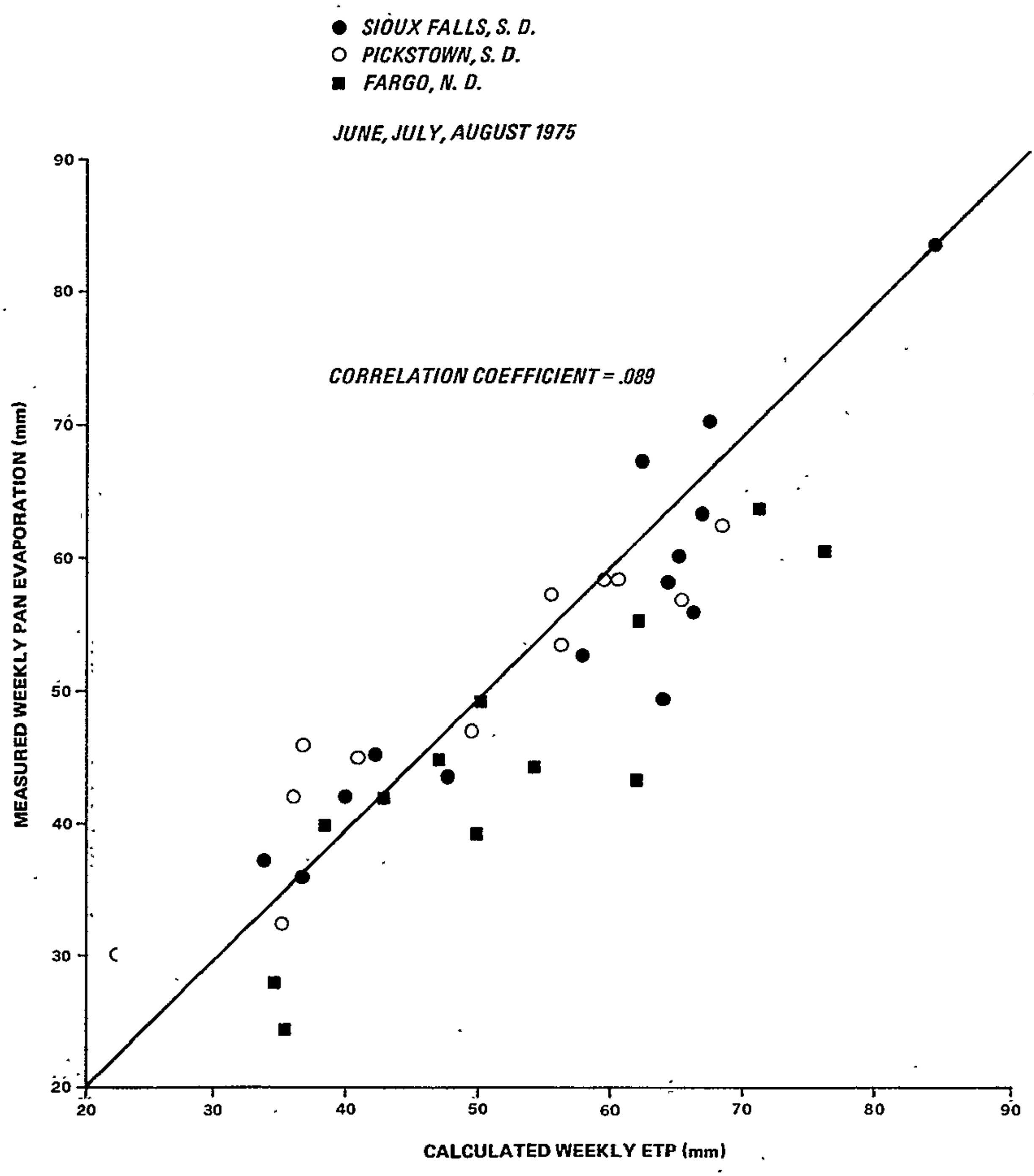

Figure 6-36: Comparison of measured weekly pan evaporation and ETP calculated by METRUN during June, July, August 1975, at Fargo, Sioux Falls, and Pickstown.

Central North Dakota, Southwest Minnesota and East Central South Dakota. Running totals of ETP and evaporation for the entire period of study (90 days) were calculated and plotted Figure 6-37a, b, c, d). Percent differences between the estimated ETP and the evaporation observed were small, both on the weekly level and for the entire period. The differences ranged from less than 1 percent in West Central North Dakota to about 7 percent in Northeast Montana. Weekly differences were within ± 10 percent in all but two cases, both of which contained one or two missing observations.

METRUN ETP overestimated pan evaporation in three out of the four cases. The exception was East Central South Dakota where reports of extremely high evaporation were common during the entire summer.

It is evident from our error analysis that estimations of ETP can be improved considerably by 1) improving our estimates of solar radiation using the Klein method and improved cloud transmission coefficients, and by 2) deriving best-fit coefficients for the advection term of the Penman equation from available reports of pan evaporation, surface observations of wind, air temperature, dew point, and satellite derived net radiation.

COMPARISON OF WEEKLY CROP REPORTING DISTRICT, PENMAN EVAPOTRANSPIRATION, AND PAN EVAPORATION TOTALS FOR JUNE - AUGUST, 1975

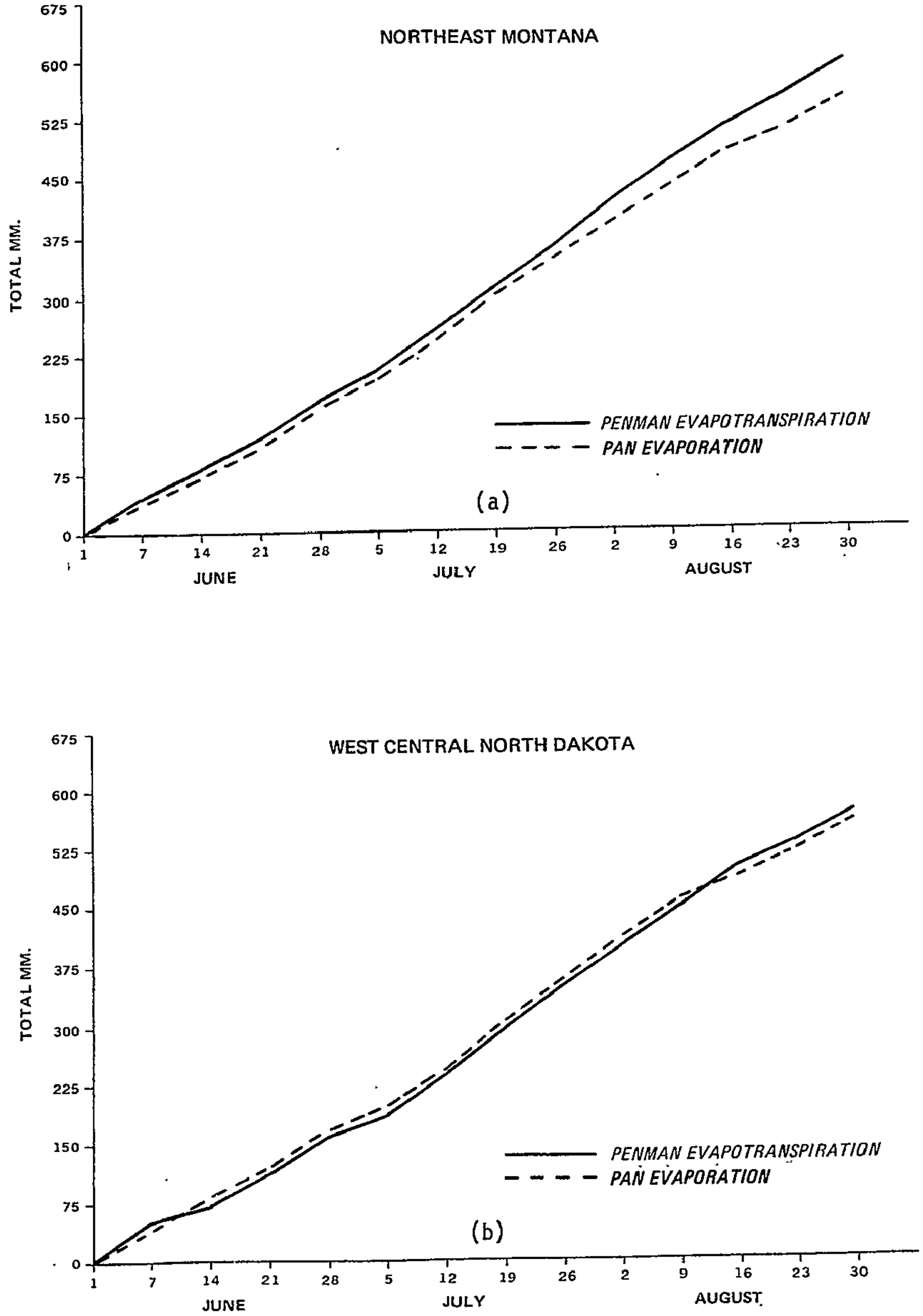

Figure 6-37: Cumulative weekly pan evaporation and METRUN ETP for four representative Crop Reporting Districts in the test area for the period 1 June to 30 August 1975. a) N.E. Montana, b) W.C. North Dakota, c) S. W. Minnesota, d) E.C. South Dakota.

COMPARISON OF WEEKLY CROP REPORTING DISTRICT, PENMAN EVAPOTRANSPIRATION AND PAN EVAPORATION TOTALS FOR JUNE - AUGUST, 1975

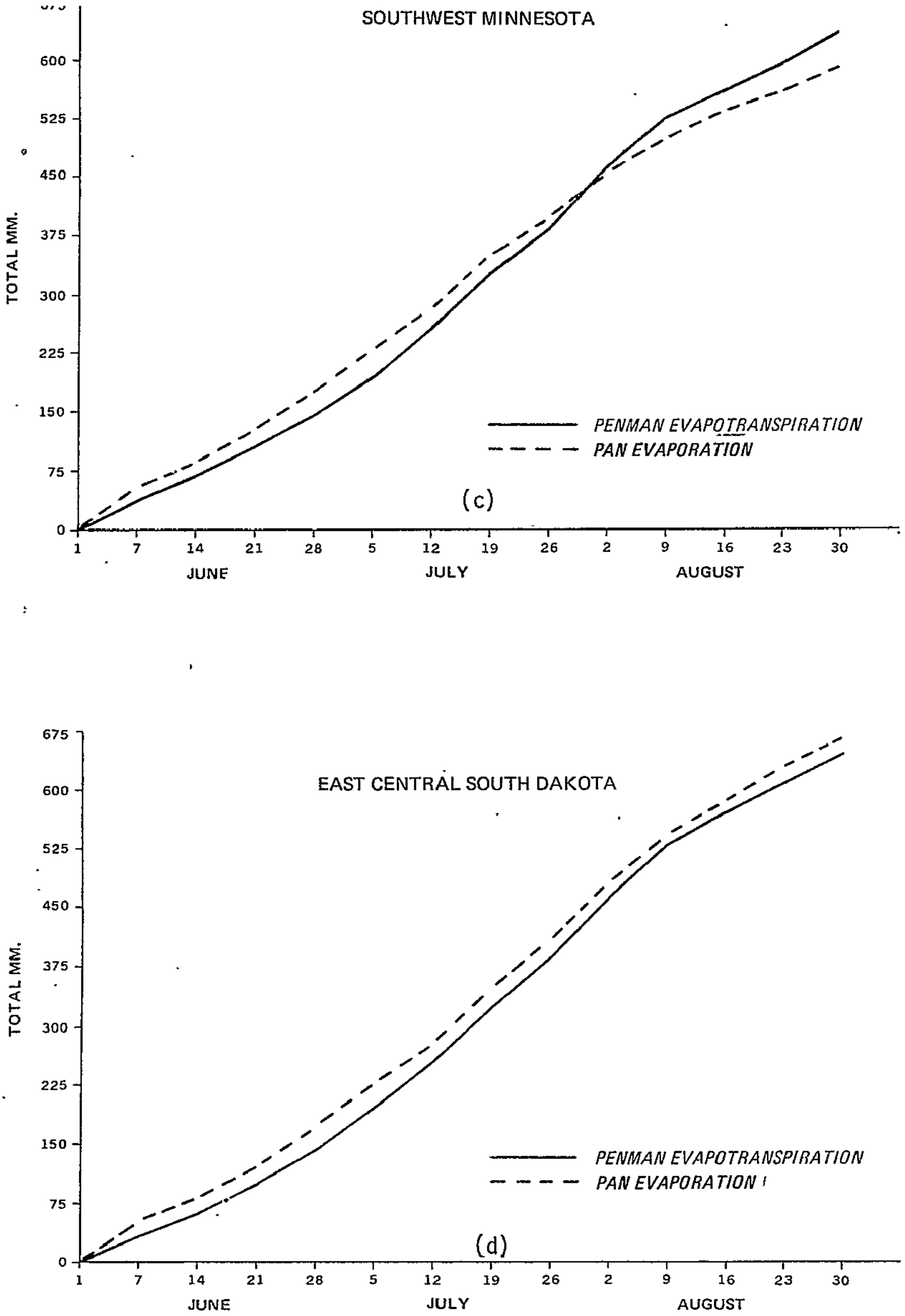

Figure 6-37: Continued

7.0 PLANT GROWTH/MOISTURE STRESS DIAGNOSTIC

The plant growth/moisture stress diagnostic operates in the 12.5 x 12.5 nautical mile cells and utilizes the Precipitation and ETP diagnoses spread equally into the four cells which surround each of the 25 nautical mile grid mesh points. The key activities performed include:

(a) Calculation of "percolation" and runoff utilizing various approximations and models. The output of this step is a three layer soil moisture profile for the specific soil specified in that cell.

(b) Calculation of actual transpiration as a function of crop phenology. These calculations operate on the soil moisture profile resident in the file from the previous day. The output from this calculation is the moisture budget account balance from the start date.

(c) The results of the ETP and ET calculations are ratioed to provide a "stress" value.

7.1 Moisture Budget Discussion

The basic soil moisture budget used in the EarthSat "System" was developed by Baier and Robertson (1966). The so-called "Versatile Budget (VB)" divides the total crop available moisture into several zones. Water is extracted simultaneously from different depths in the soil profile permeated by the wheat plant roots in relation to the rate of potential evapotranspiration (ETP) and the available soil moisture in each zone. The general equation for the Versatile Budgeting model for calculating daily actual transpiration per zone is:

$$ET_i = \sum_{j=1}^{n} k_j \frac{S'_j(i-1)}{S_j} Z_j \; ETP_i e^{-0.01w(ETP_i - \overline{ETP})} \qquad [7\text{-}1]$$

where

ET_i = actual evapotranspiration for day i ending at the morning observation of day i + 1

$\sum_{j=1}^{n}$ = summation carried out from soil zone 1 to N

k_j = coefficient account for soil and plant characteristics in the jth zone

$S'_j(i-1)$ = available soil moisture in the jth zone at the end of day i-1, that is, at the morning observation of day i

S_j = capacity for available water in the jth zone

Z_j = adjustment factor for different types of soil dryness curves

ETP_i = potential evapotranspiration for day i

w = adjustment function accounting for effects of varying PE rates on the AE:PE ratio

$\overline{ETP}$ = long-term average daily PE for month or season.

7.1.1 Standard Zones

The total volume of plant-available soil moisture in the soil profile is subdivided into three zones of varying capacities (S_{cap}). The subdivision into zones and the amount of moisture held in each zone are arbitrary, but three "standard zones" have been adopted and contain respectively 5.0, 20.0, 75.0% of the total plant-available moisture in the soil profile. Because the root distribution differs in depth from soil to soil, the location of the zones also differs but not the fractional subdivision of the total available soil moisture. The adoption of standard zones makes it possible to use one set of crop coefficients for a particular crop in any type of soil, because it is assumed that the uptake of available water by crops always follows a characteristic pattern that depends on plant rooting habits. Although the model works with standardized zones, it is possible, and for comparing soil moisture estimates with measurements it is necessary, to relate these zones to depths for specific soil types.

Crop coefficients (k) express the amount of water that is extracted by plant roots from the different zones during the growing season as a fraction of ETP. To simulate this water uptake, the k-coefficients change during the growing season according to crop developing stages or on a biometeorological time scale basis. Robertson (1968) developed a mathematical model that relates rate of crop development to photoperiod and to day and night temperatures. Only standard climatic data of daily maximum and minimum temperatures and of day length available from the METRUN program are required. Allowance is made for lower and upper critical limits and the optimum value of each of the three environmental factors. Daily rates of progress toward maturity, calculated by means of the model, is integrated to give a biometeorological time scale.

In comparisons between observed and estimated soil moisture under non-irrigated crops, Baier (1969a) found that during drought periods plant roots absorbed from the lower, relatively moist layers comparatively more water than they did in a uniformly moist soil profile. This adjustment by plants is simulated in the VB by distributing the k-coefficients for the upper zones, where water is no longer or less readily available, over the lower zones, where water is still available in proportion to the assumed vertical root distribution. This adjustment is introduced between emergence and jointing. The adjustment takes the form:

$$k'_j = k_j + k_j \sum_{m=1}^{m=j-1} k_m \left[1 - \frac{S'_m(i-1)}{S_m} \right] \qquad [7\text{-}2]$$

where

k'_j = adjusted k-coefficient for the jth zone

$S'_j(i-1)$ = available soil water in the jth zone

S_j = capacity for available water in the jth zone

For the purpose of this budget, plant-available soil moisture is considered to be the amount of moisture over the range from field capacity (1/3 atm or pF = 2.7) to permanent wilting 15 atm or pF = 42). Contradictory viewpoints exist on the availability of soil moisture over this range for growth and transpiration. Recent reviews of literature pertaining to soil-moisture regime experiments (Baier, 1968) suggested that the relationship between available moisture in the soil and the ET:ETP ratio still depends on the physical character of the soil, even though all other factors such as plant physiological characteristics of water uptake transportation and transpiration, and atmospheric demand as reflected in the ETP rate, are taken into account.

7.1.2 Soil "Dry Down" Relationships

Eight general relationships between available soil moisture and the ET:ETP ratio are shown in Figure 7-1. The decision as to which curve to use was based on the soil characteristics of the region under study. In the Great Northern Plain area, 3 predominant soil classes were identified and dry-down curves associated with each. For soil categories 1, 3, and 4, the assigned dry-down curves were D, A, and D respectively.

Broad guidelines for the curves used in this project are given below. Type G, although not used, is included since most previous EarthSat use with the Baier model used this curve.

Type A. Water is equally available to plants for evapotranspiration over the range from field capacity to permanent wilting. Viehmeyer and his coworkers (1956) proposed this concept. This hypothesis is probably acceptable for many sandy soils that are well permeated with roots and also for soils under irrigation when a moisture content close to field capacity is

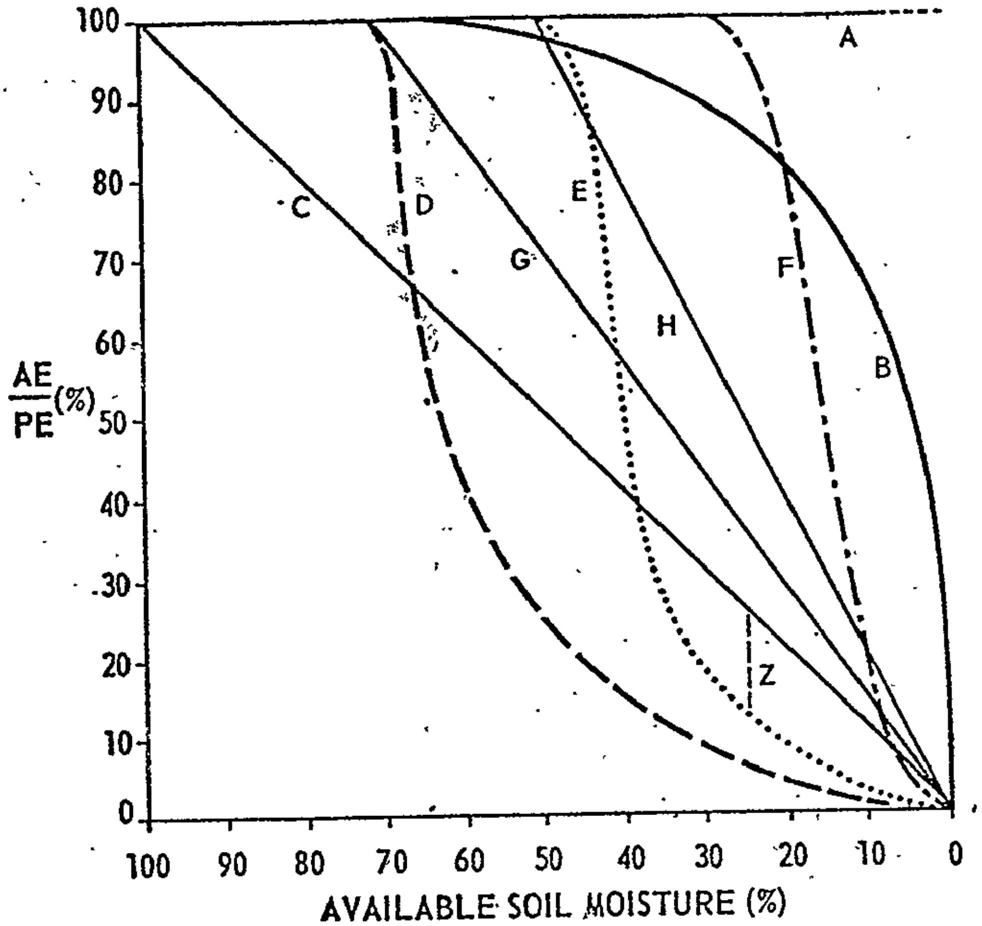

Fig. 7-1: Various proposals for the relationships between AE:PE ratio and available soil moisture (after Baier and Robertson, 1966).

maintained throughout the growing season.

Type D. Several researchers have held the view that soil moisture is almost equally available to plants up to a point where the demand rate for a particular evaporation condition exceeds the supply of water to plants from the soil. Beyond this point, the ET:ETP ratio decreases sharply with decreasing soil-moisture content. Type D assumes no reduction in the ET:ETP ratio over the range of available soil moisture from 100% to 70% (Type D). Beyond these limits the ET:ETP ratio declines rapidly with drying of the soil after an exponential decay form relationship. When the moisture content is extremely low, water movement is very slow and takes place only by diffusion, mainly from the dry surface layer. The range which moisture is readily available depends on the moisture release characteristics of the soil (Holmes and Robertson, 1963). The relative transpiration rate declines in a clay soil at a higher available soil-moisture content than in a sandy soil where the actual transpiration rate is close to the potential over a much wider range of soil-moisture content (Gardner, 1960; Gardner and Ehlig, 1963; Marlatt et. al., 1961; Denmead and Shaw, 1962).

Type G. This relationship assumes no reduction in the ET:ETP ratio over the range from 100% to 70% available soil moisture and a linear relationship over the range from 70% to 0%. This type was used by Fitzpatrick et. al. (1967). From a comparison of observed soil moisture with estimates obtained from the VB using five types of relationships, Baier (1960b) concluded that Type G would have given best results under the local experimental conditions where well-established grass was grown in Matilda loam soil. Use of Type G is recommended as a first approximation in most medium-textured, nonirrigated soils.

Stanhill (1957) concluded from his literature review that the intensity of the evaporating power of the atmosphere must also be considered in analyzing the relationship between soil-moisture status and plant growth. Several authors have shown that the effects of the atmospheric demand rate must be accounted for (Holmes and Robertson, 1963). Denmead and Shaw (1962) demonstrated this experimentally in container studies with corn plants. In the VB, the term $e^{-.01w(ETP_i - \overline{ETP})}$ accounts for effects of varying daily atmospheric demand rates (ETP_i) on the ET:ETP ratio as a function of available soil moisture. From a graph given by Shaw (1964) a regression equation was developed by Baier that estimates with sufficient accuracy ($r = 0.87$) the value of w from the soil-moisture stress occurring on the preceding day:

$$w = 7.91 - 0.11 \left[100 \cdot \frac{S'_j(i-1)}{S_j} \right] \qquad [7\text{-}3]$$

To account for water losses through runoff, if applicable, a simplified relationship between soil moisture in the top zone, daily precipitation total, and runoff is included in the VB. On days with $P \leq 1.00$ inch, the total amount of precipitation is considered to infiltrate into the soil. On days with $P \geq 1.00$ inch, runoff is estimated from equation [7-4]:

$$\text{Runoff}_i = RR_i - I \qquad [7\text{-}4]$$

where: I = amount of water infiltrating into the soil

$$= 0.9177 + 1.811 \log RR_i - 0.0097 \log RR_i \, \frac{S'_{j(i-1)}}{S_j} \, 100 \qquad [7\text{-}5]$$

RR_i = rainfall in inches for 24 hr. ending the morning of day i+1

$100 \cdot \frac{S'_j(i-1)}{S_j}$ = available soil moisture in percent of capacity (S_j) in the top zone at the end of day i-1.

Equation [7-5], taken from Linsley, Kohler, and Paulhus (1949), gives the amount of water infiltrating into the soil as a function of 24-hr precipitation total and soil-moisture content in the top zone before the day with precipitation. A level soil surface is assumed. Daily runoff is listed in the output of the VB program.

It is assumed in the VB model that the water infiltrating into the soil recharges the moisture content in the top zone to its field-capacity value and that the remaining water infiltrates into the next zone and so forth until either all infiltration water is used up or all zones are brought to capacity. Drainage is obtained on days when the precipitation exceeds the total of ETP, runoff, and the sum of moisture deficits over all zones.

7.2 Biometeorological Time (BMT)

The moisture budgeting routine includes by necessity an estimation of the phenological events, i.e., a crop calendar. The procedure used by the EarthSat "System" was developed by Robertson (1968).

The biometeorological time scale (BMT) for wheat and other cereals uses day and night temperatures and photo period. The phenological events estimated by BMT for wheat include:

- Emergence (E) - the date when a specified plant density can be seen.
- Jointing (J) - the earliest date of the first internode elongation. (This stage usually occurs just prior to the appearance of the 5th leaf.)
- Heading (H) - defined as the stage when the base of the head reached the same height as the base of the shot blade.
- Soft Dough (S) - the stage at which the kernel can be easily deformed but no "milk" or liquid appeared under pressure.
- Ripe (R) - when the kernel can no longer be deformed by finger pressure, but could still be cut by fingernail pressure.

Marquis wheat was used in the tests by Robertson which were conducted over extended periods in Canada and Argentina.

The final model is a triquadratic equation which relates the daily photoperiod and the daily maximum and minimum temperatures to plant maturity from planting (must be specified):

$$m = \sum_{S_1}^{S_2} \left[\left\{ a'_1(L-a_o) + a'_2(L-a_o)^2 \right\} \left\{ b'_1(T_1-b_o) + b'_2(T_1-b_o)^2 + d'_1(T_2-b_o) + d'_2(T_2-b_o)^2 \right\} \right] \qquad [7\text{-}6]$$

where

L is daily photoperiod

T_1 is daily maximum temperature

T_2 is daily minimum temperature

and a_0, a_1, a_2, b_0, etc. are characteristic coefficients.

7.3 Initialization for the 1975 Season

Since the system start date was after the normal planting period in most regions, accurate assessment of the status of each cell, as of the start date, was essential. Three critical parameters are planting date, soil moisture levels, and estimation of stress that had been experienced from planting to the start date of 1 June. Since the model is iterative, initial errors will be propagated throughout the entire growing season. While the magnitude of these errors have not been determined, the qualitative effects can be estimated.

Since planting is a discrete event, it can be accurately measured. The data used this year were supplied by the U.S. Department of Agriculture and were in the form of mean planting dates by crop reporting district. The dates ranged from late April in southern South Dakota to late May in Montana and North Dakota. On average, planting was delayed by 2-3 weeks due to heavy spring rainfall.

More difficult to assess is the amount of stress experienced by each cell from planting to 1 June. The yield relationship in this project defines yield as a function of planting-ripe average daily stress. Thus for each cell, estimates of the dates of significant phenological events were required where these events occurred prior to 1 June. In Montana and North Dakota, almost all areas were at or before emergence. Minnesota was estimated to be between emergence and jointing. For the most part, South Dakota followed the same pattern as Minnesota, however, the southern crop districts were past jointing. In order to estimate stress, soil moisture profiles at planting were generated using NOAA soil moisture measurements. Combining these data with observed weather, historical weather and historical dates of the phenological events, it was possible to estimate changes in the soil moisture profile and, consequently, derive a stress value for each area. This process was repeated for each crop reporting district within the study area and spread to each cell within the respective crop districts.

Equally important and directly following from the stress estimation were assessments of the growth stage of each cell as of 1 June. Since the BMT calculation is of daily change, initial growth stage errors would cause a shift of the growing season. The timing of meteorological events with respect to plant growth stage is critical, and thus a shift of an event, especially when near a change in growth stage, can have a large effect. In this project the average historic length of the interval within which 1 June fell was divided into the number of days from the start of the interval or growth stage to 1 June given a fraction between 0 and 1. Using the intervals defined in section 7.2, 0 - planting, 1 - emergence, ..., 5 - ripe, this fraction is added to the value of the preceeding event. This procedure was repeated for every crop district, and spread to each cell within the district.

Measurement of the soil moisture profile is a more complex problem. Soil profiles obtained within the same field will vary significantly from each other. The source of the data used for this project was provided by NOAA (Dr. Richard Felch). Data were provided for starting soil moisture as of April 5th and May 3rd. As the closest to the model start date of 1 June, the May data were used. These data indicated that Minnesota and most of North Dakota were at capacity in each soil type. The western and central crop districts appeared to be close to capacity with the remaining areas at or below 50%. Similarly, South Dakota ranged from about 75% in the northeastern area to 25% in the southcentral district. Figure 7-2 presents a map of the starting soil moisture percentages as assigned to each cell within the district according to local soil categories. That is, total soil moisture for a cell was obtained by multiplying the Crop Reporting District's percentage times the capacity of cell's soil type. The resultant total moisture was further allocated to each layer on the basis of the 5,20, and 75% standard zone definition discussed in section 7.1.1.

7.4 Plant Growth/Moisture Stress Diagnostic Error and Sensitivity Analyses

Evaluations of the errors and sensitivity associated with the 1975 operations of the EarthSat "System" Plant Growth/Moisture Stress functional element requires separate evaluations of the Baier

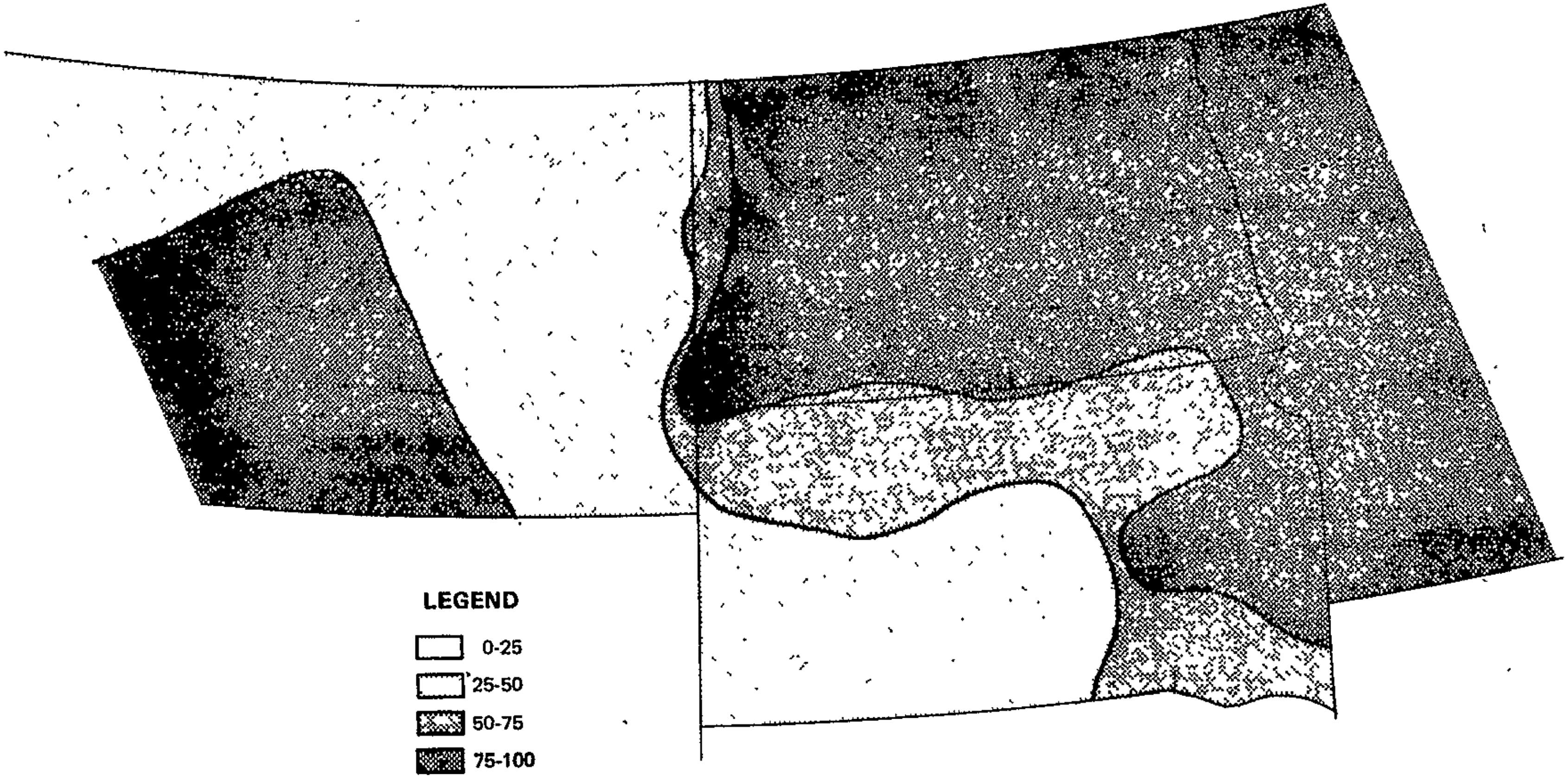

Figure 7-2: Initial soil moisture

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VB model and its sub-elements as implemented and the Robertson BMT model as implemented. The basic mathematical discussions associated with each of these models has been presented in Sections 7.1 and 7.2 respectively. The following sections will examine the relationship between the ground observational data at the USDA sites including the neutron probe data acquired under subcontract, USDA gravimetric data at selected sites, and crop growth stage estimates. The evaluations of the soil moisture profiles and actual transpiration (ET) will be limited, in part, by the available ground data and its inherent lack of representativeness.

7.4.1 Growth Stage (BMT) Evaluations

The Robertson (BMT) model, as described in Section 7.2 and as implemented in the EarthSat "System" in 1975, provides growth stage estimates in each 12.5 x 12.5 nautical mile cell for each day of the 1 June - 30 August test period. Growth stage observations were collected from 7 of the USDA ground truth sites. The growth scales used were not the same, however, so we have made an attempt to equate them. The best estimate is shown in Table 7-1. Once comparable scales were established it was a rather straightforward procedure to evaluate the errors.

Assuming that our scale match (Table 7-1) is correct we used the USDA field reports to define the percentage frequency of fields in each growth stage. The median "site" growth stage was derived from these distributions. BMT = 2 (Jointing), BMT = 3 (Heading), and BMT = 4 (Soft Dough) were used for the evaluation since these stages are critical to the soil moisture

TABLE 7-1

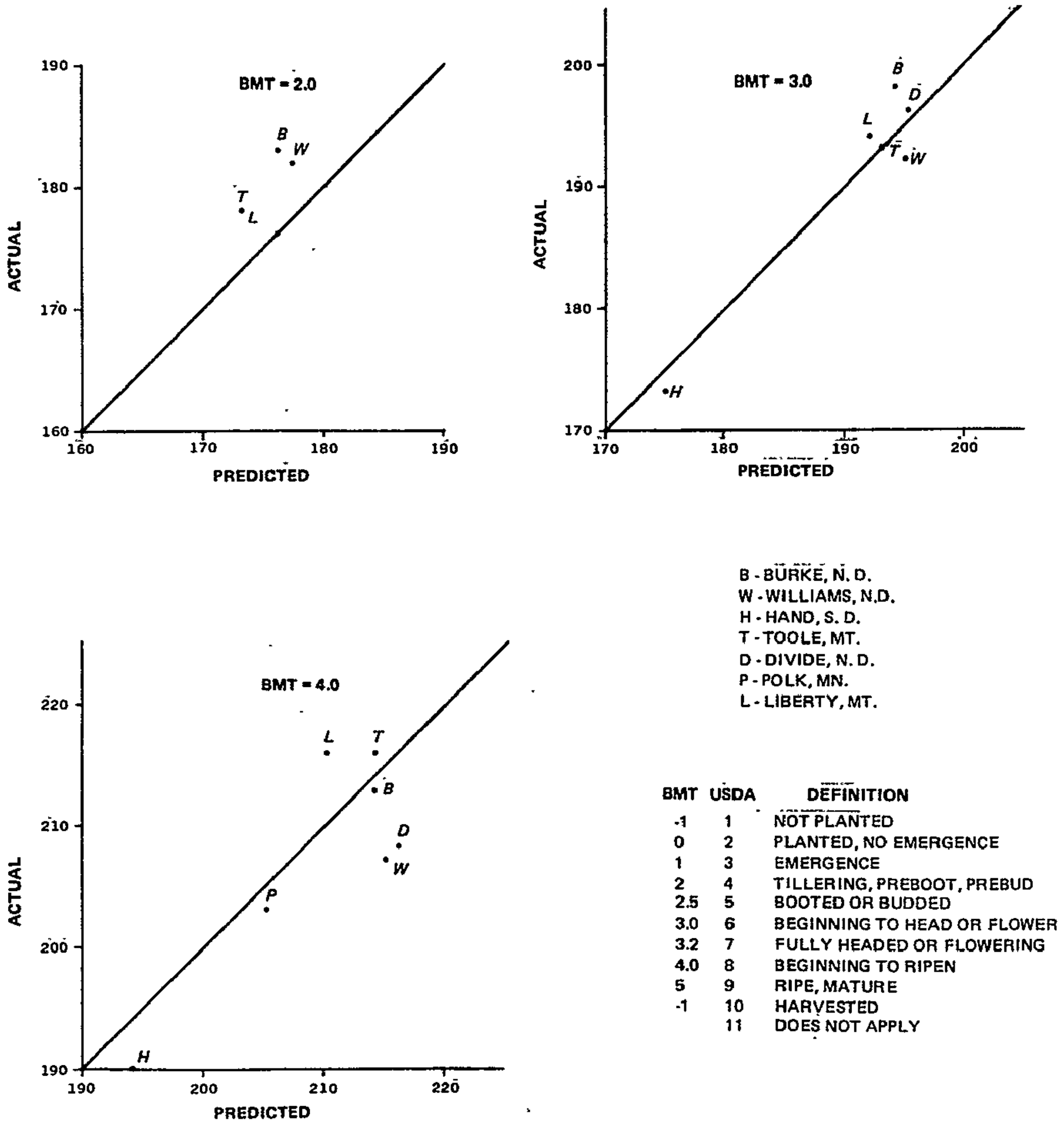
BMT/USDA GROWTH STAGE COMPARISONS

	BMT	PLANT PROCESS	USDA	
Not Planted	-1		1	Not Planted
Planted - No Emergence	0		2	Planted - No Emergence
Emergence	1	Shoot Extension	3	Emergence
Jointing	2		4	Tillering Pre-Boot
Booted	(2.5 est.)		5	Booted
Budded				
Heading	3		6	Beginning to Head
(Flowered)	(3.2 est.)	Flowering (Pollination)	7	Fully Headed or Flowered
Soft Dough	4	Filling	8	Beginning to Ripen
Ripe	5		9	Ripe Mature
Harvested	-1		10	Harvested

budgeting and yield evaluation. The median day was defined from the Julian days (J-day) of the USDA ground observations. The comparisons are summarized in Figure 7-3. Interpolation was used to determine the date of occurrence of the BMT = 2, 3 and 4 J-days. Two sites did not report any spring wheat, i.e., Hill and Glacier, while Polk and Hand did not provide enough reports to estimate each of the three phenology events.

While the small sample size precludes definite conclusions, two observations can be made about to the BMT model's performance. First, taken as a group, the error level is well within an acceptable range with an average absolute error of 3.4 days. Secondly, there may well be a systematic error in the model. Toole and Liberty composite values were similar (in terms of error) throughout the season with the predicted BMT values running ahead of the observed, i.e., the clock was "fast." Similarly, the three North Dakota sites (Burke, Williams, and Divide) had similar responses initially behind predicted BMT but eventually were ahead of it. The two observations for Hand show that the model is behind observed data, i.e., the clock is "slow" in both cases. An analysis of reported planting dates does not support attributing the Montana and South Dakota errors to error in planting date. Additionally, the relative change observed in the North Dakota sites suggests that the model may not adequately respond to certain temperature situations. All of this presumes, of course, that the reported observations are "truth" and do represent the growth stage of the spring wheat test site. Prior tests of the Robertson

SCATTER DIGRAMS FOR BMT



BMT	USDA	DEFINITION
-1	1	NOT PLANTED
0	2	PLANTED, NO EMERGENCE
1	3	EMERGENCE
2	4	TILLERING, PREBOOT, PREBUD
2.5	5	BOOTED OR BUDDED
3.0	6	BEGINNING TO HEAD OR FLOWER
3.2	7	FULLY HEADED OR FLOWERING
4.0	8	BEGINNING TO RIPEN
5	9	RIPE, MATURE
-1	10	HARVESTED
	11	DOES NOT APPLY

Figure 7-3: Scatter Diagrams for BMT

model over 66 location years of data in North Dakota seemed to suggest that BMT = 2, 3 and 4 were +9, +5, and -1 days respectively from the observed. The Robertson model does not consider soil moisture level which does appear to be significant, e.g., some years with slow growth were moisture deficient, while those with rapid growth showed a tendency for "normal moisture."

In conclusion, it appears that the model is working adequately and does give a reasonable estimate of plant growth stage. The System Sensitivity evaluation for BMT (Section 9) will examine the model in light of the observed errors.

7.5 ET Error Analysis

A critical function of the AGRUN subsystem is the accurate estimation of daily evapotranspiration (ET) in each I,J,K cell within the study area. ET serves a dual role in that it measures the daily change in the plant-available soil moisture profile as well as being used to assess yield when through a ratio with ETP. Figure 7-4 shows a schematic of the Plant Growth Model which illustrates the interrelationships between calculated and observed variables. The feedback nature of the model makes accurate estimation of ET a necessity since errors will be propagated through time.

7.5.1 Overview of Analysis

ET can only be evaluated as it relates to changes in the soil moisture levels since the neutron probe data only provides the net change in soil moisture between measurements.

The ET calculated by the Baier VB model in the "System" uses the METRUN ETP and precipitation estimates which are area not point estimates. The calculated soil moisture thus may have errors associated with the area aggregates. Because of these uncertainties our ET error analysis emphasized evaluation of each of the key components of the ET calculation. The basic equation for ET (discussed in Section 7) is:

$$ET = \sum_{i=1}^{3} DC_i \cdot K_i \cdot ETP \cdot e^{-W(ETP - \overline{ETP})} \qquad [7\text{-}7]$$

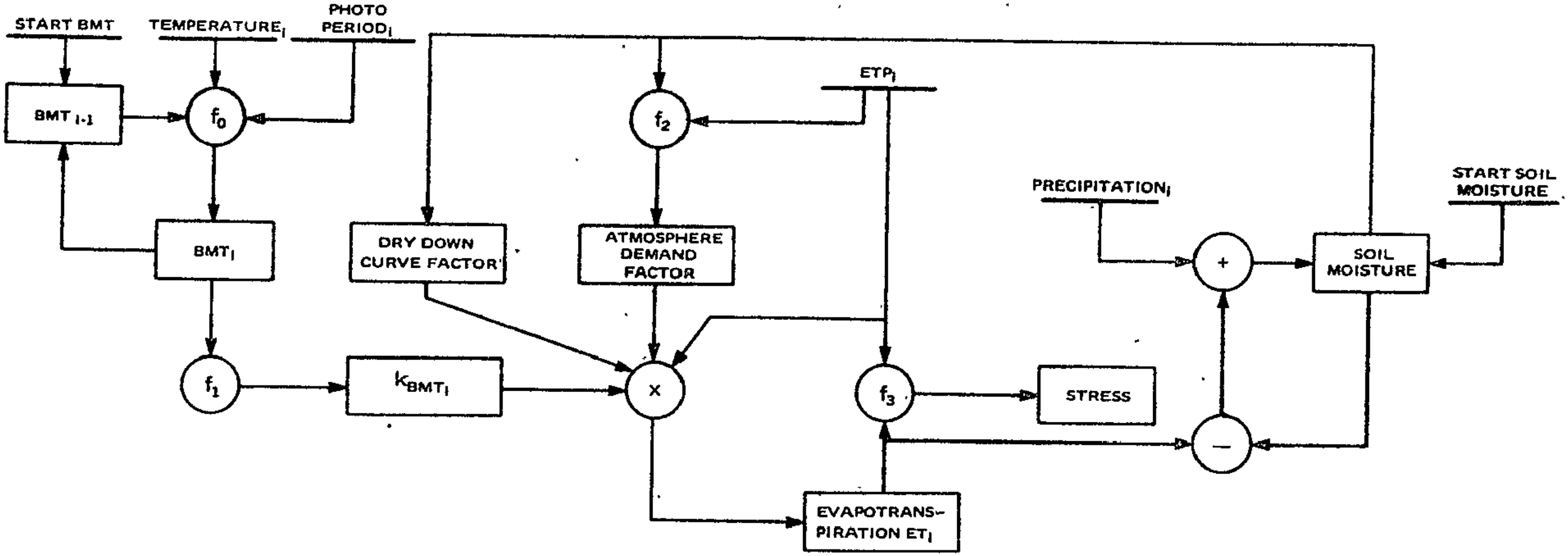
where

$$DC_i = \frac{S_j(i-1)}{S_j} Z_j$$

It directly follows that

$$SM_i = SM_{i-1} - ET_i + I \qquad [7\text{-}8]$$

where I is the amount of infiltration of rainfall (usually equal to the rainfall but reduced by runoff in instances of large rainfall amounts). The ET evaluation thus should best consider each component of in equation [7-7]; and include effects of ETP errors, precipitation/infiltration errors and starting soil moisture level errors. In order to reduce the number of variables being examined and place emphasis on the most significant ones it was assumed that the random error associated with ETP would cancel out the impact of the atmospheric



SYSTEM DIAGRAM OF PLANT GROWTH MODEL

Figure 7-4: System Diagram of Plant Growth Model adjustment factor $e^{-.01w(ETP_i-\overline{ETP})}$ [7-9]

The major terms evaluated therefore were the crop rooting coefficients. The neutron probe and gravimetric data were considered "truth" in spite of the known problems with each of these techniques of soil moisture measurement.

7.5.1.1 Dry Down and K-Coefficient Evaluations on ET

The importance of the dry-down curve component, DC in equation [7-7] was stressed at the project Mid-Term review and thus a primary emphasis placed on evaluating this component. In the 1975 test the A and D dry-down curves were used (see Figure 7-1). During the initial evaluation phase, prior to the interim report, several comparisons of reported soil moisture levels with predicted levels indicated that the D curve (used in type 1 and 4 soils as defined in Section 4) tended to be overly restrictive, i.e., a greater amount of moisture predicted less change in total profile than observed. As a result of these observations, and the discussions held during the interim review, a third new dry-down curve was developed in which moisture is freely available to the 35% capacity level and then is restricted. This curve lies between the E and F curves in Figure 7-1 and is referred to as the E-normal curve.

The rooting coefficients, i.e., K-coefficients, are an integral element of the VB model relating closely to the dry down. Several sets have been derived by Baier over the years. Two sets are shown in Table 7-2. The newest of the set of coefficients were substantially different from the set used in the 1975 operational test phase. Consquently, since these coefficients are very important it was felt that the error analysis of ET should include an evaluation of each set of coefficients.

7.5.2 Methodology

Upon receipt of the neutron probe final reports from Montana State University and North Dakota State University, a data file was constructed which would permit repetitive processing of the Plant Growth Diagnostic model on each I,J,K cell containing a reporting intensive test site. The Agronomic Season Master File (described in Section 5) contains, in addition to the variables describing plant status and history, the daily weather parameters used in the plant model: maximum and minimum temperatures, potential evapotranspiration (ETP), and precipitation. These variables were extracted for each study cell and merged onto the test site file.

7.5.2.1 Point to Area Precipitation Evaluations

Since the neutron probe and gravimetric analysis are point measurements, any error analysis of ET using these data is meaningless unless the rainfall at the I,J,K cell level is representative of the actual rainfall at the probe site. In an attempt to assure

TABLE 7-2

OLD COEFFICIENTS

STANDARD ZONE	P-E R-P	E-J	J-H	H-S	S-R
1	.60	.55	.40	.45	.45
2	.20	.30	.35	.35	.35
3	.00	.00	.15	.20	.10

NEW COEFFICIENTS

1	.40	.40	.40	.40	.40
2	.27	.33	.40	.50	.50
3	.13	.17	.25	.30	.25

representative rainfall field gauge reports from the USDA Ground Truth sites were used to provide rainfall estimates at each of the test sites. Five gauged fields within each test site were selected to provide a reasonable spatial sample of the test site. The rainfall amounts for the sample fields numerically averaged to derive an estimate of precipitation for the probe hole site. Variations between gauge readings within a site ran as high as 3mm in a light (<12.5mm) event and 12.5mm in heavier amounts ($\geq$25.5mm).

Merging the derived site rainfall estimates into the test site archive file created a data base which could be repetitively processed using differing combinations of dry-down curve, k-coefficient, or rainfall event. In the analyses the soil moisture budgeting model was initiated on the date of the first probe measurement in the June 1st to August 30th time interval using the moisture level observed on that date. For the neutron probe data, volumetric readings were available which permitted the estimation of the 1/3 bar to 15 bar moisture capacity at each site. Since the readings gave capacity in layers (0-10cm, 10-25cm, 25-40cm, 40-60cm, 60-100cm) it was possible to estimate the capacity values in terms of the 3 standard soil zones used by the Soil Moisture Budgeting model.

For each probe site used, the growth model was run in 12 operating models including 3 different dry-down curves, 2 sets of k-coefficients, and 2 sets of precipitation readings. The model operated from the date of the first probe measurement, using observed soil moisture readings as a start point, through to the end of the season. On the dates corresponding to probe readings subsequent to the first, the two soil moisture readings observed and predicted, were obtained. For each of the 12 modes, an error histogram was constructed by calculating the differences between observed and predicted readings. No corrections were introduced after model "turn-on."

7.5.3 Analysis of Results

The composite error histograms for all 12 operating modes are shown in Figure 7-5; positive errors indicate that the soil moisture levels measured by the probe were greater than the model predicted, negative results mean that the soil moisture levels measured were higher than observed. The analysis of the histograms was based primarily on the median error value for two reasons. First, the range of values did not substantially vary among modes because two or more soil types were used for each test site. Sand and loam soils were included in an effort to find a best or most representative

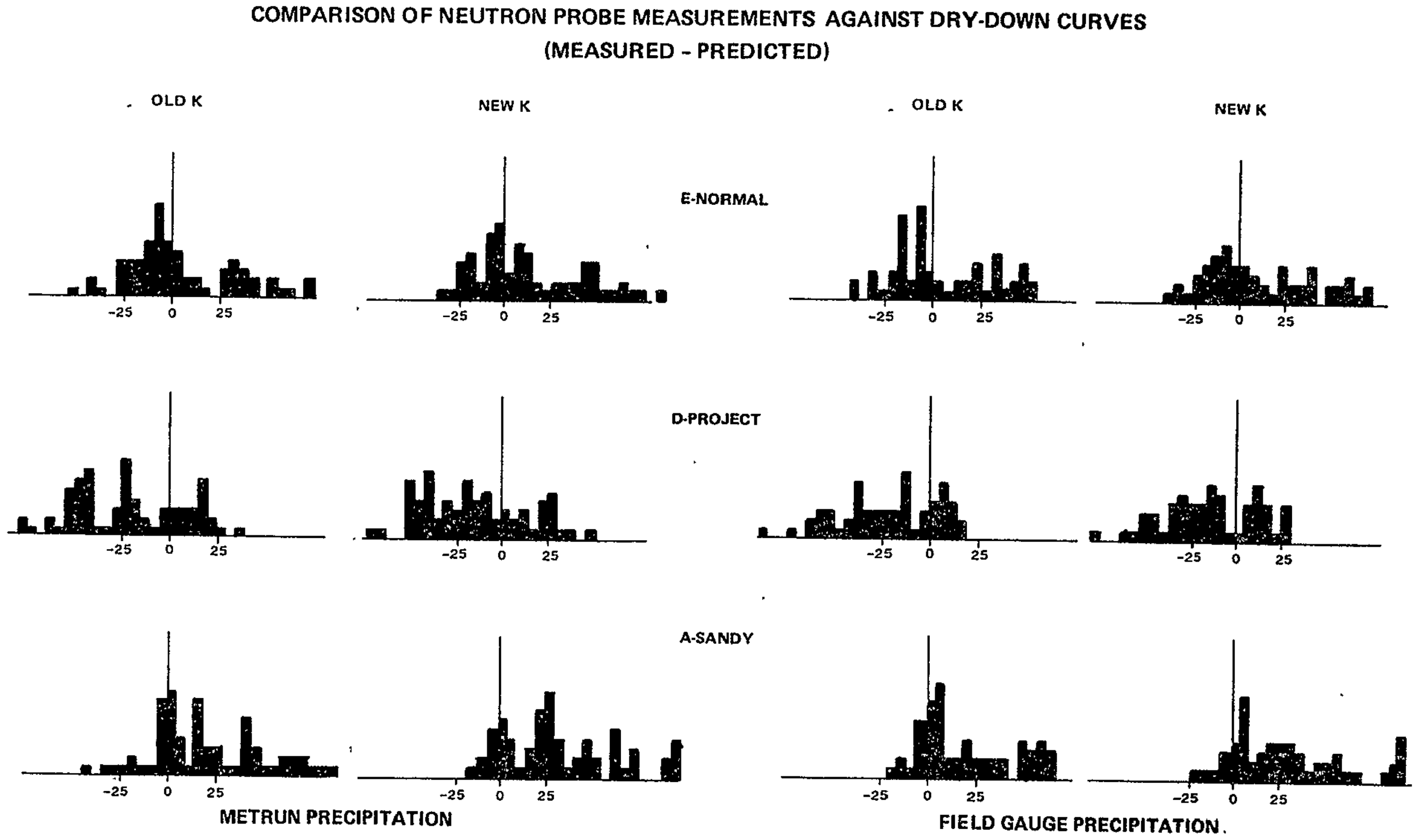


Figure 7-5: Comparison of Neutron Probe Measurements against Dry-down Curves.
(Measured-Predicted)

dry-down curve for the type 1 soils. (It should be noted that soil type class 1 was used for all the intensive test sites in the 4-state study area.) Second, it was felt that the mixture of soil classes might distort the interpretation of an arithmetic mean.

TABLE 7-3

MEDIAN ERROR RANGES (IN MM.)

	METRUN PREC.		FIELD PREC.	
CURVE	OLD K	NEW K	OLD K	NEW K
E-NORMAL	0 to -5	+5 to +10	-5 to -10	0 to -5
D-PROJECT	-20 to -25	-15 to -20	-15 to -20	-10 to -15
A-SANDY	+15 to +20	+25 to +30	+10 to +15	+25 to +30

Examination both of the histograms and the median error ranges (Table 7-3) for each mode indicates that the E-normal curve is the best general approximation of the 3 curves examined for both models of precipitation and k-coefficients. The D and A curves are restrictive and too free respectively in the soil moisure budgeting process. It is immediately apparent that, among the 3 variables tested, the estimation of ET estimates are most affected by the dry-down curve. The use of the new k-coefficients causes a positive shift of the median error of about 5mm from the old k-coefficients. The field precipitation estimates appear to cause a negative 5mm shift. The precipitation error analysis indicates that the reason for this is the METRUN tendency to overestimate small precipitation amounts and to estimate light rainfall amounts where none was observed.

Within the 4 analytical modes for the E-normal curve, it is difficult to determine which set of k-coefficients is best. The sensitivity of the model to the dry-down curve make the observed changes due to different k-coefficients statistically insignificant.

Further analysis of ET was conducted using time series plots of model versus probe responses (Figures 7-6 through 7-10). Of particular interest is the fact that each curve seems to have a lower limit. That is, for a certain dry-down curve and set of k-coefficients, there exists an effective lower limit to the amount of soil moisture predicted for the profile. Examples of this can be seen in Figure 7-6 (Burke County), Figure 7-7 (Liberty County), and Figure 7.9 (Williams County). The limit for the E-normal, D and A curves appears to be 17%, 35%, and 0% of the soil capacity respectively. The limit observed by the neutron probe samples, as for example in Liberty County, Montana (Figure 7-7) should define the type of dry-down curve for that soil. At the Liberty site a curve that is limiting after 90% might be best.1/

Using the same test criteria, comparisons were made against the gravimetric analysis readings shown in Table 7-4. The major reason for evaluating this data separately was that

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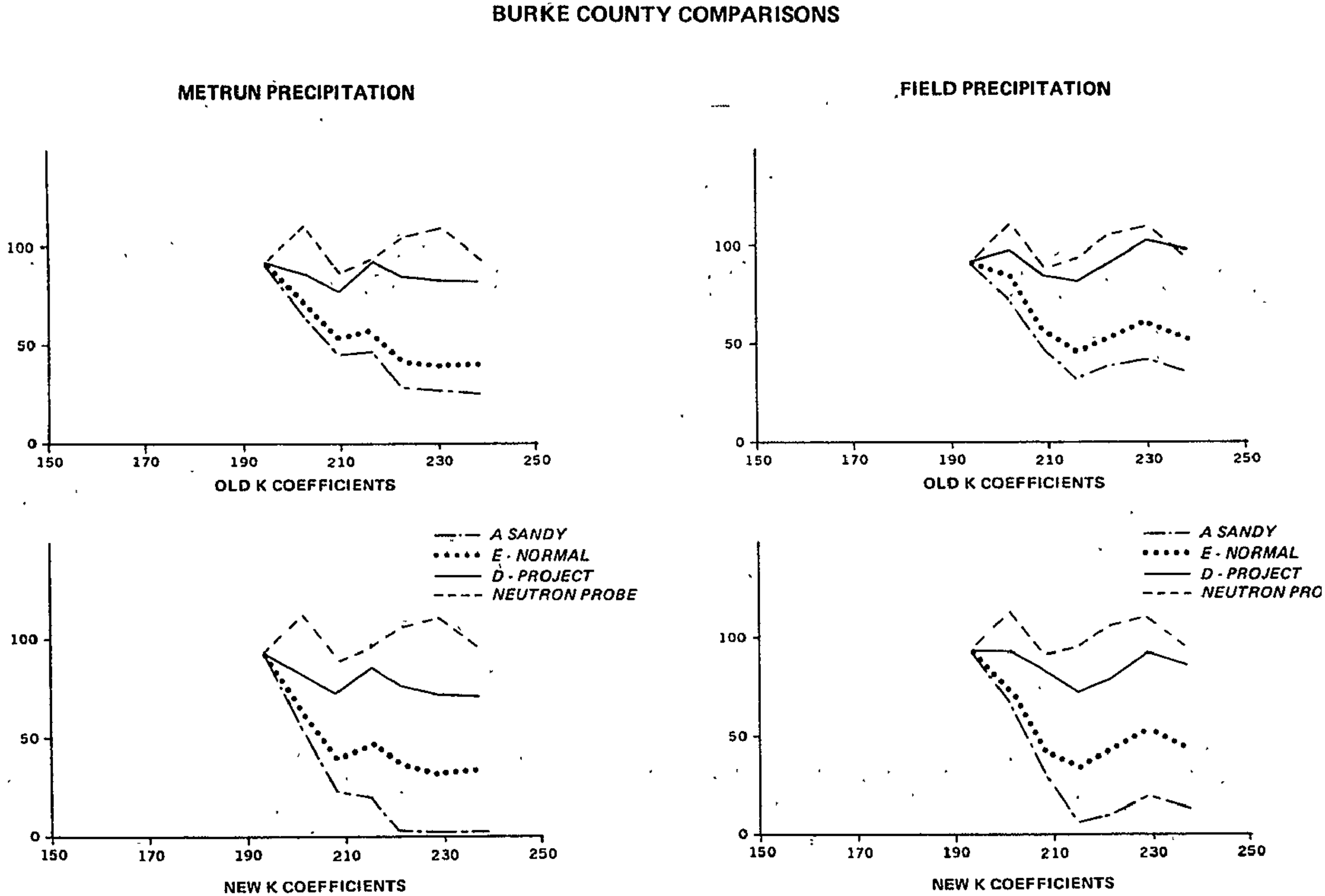
1/ The moisture release characteristics of soils is a function of texture, and may be, in part, related to the presence of stones, local compaction, etc. Liberty has large stones visible on the surface.

C-3


BURKE COUNTY COMPARISONS

METRUN PRECIPITATION

FIELD PRECIPITATION

Figure 7-6: Burke County Comparison

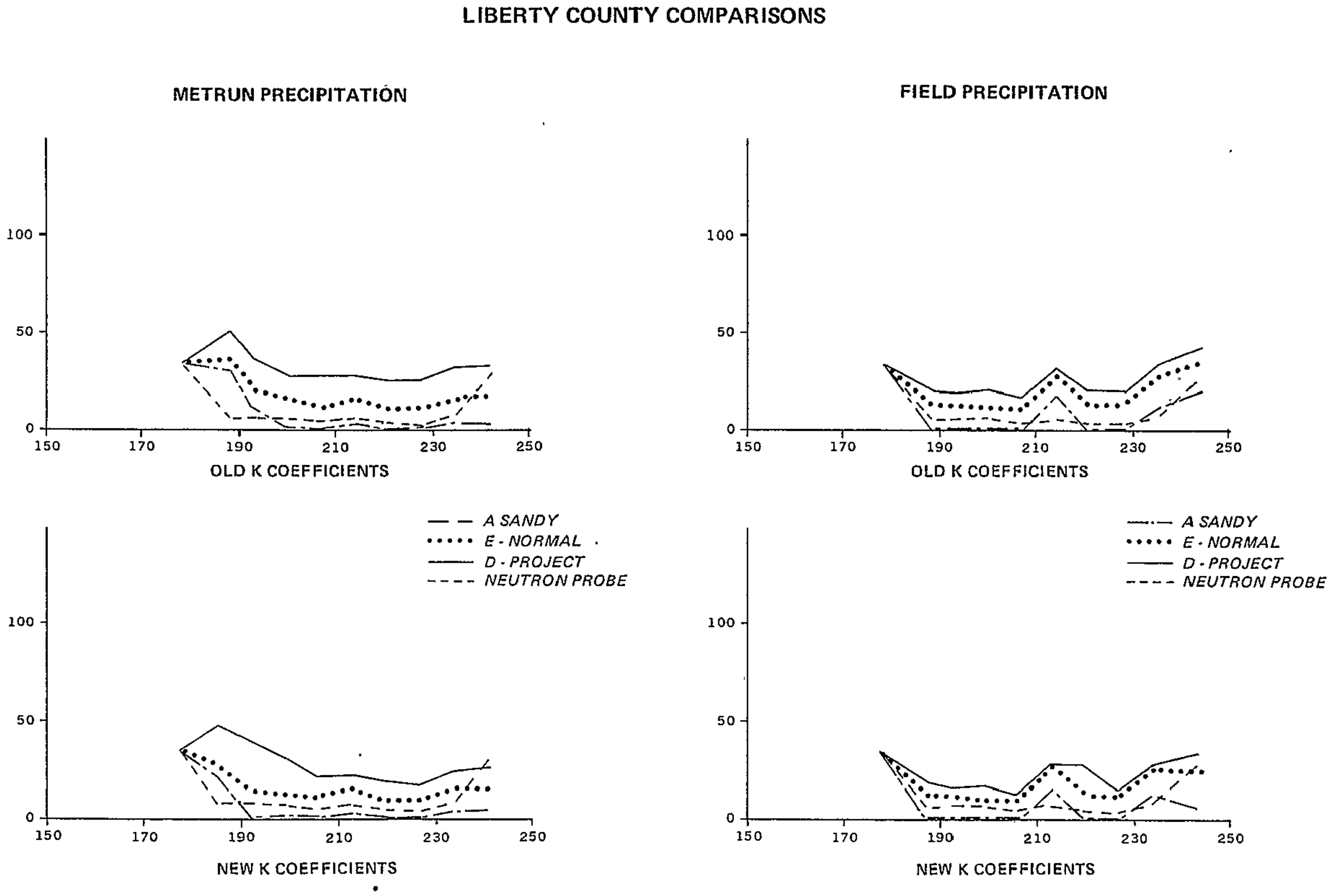


Figure 7-7: Liberty County Comparison.

HILL COUNTY (2) COMPARISONS

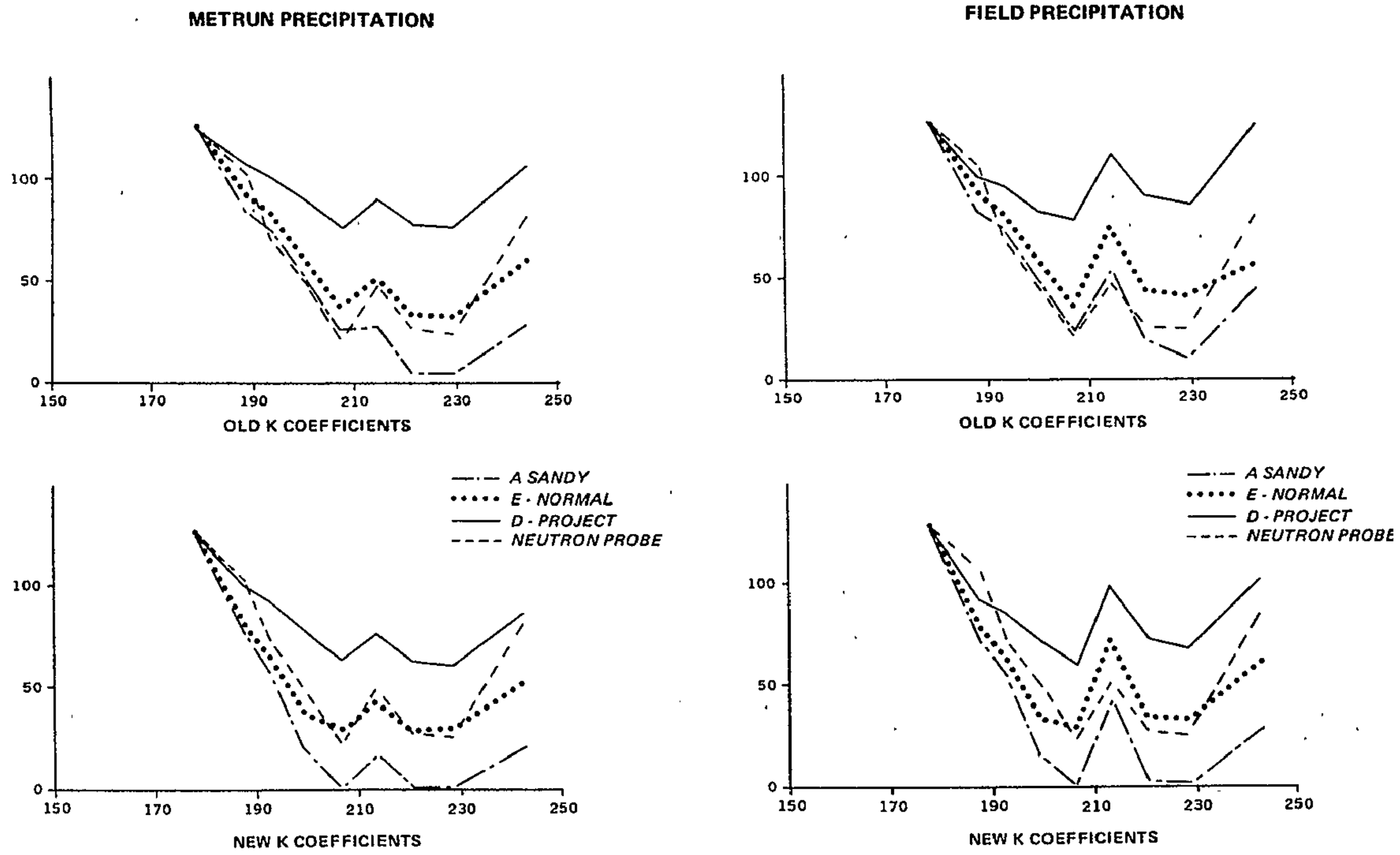


Figure 7-8: Hill County (2) Comparison.

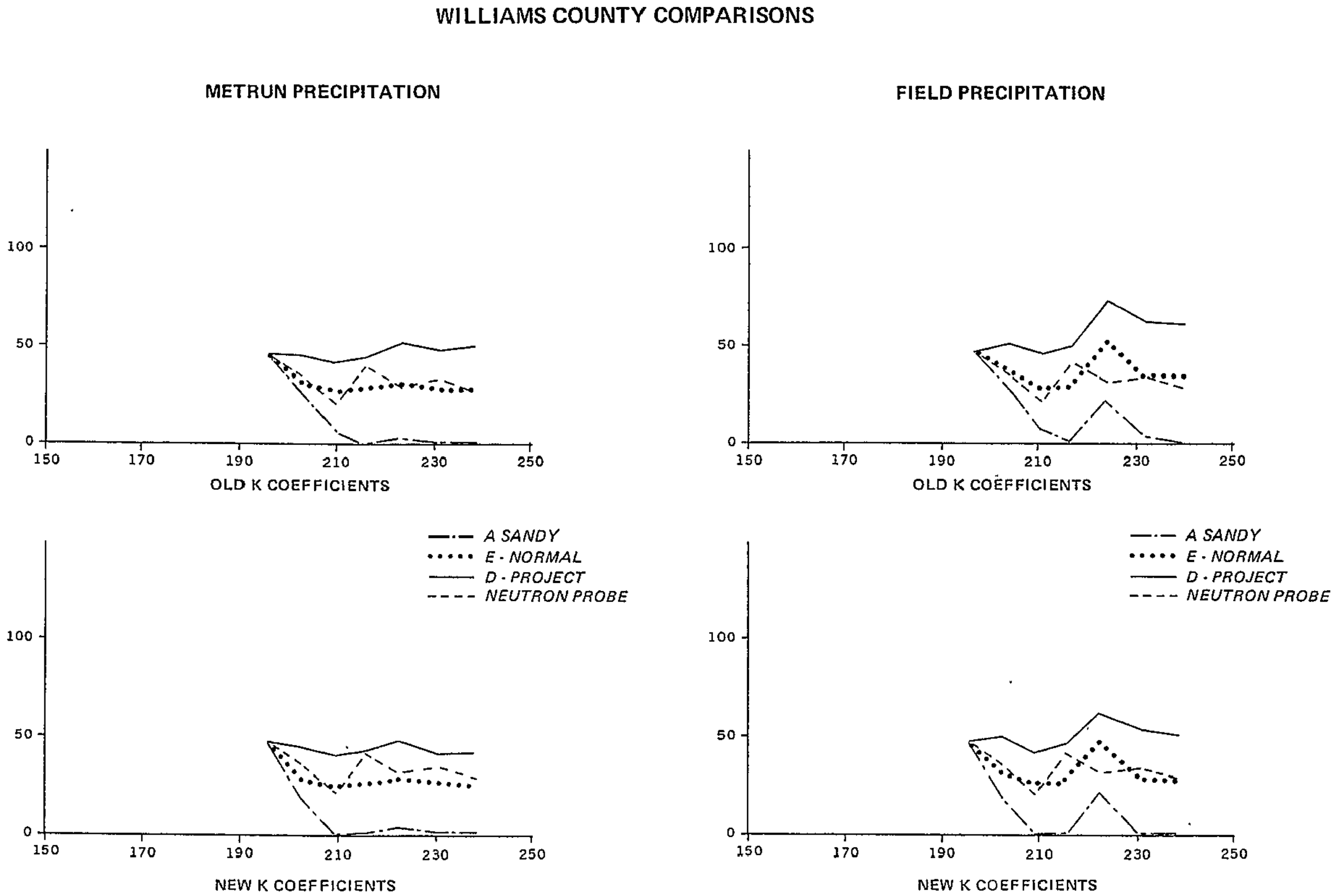


Figure 7-9: Williams County Comparison.

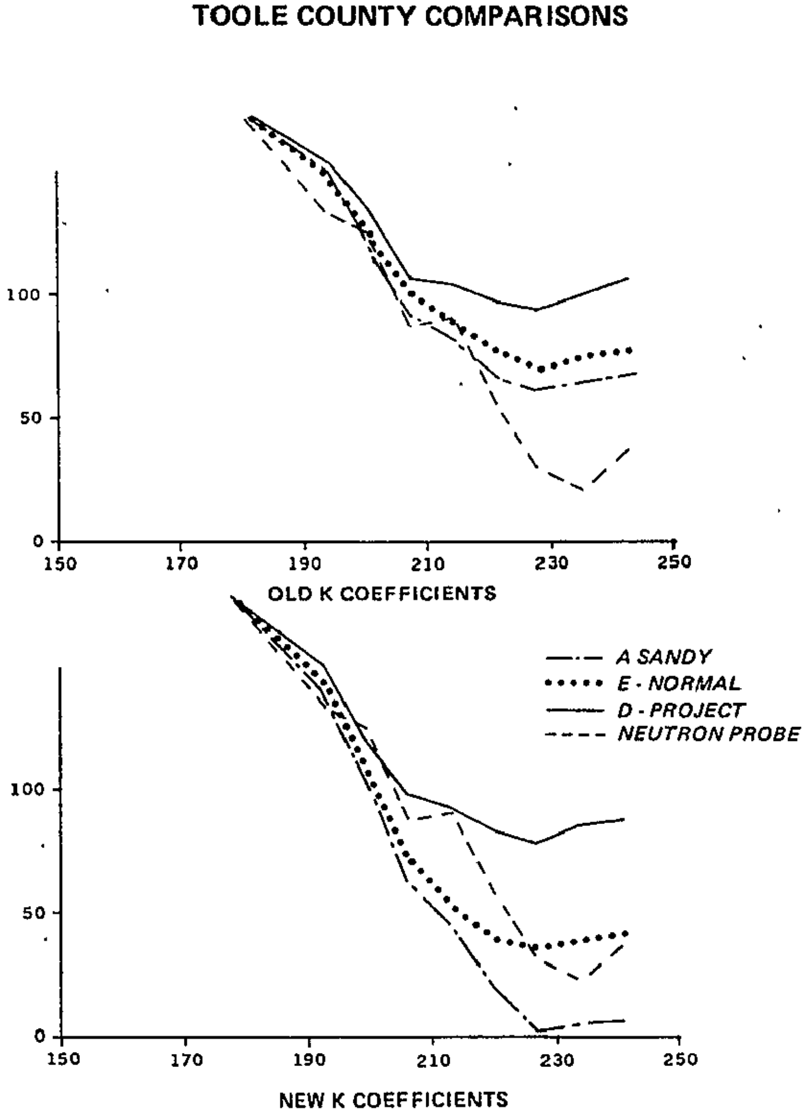


Figure 7-10: Toole County Comparison.

the measurements were taken only at the significant growth stages which meant that in 3 of the 4 sites only two readings fell with the June 1st to August 30th model interval. Consequently, for the North Dakota and Montana sites, only one error measurement was possible. These data are summarized in Figure 7-11 which has the same format as the error histograms derived from the neutron probe comparisons. For each site, two probe measurements were used.

TABLE 7-4
USDA GRAVIMETRIC DATA

	Soil No.
Burke, N.D.	75ND-13-3 and 75ND-13-4
Divide, N.D.	75ND-23-1 and 75ND-23-2
Hand, S.D.	7550-30-2 and 755D-30-5
Glacier, Mt.	75MT-35-1 and 75MT-35-2

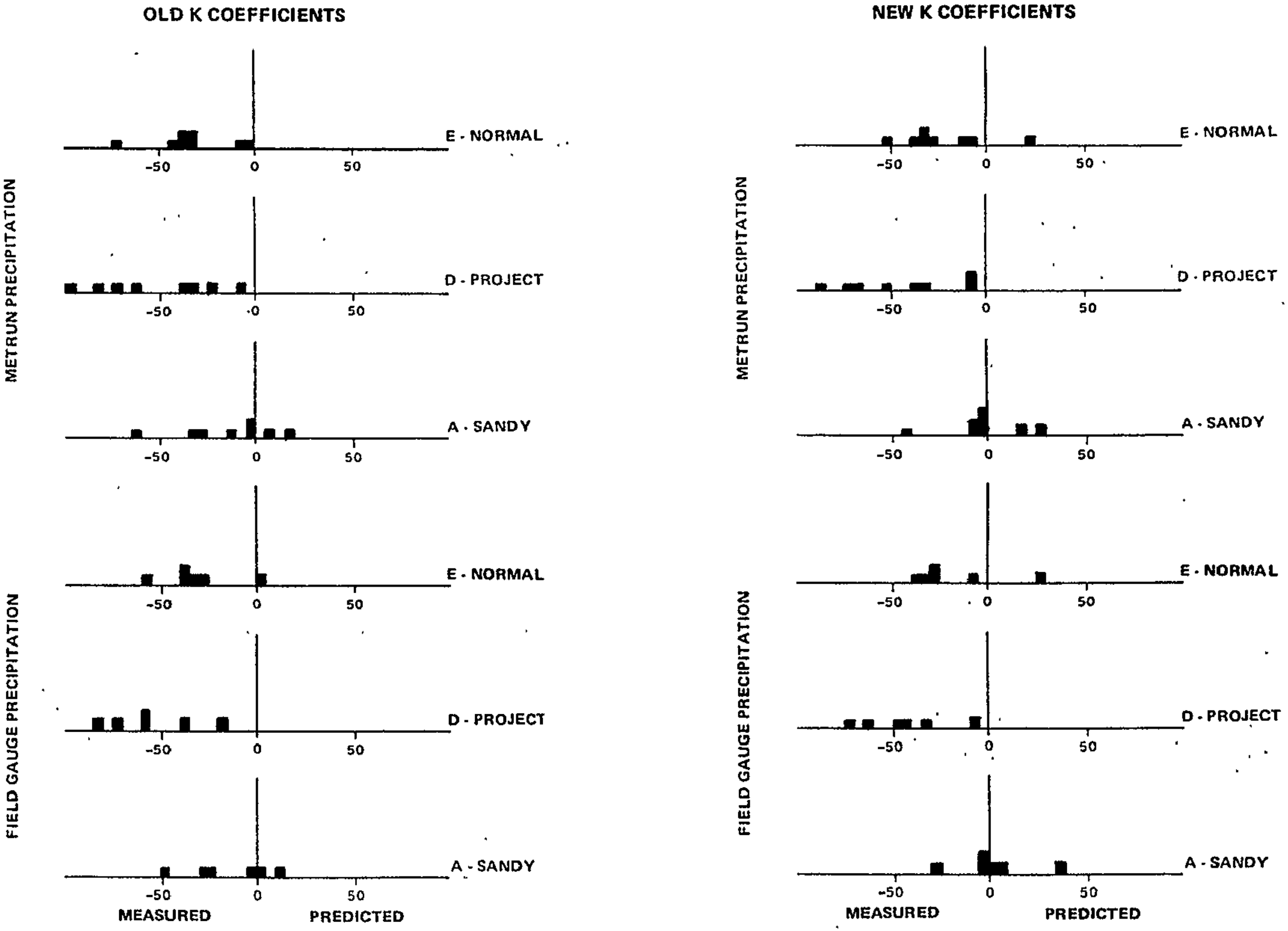
The start point was taken to be the soil mositure amount measured at heading distributed using the 5%, 20%, 75% standard layer concept discussed above. Comparisons were made between predicted and measured soil moisture levels at the Dough Stage.

The size of the data set prevents any significant conclusions to be made. However, in comparison to the neutron probe data for the Montana and North Dakota sites, the Heading measurements are of the same magnitude. However, uniformly, the gravimetric analysis readings for Soft Dough are substantially

Figure 7-11:

COMPARISON OF GRAVIMETRIC MEASUREMENTS AGAINST DRY-DOWN CURVES

(MEASURED – PREDICTED)



below corresponding neutron probe levels. Correspondingly, the "best" mode approximation to the data appears to be the sandy dry-down curve.

7.5.4 Errors as Applied to the 1975 Season

A major question which is yet unanswered is the impact of the D-curve selection for all type 1 soils for the 1975 season. A complete answer to this question would require more exact knowledge of the actual dry-down curves everywhere in the study area. However, a partial answer was attempted by growing four sites (Williams and Burke in North Dakota and Toole and Glacier in Montana) from June 1st, with the estimated start soil moisture conditions and capacities. Comparisons between the D and E curve estimates could then be made for those dates having neutron probe readings. These data are shown in Figures 7-12 through 7-15. It appears that Williams County (which started at 75% of capacity) experienced higher average stress due to the use of the D-curve instead of the E-curve. A similar situation appears in Glacier County. Conversely, both Toole and Burke appear to have been adequately represented by the D curve.

In summary, the use of any one dry-down curve will introduce some error. The analysis reported in Section 7.5.3 indicates that the E-normal dry-down curve in conjunction with the old k-coefficients gives as good a representation of ET as can be expected. The error histograms indicate that without specific local knowledge, the probable instantaneous error

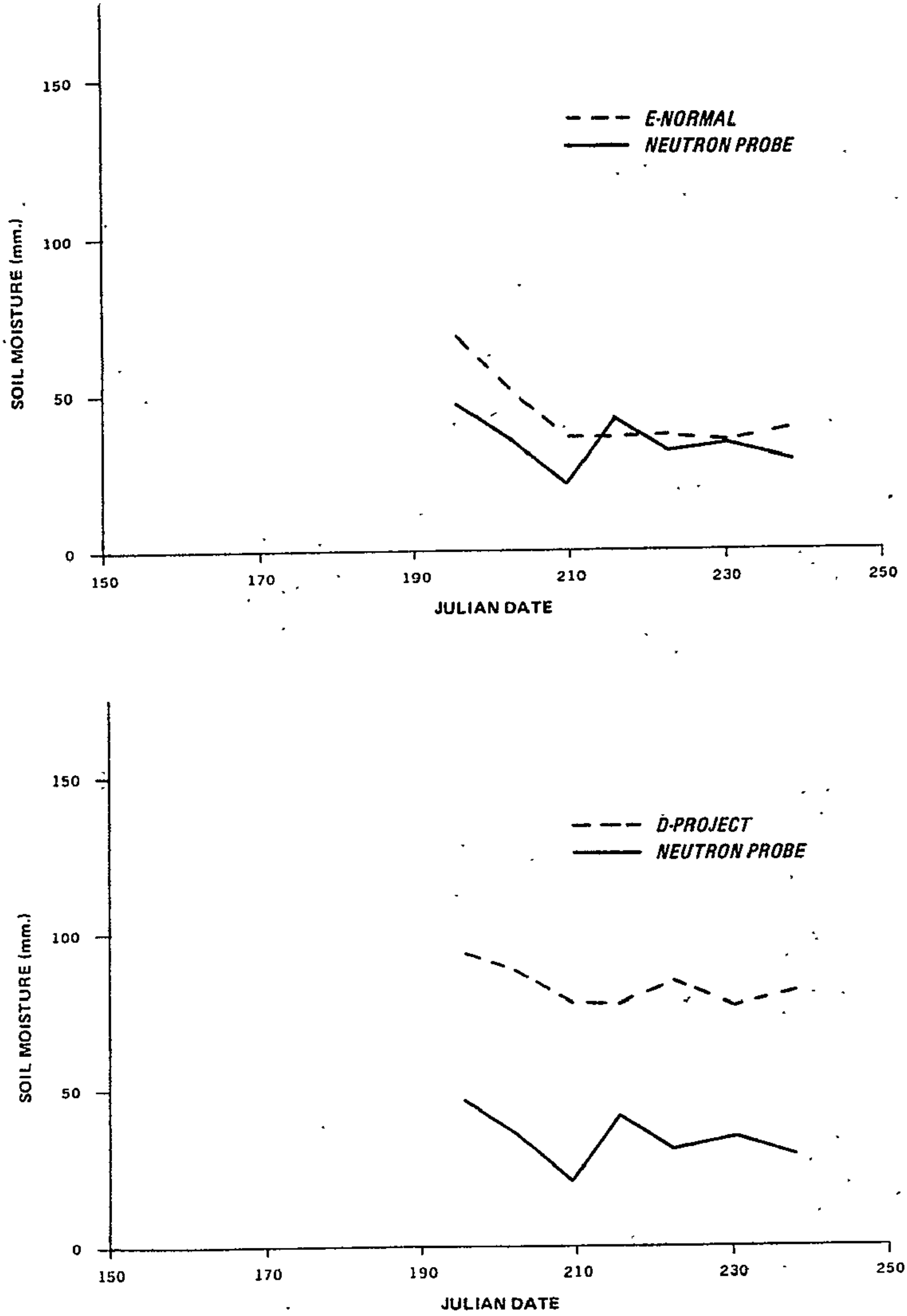


Figure 7-12: Comparison of Neutron-probe readings to soil moisture levels derived from E-normal and D-project curves using project start conditions.

WILLIAMS COUNTY, NORTH DAKOTA
[PROJECT START CONDITIONS]

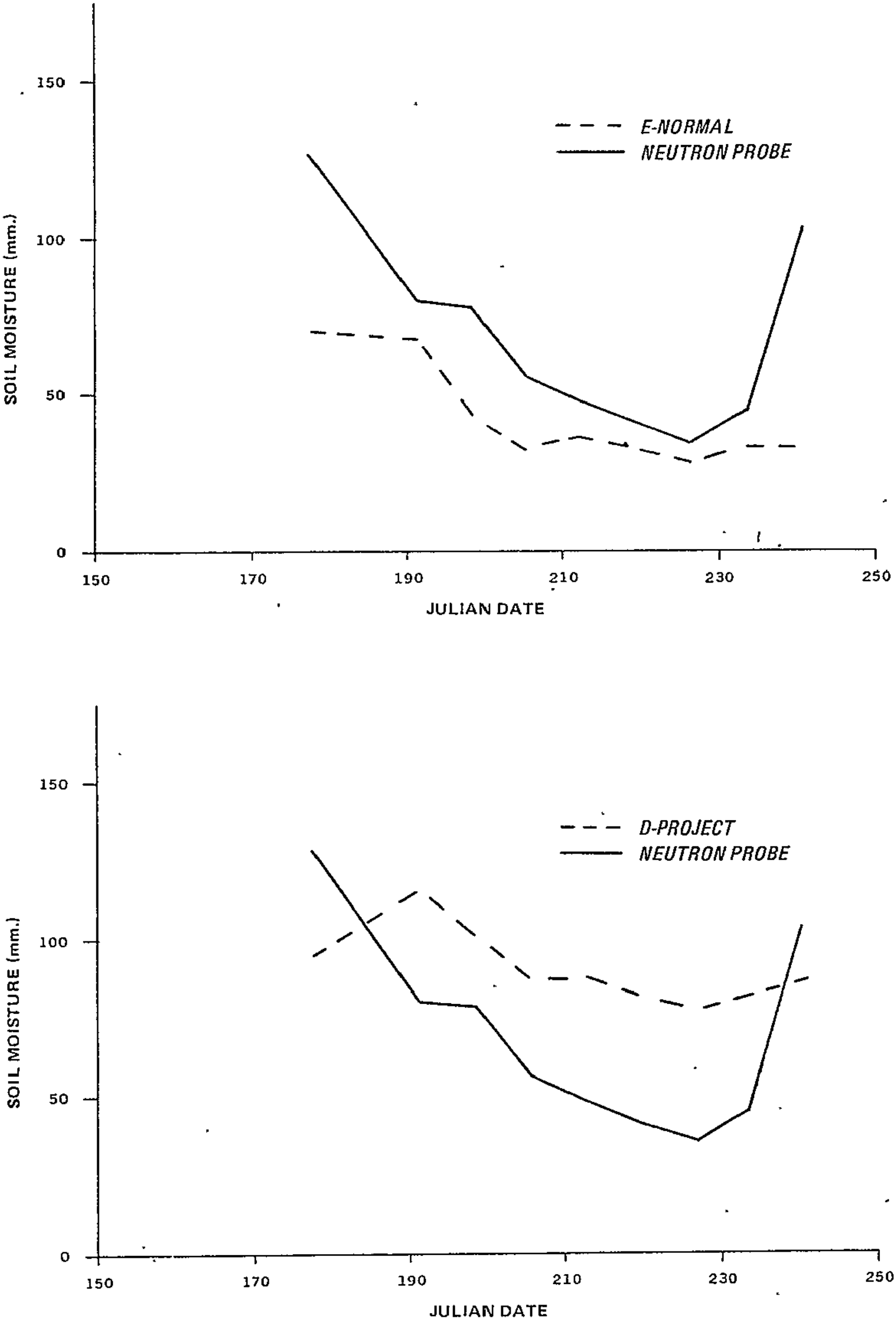
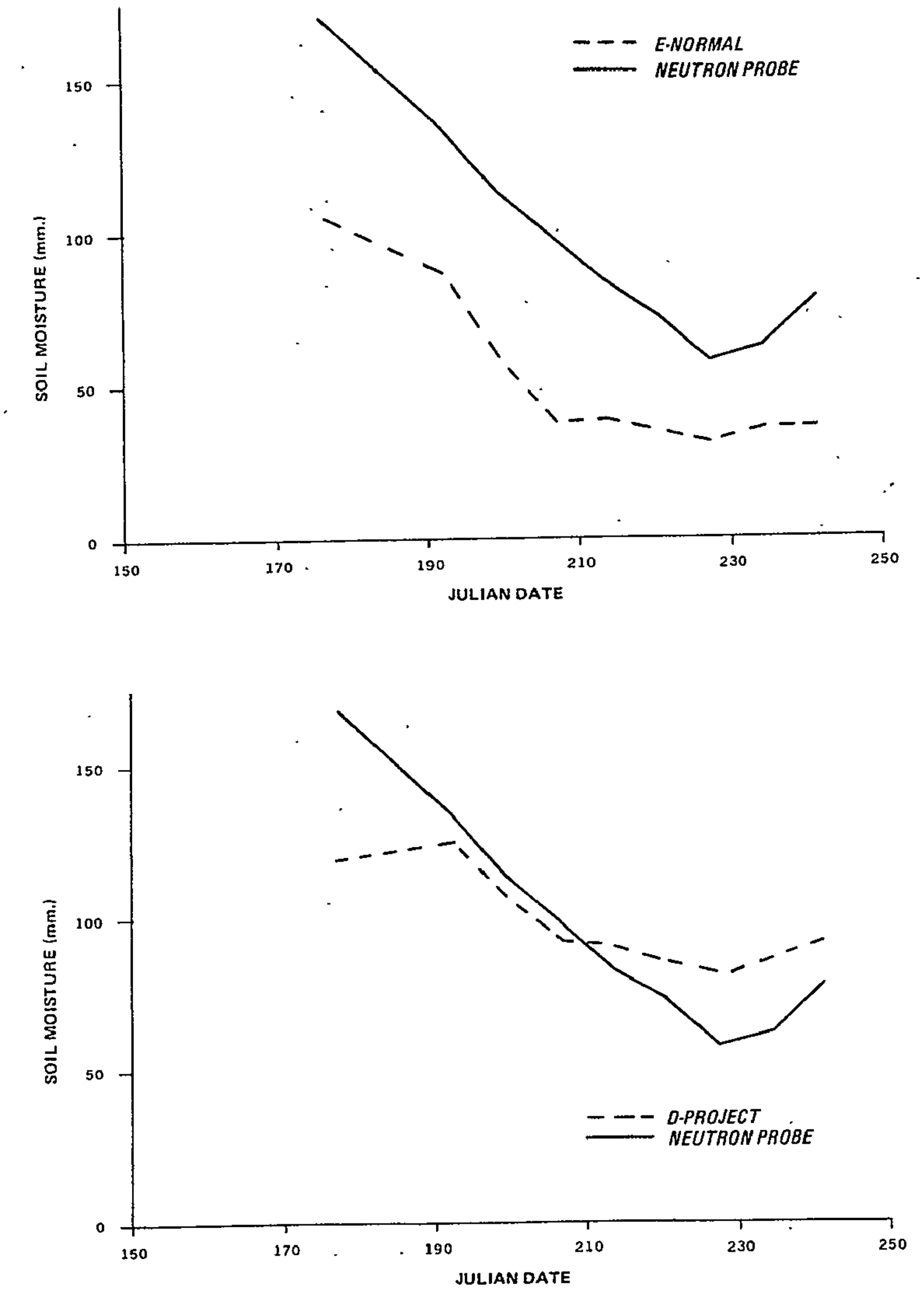


Figure 7-13: Comparison of neutron-probe readings to soil moisture levels derived from E-normal and D-project curves using project start conditions.

GLACIER COUNTY, MONTANA

[PROJECT START CONDITIONS]



TOOLE COUNTY, MONTANA
[PROJECT START CONDITIONS]

Figure 7-14: Comparison of neutron-probe readings to soil moisture levels derived from E-normal and D-project curves using project start conditions.

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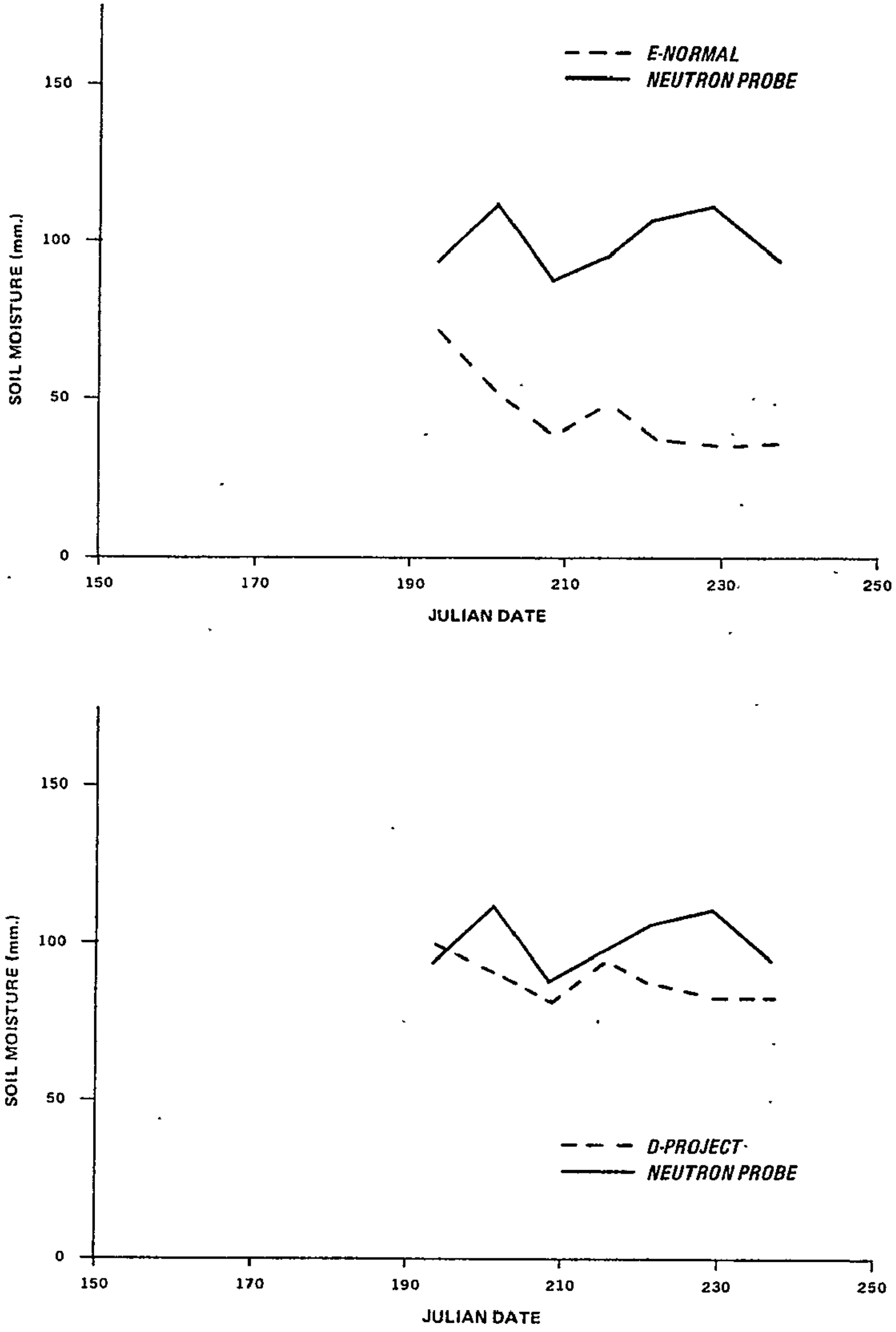

BURKE COUNTY, NORTH DAKOTA
[PROJECT START CONDITIONS]

Figure 7-15: Comparison of neutron-probe readings to soil moisture levels derived from E-normal and D-project curves using project start conditions.

range for estimation of the total profile will be on the order of ± 25mm. The time series graphs indicate that in several cases an error level is reached then maintained, neither increasing nor decreasing. Thus, the impact of the wrong curve selection will be most evident when the soil is in a drying phase. If the moisture drying-filling cycle is repeated over time, the effect on average stress can be significant. Assuming that this cycle happens once, the inherent stability caused by the feedback nature of the ET-SM model clamps the error and reduces the effect on the average stress to the equivalent level of about 2.5 - 3.5 bu/acre for those sites represented by the wrong curve. The aggregate error will be substantially less.

7.6 Start Condition Error Analysis

Since the June 1st start date for model processing was after planting for all Crop Reporting Districts (CRDs) in the study area, the estimation of the start conditions, including both soil moisture and plant growth parameters, was of major importance. As was seen in the discussions on BMT and ET, the model is an additive feedback system. This means that initialization errors will cause offsets which will affect every day thereafter. The BMT model estimates daily change in growth stage based on the stage at the beginning of the day. Hence an initial error will systematically bias the growth stage estimates for the remainder of the season. Similarly, since the yield model used in this project is based on planting-to-ripe average stress, the effects of errors in estimating pre-June

1st moisture stress will vary with the magnitude of the error and the length of time the assumption was made for.

In this project, there were two factors of prime concern. First, the best soil moisture measurements available for the estimation of the June 1st soil moisture profile were the May 3rd Palmer analyses supplied by NOAA. These estimates were applied without change. Second, as of June 1st most of South Dakota was past emergence and three CRDs were at or past jointing (Central, South Central, and South East). Thus, estimates of pre-June 1st moisture stress would carry significant weight in the final yield estimates for these areas. Analysis of the validity of the initialization assumptions is therefore necessary.

The method used was essentially the same as in the ET error analysis. Specifically, fifteen Cooperative Climatologic Weather Stations in the four state area were selected and the four necessary weather parameters extracted (i.e., temperature maximum and minimum, precipitation, and pan evaporation for ETP). While many stations report temperature and precipitation data the determining factor in station selection was the availability of these data and pan evaporation from May 4 or as close to that date as possible. These data were entered into a data base and the Plant Growth Model run on the data beginning on May 4th using May 3rd soil moisture and USDA planting dates. An assumption was made of a type 1 soil (175mm) and E-normal dry-down curve. The last day processed was May 31st and the cell status at the end of that day provided a basis for comparison with the start condition estimates.

A tabular listing of selected results of the comparative runs is shown in Table 7.5. The columns headed "est." show the start condition estimates used in this project. The columns headed "model" list the results derived from the Plant Growth Model run on the co-op stations. The results of the analysis are given on a state by state basis below.

Montana

Four co-op stations from 3 CRDs were processed. BMT comparisons in this state were not available. Examination of the soil moisture estimates showed a maximum error of 12mm or 6.8% of the total profile. This is well within acceptable tolerances and below the expected error resulting from the use of a generalized dry-down curve. More significantly the estimated stress was substantially below measured. The net effect of this error would be to raise planting-to-ripe average stress by about 0.035 based on a 90 day growing season.

North Dakota

Four co-op stations were grown in four crop reporting districts (WC, SE, NW and NE). BMT comparisons were available at Williston and Langdon. The Williston error was insignificant while the Langdon error corresponded to about a 3 day effect. The soil moisture errors remained in the acceptable area, ranging from 20mm in Williston to 2mm at Dickenson. The stress errors for Williston and Dickenson were high, but offset by the fact that the error was made for only two days. Riverdale and Langdon estimates were much

TABLE 7-5

COMPARISONS OF ESTIMATED AND PLANT GROWTH MODEL RESULTS FOR MAY 31, 1975

STATION (CRD)	BMT		SOIL MOISTURE (of a 175mm Profile)		AVG. STRESS		ND
	EST.	MODEL	EST.	MODEL	EST.	MODEL	
Tiber Dam Mt, (NC)	0.70	NA	89.05	77.73	0.30	0.71	7
Ft. Assinniboine, Mt. (NC)	0.70	NA	89.05	97.17	0.30	0.72	7
Ft. Peck, Mt. (NE)	0.82	NA	52.01	53.50	0.30	0.79	9
Huntly, Mt. (C)	0.70	NA	170.81	158.86	0.30	0.52	7
Riverdale, ND (WC)	0.45	NA	175.00	158.18	0.40	0.52	6
Dickenson, ND (SW)	0.09	NA	160.8	158.53	0.40	0.80	2
Williston, ND (NW)	0.09	0.13	131.21	111.80	0.40	0.78	2
Langdon, ND (NE)	0.73	1.07	120.94	105.39	0.40	0.21	9
Redfield, SD (EC)	1.75	1.97	144.84	132.76	0.50	0.53	28
Oral, SD (SW)	1.50	1.27	83.10	78.18	0.50	0.58	18
Lake Sharpe, SD (C)	1.95	2.03	98.00	76.75	0.50	0.86	20
Shadehill Dam, SD (NW)	0.70	1.31	115.69	96.03	0.50	0.77	17
Oake Dam, SD (C)	1.95	1.88	98.00	81.71	0.50	0.57	28
Sioux Falls, SD (SE)	2.05	2.12	109.37	79.72	0.50	0.66	28
Lamberton, MN (SW)	1.81	2.07	175.00	131.86	0.30	0.62	28

closer with the Langdon error causing a net rise of 0.02 in average stress based on a 90 day season.

South Dakota

Because of the advanced growth stage of South Dakota at model start, six stations in five CRDs were examined. Comparative analysis shows basic agreement, with errors corresponding to a day or two at worst. The one exception appears to be in the Shadehill Dam area where the error corresponds to a lag of about 6 or 7 days. The soil moisture follows the pattern seen in Montana and North Dakota. The model profiles tend to be drier than estimated. The bulk of the errors fall in the 10-20mm range. Sioux Falls shows a 30mm drying pattern. Of additional concern, especially because of the growth stage, is the stress comparison. Using the model measurements as "truth" the effects on average stress vary from 0.01 in Redfield, 0.08 at Lake Sharpe, to 0.05 at Sioux Falls.

Minnesota

Only one co-op station met the data requirements in Minnesota, Lamberton in the Southwest CRD. The BMT error was small, about 2 or 3 days. The soil moisture error was more than 40mm, or 25% of capacity. Similarly, the stress estimate was low for this area resulting in an understatement of average stress by about 0.10.

8.0 YIELD FORECASTING EVALUATION

The operational portion of the EarthSat 1975 test was conducted in the period from early June until the end of August. During that testing period, all efforts were directed to setting up and implementing the "System" over the four-state, upper Great Plains test region. Yield forecasts were prepared beginning on 7 June 1975 and were continued at two-week intervals for the entire season. The yield model used in that time had been previously developed for North Dakota. The "future weather" part of the yield forecast was the simplest possible, i.e., persistence where the (average) future is the same as the (average) past. The results of this North Dakota model test and subsequent regional and procedural adjustments will be the subject of evaluations discussed in the following paragraphs of this section.

8.1 Background and General Problem

The basic objectives of the EarthSat "system" approach to yield forecasting are contained in two words; i.e., sensitivity and explicitness. Can we achieve accurate yield forecasts for various geographical regions of the world with minimum regression coefficient adjustments? Can we "explain" and even see, through the use of repetitive remote sensing techniques (i.e., LANDSAT) the manifestation in the plant of our prediction?

The large area regression approach, which has been employed reasonably successfully over the past two or three decades and most recently was used by McQuigg in the NASA/USDA/NOAA Large Area Crop Inventory experiment, has basic limitations that impact achievement of the objectives stated in the previous paragraph:

a. They are fully data dependent in that they represent a sample draw from a unique environment and a constantly changing climate.

b. The relationship between cause and effect are obscure because the large area regression models do not specifically examine physiological interactions between the environment and the plant/soil system.

c. The spatial variations in nutrients, soil water characteristics, etc. are handled implicitly in the historical yield data and as such cannot represent specific variations in these cause and effect factors.

The EarthSat "system" has made a significant breakthrough in the one area that has truly limited the opportunity for weather yield models to examine new approaches. The EarthSat "system" weather diagnosis provides accurate weather data on a grid interval that has heretofore been impossible to obtain. The availability of such data permits an assessment of the environment that drives plant growth and influences yield via its influence of the physiological processes operating in the plant. Net radiation and precipitation data have not been available on a fine grid mesh on a regular six-hour basis over the entire globe. The EarthSat "system" utilizing ground observation and meteorological satellite provides such data potentiality in a very timely, accurate, and economical manner.

8.2 1975 Operational Period Model Evaluation

The 1975 operational period yield estimates were, as previously stated, prepared with a model developed from three counties in North Dakota. Yield, Y, in bushels per acre was given by:

$$Y = -10.05556 + 0.56386 \cdot YR -31.2954(\overline{S})^2 \qquad [8\text{-}1]$$

where $\overline{S}$ is the average daily plant stress from planting to ripe and YR is the year (=75). The simplest possible "weather simulator" was assumed: $\overline{S}$ for the entire season was taken to be exactly the same as the value which had existed from planting to the date from which the yield was being projected.

The use of county yield data has been questioned in the past. In order to test this approach, we have examined the relationships between the county and CRD yields (See Figure 8-1). Here the county-level yields for 1950-72 for three North Dakota counties are plotted with the corresponding calculated crop reporting district yields for the same year. The data are closely distributed about the 1:1 line. Williams county yields tend to be lower than those for its crop reporting district (Northwest). This can be explained by its location in the drier portion of the district. The wide distribution of the selected counties within the state seem to contribute to the generation of a reasonable state-wide regression expression.

The above equation was used to predict yields for each of the 12.5-mile cells. County yields were calculated using the straight numerical average of the N cells assigned to the county:

$$Y_{co} = \frac{1}{N} \sum_{i=1}^{n} \cdot Y_i \qquad [8\text{-}2]$$

Yields at the crop reporting district level and state level were formed by weighted aggregations of the next smaller reporting unit:

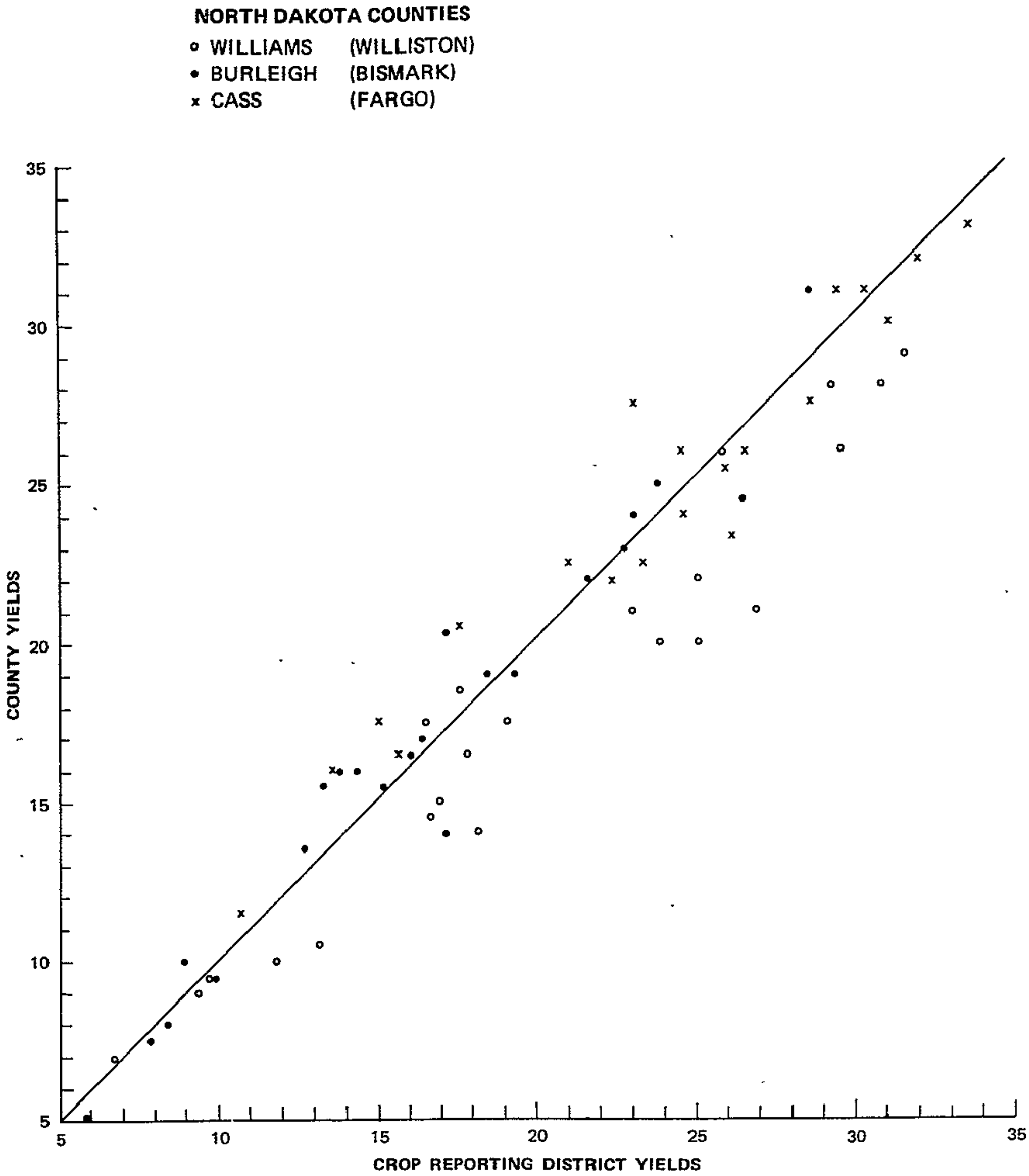

Figure 8-1: Relationship between county-based yield regression data and the crop reporting district yields they produce.

$$Y_{crd} = \sum_{i=1}^{N_{co}} Y_{co_i} \cdot R_{(co/crd)_i} \qquad [8\text{-}3]$$

$$Y_{st} = \sum_{i=1}^{N_{crd}} Y_{crd_i} \cdot R_{(crd/st)_i} \qquad [8\text{-}4]$$

where the R's represent the fraction of planted wheat acreage in the larger aggregate contained in each element of the smaller aggregate. These fractions represent the average of all available data beginning in 1970. (Note that the R's are defined such that

$$\sum_{i=1}^{N} R_i = 1.0.)$$

8.2.1 North Dakota Model Performance

Figure 8-2 illustrates the manner in which the predicted yield varied through the season as a function of prediction date. There was a general rise through June as the very wet weather lowered the average daily stress. The drier conditions of July and August raised the average stress and lowered the yields to near their initial values. Table 8-1 is a summary of the predicted state and crop reporting district yields as of August 16, 1975. Since virtually all cells were ripe by this date, this prediction can be taken as final. Preliminary September 1 yield estimates supplied by USDA showed our yields to be low by about 2.2 bu/a in Minnesota and Montana, and by only 0.5 Bu/a in North Dakota. They were too high by 6.7 Bu/a in South Dakota.

Identification of the factors contributing to the errors fall into two main areas: 1) the trend line, which accounts for non-weather related technological factors, and 2)

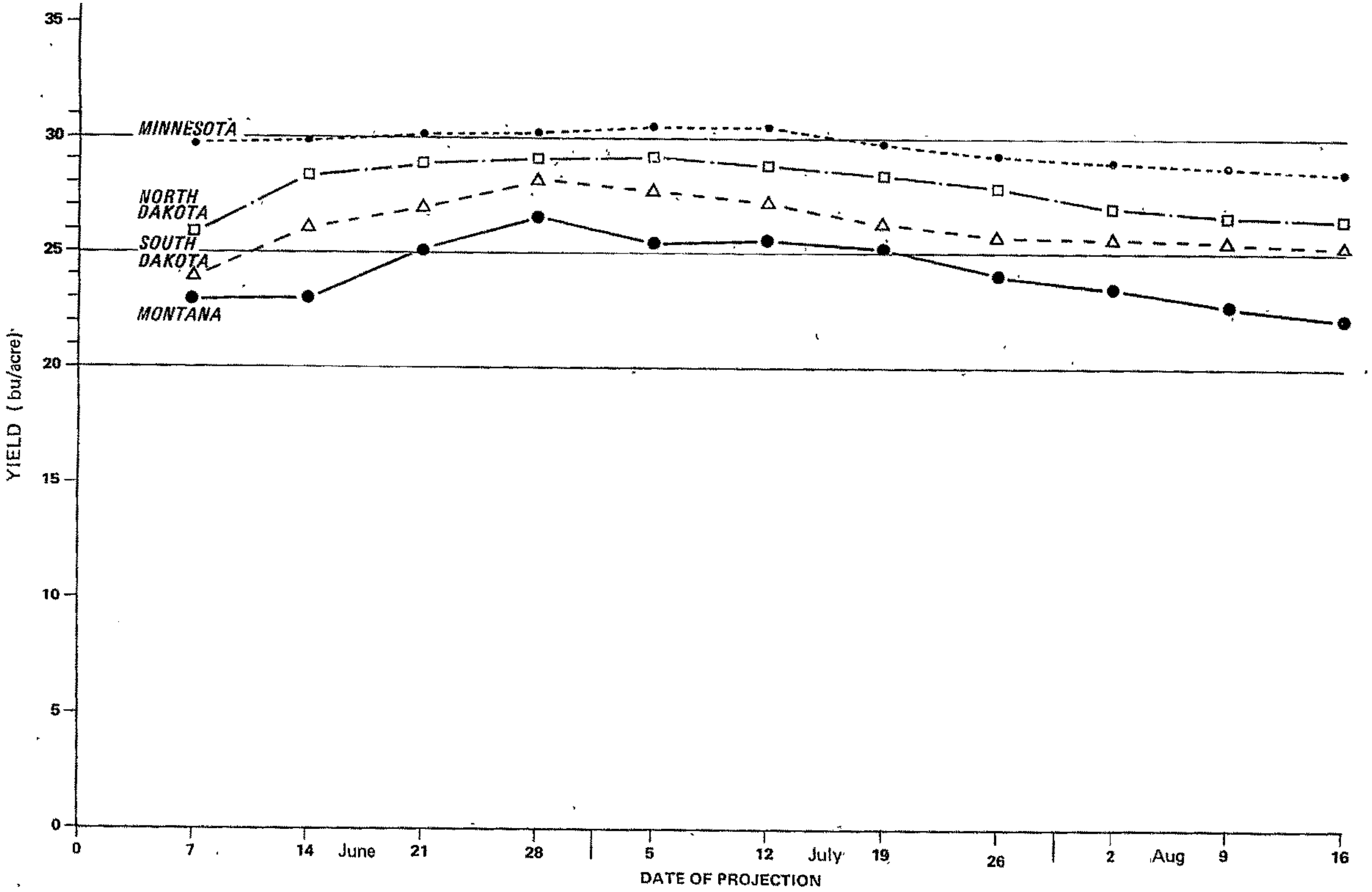

Figure 8-2: Results of simplified yield projections.

TABLE 8-1

EARTH SATELLITE CORP.
ESTIMATED YIELD (BU/A)
STATES & CROP REPORTING DISTRICTS
PROJECTED FROM AUGUST 16, 1975

STATE	CROP REP. DIST.	YIELD
MONTANA		22.80
	NORTH CENTRAL	23.43
	NORTHEAST	22.19
	CENTRAL	25.49
	SOUTH CENTRAL	24.53
	SOUTHEAST	22.83
SOUTH DAKOTA		25.68
	NORTHWEST	24.11
	NORTH CENTRAL	26.45
	NORTHEAST	25.90
	WEST CENTRAL	23.80
	CENTRAL	25.00
	EAST CENTRAL	26.30
	SOUTHWEST	23.70
	SOUTH CENTRAL	25.87
	SOUTHEAST	24.98
NORTH DAKOTA		26.48
	NORTHWEST	24.53
	NORTH CENTRAL	27.03
	NORTHEAST	27.31
	WEST CENTRAL	24.96
	CENTRAL	26.71
	EAST CENTRAL	27.98
	SOUTHWEST	25.33
	SOUTH CENTRAL	26.78
	SOUTHEAST	28.17
MINNESOTA		28.86
	NORTHWEST	28.85
	NORTH CENTRAL	29.24
	WEST CENTRAL	28.91
	CENTRAL	28.74
	SOUTHWEST	28.17
	SOUTH CENTRAL	28.43

the stress effect which accounts for departures from the trend line due to weather. Figure 8-3 presents a plot of North Dakota yield since 1950. The filled circle indicates our estimated 1975 yield, the X indicates USDA's 1 September estimate. It is felt that the most reasonable definition of a technology trend-line should be based on only those years in which yields are highest (i.e., weather has the least influence on technology). Stress then would be used to estimate the decrease in yield due to weather. The solid line in Figure 8-3 is the trend line from our regression equation. It agrees well with the data points, but it is probably rising too steeply in recent years. A more reasonable trend as suggested by Dr. J. McQuigg of NOAA CCEA is shown as a dashed line.

8.2.2 1975 Yield/Stress/Phenology Relationships

Figure 8-4 displays a map of sampled cell yield values. These correspond to cells at a spacing of 50 miles and do not represent aggregations. The general decrease in yield from east to west is a reflection of the rainfall distribution.

Stress presented as a function of phenology (Figure 8-5) generally parallels the overall rainfall distributions, i.e., low stress in the east, higher stress to the west. In this case, the highest stress is found in eastern Montana. The values in Figure 8-5 are stress averaged as a function of phenology. Comparison of the BMT 2-3 (Jointing-Heading) stress pattern with the yields presented in Figure 8-4 suggest a near one-to-one pattern relationship.

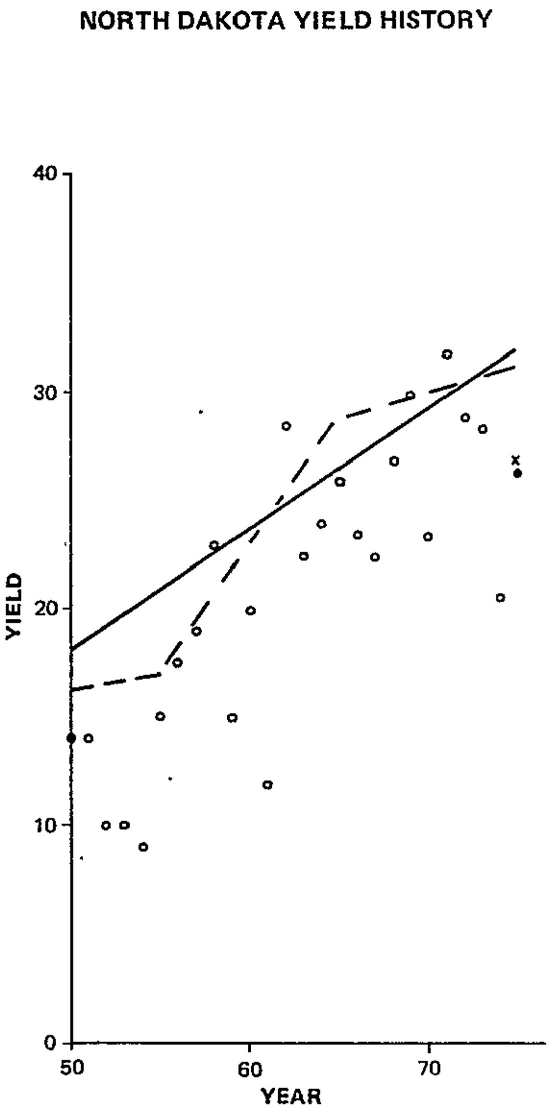

Figure 8-3: North Dakota yield history.

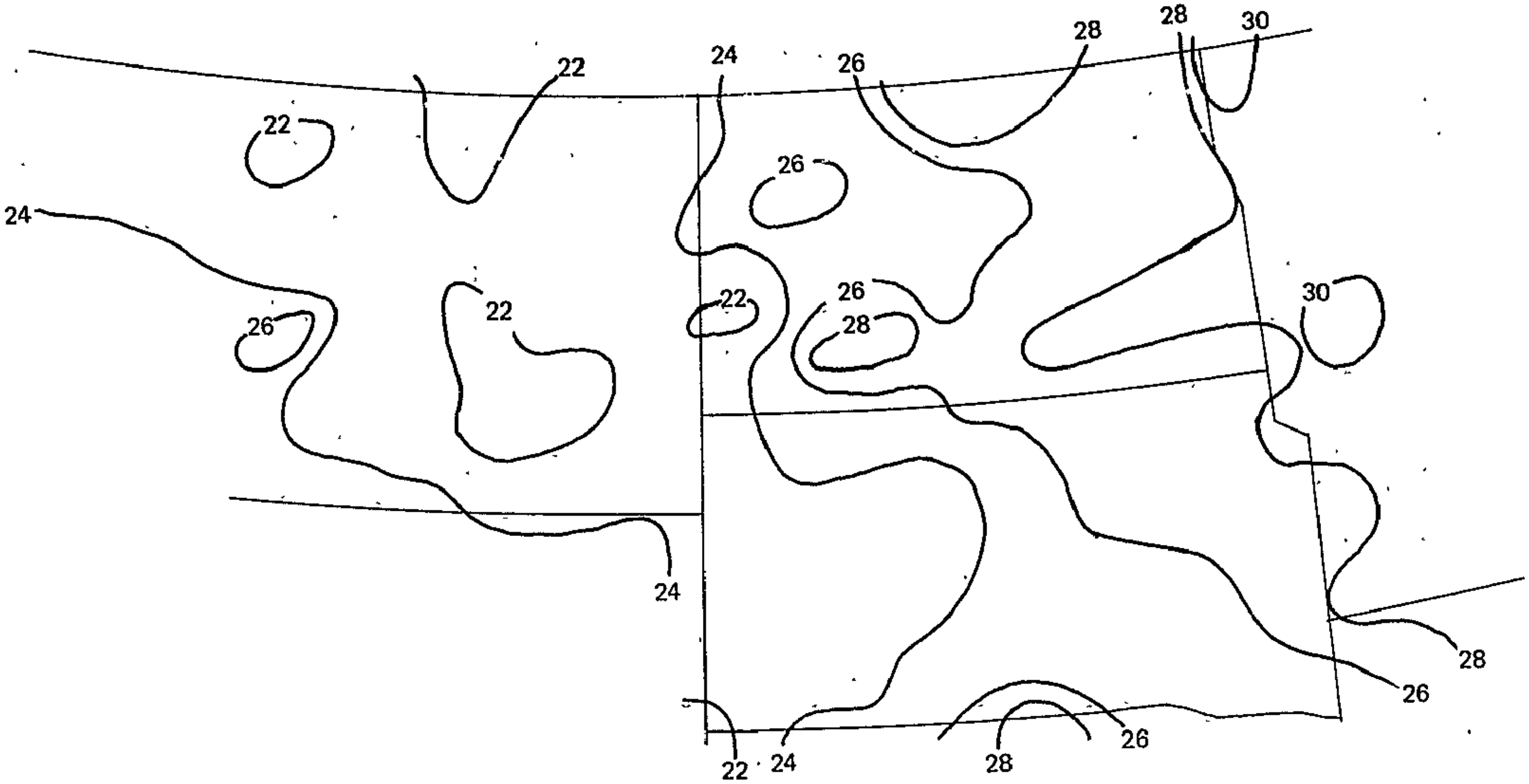

Figure 8-4: Sampled yield map based on projection of 16 August 1975.

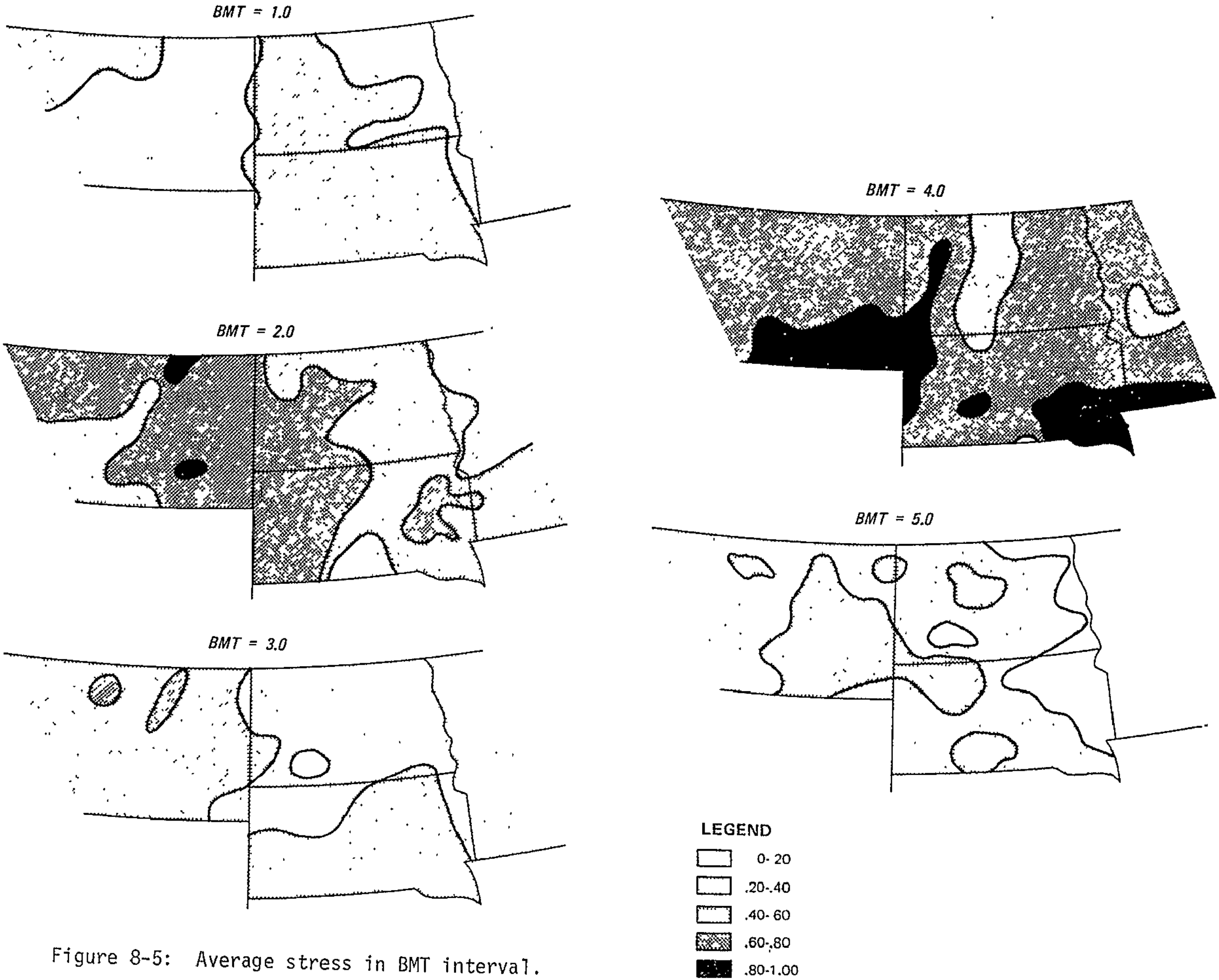

Figure 8-5: Average stress in BMT interval.

8.3 Post-Operational Yield Evaluation

The post-operational yield evaluation phase of the contract has been directed toward evaluation of those factors touched on in the material presented in Section 8.2 drawn from the Mid-Term Report dated October 1975. Specifically, the following items have been emphasized and will be discussed in detail:

a. Yield trend values have been derived for 22 Crop Reporting Districts in the test region.

b. Stress coefficients have been re-evaluated at various locations over the test area using historical first-order weather station data rather than satellite data (i.e., the surface observations provide the cloud data as well as the other conventional observations used in the model).

c. A factor to account for temperature stress effects at a critical growth stage has been evaluated.

d. Correlations of estimated and actual yield have been made to examine the effects of aggregation size on accuracy.

e. Final yield estimates were made at the Crop Reporting District and State levels using a simplified technique in which 61 sample cells were aggregated utilizing acreage weighting functions.

f. Historical yield estimates have been prepared at several locations utilizing first order weather station data.

g. A daily moisture-stress weighted model has been tested over a limited number of locations. This model provides a daily fractional reduction in yield on the basis of daily moisture stress.

h. A Monte Carlo simulation model has been implemented and tested to permit more objective estimation of future weather factors.

The following sections will present a discussion on each of the listed items.

8.3.1 Yield Trend Analyses

The yield trend question discussed briefly in Section 8.2 is critical for this project as well as that of NOAA's CCEA Dr. McQuigg justifiably believes that the "normal weather" trend is leveling its steep upward climb of the recent decade and actually shows evidence of a downward trend in some areas. This possibility is serious for the total world food picture.

The EarthSat yield regression is subtractive by definition, i.e., weather stress is always considered as a detractant from maximum possible yields. Specification of the base for a particular year is thus very important. Simplistically, the upper level base yield for a given non-nutrient limited soil is closely approximated by either experimental farm yields or irrigated field yields. For any given year, however, the limit is defined through a combination of a learning curve for individual farmers and a diffusion curve which represents the rate at which new yield improvement processes are being implemented by the farm community. The basic form of both curves is sigmoid. In the EarthSat "system", the specification of this Technology-Acceptance (T-A) trend must be defined from existing data on yields at both farm level and

CRD aggregated levels in relation to a knowledge of the rate of acceptance of:

- fertilizers
- herbicides
- insecticides
- seed treatment fungicides
- new tillage practices
- new equipment
- new varieties

Review of these data demonstrates clearly that the form of the T-A trend is only manifest in the aggregated data of CRD level when weather stress has no significant yield influence. Thompson, (1975) demonstrates this overall pattern for corn yields in relation to experimental farm yields. In areas like Minnesota, and the eastern portions of North Dakota (the Red River) near T-A trend yields are common, hence the T-A trend is fairly evident. In the drier higher stress areas of South Dakota, western North Dakota, and Montana (non-irrigated), near T-A trend yield values are highly uncommon and therefore the T-A trend is difficult to define. The 1975 Montana yields probably represent the nearest approach in 25 years of CRD yield to the T-A trend value.

Change in the T-A trend line will only occur when either the current technology maximum is approached or significant changes, either positive or negative, in the Technology-Acceptance occurs. A case in point might be when fertilizer costs exceed a cost beneficial level, fertilizer use might decline. Such a decline could well lower the T-A trend limit which would be reflected abruptly as a step function in the T-A trend (we assume that the decrease in fertilizer use is the same at both the experimental and the commercial level).

Weather stress will continue to mask the T-A trend regardless of the climatic changes that may occur. Long term climatic changes will have the influence of decreasing the T-A trend limit through the inability of the technology to achieve genetic level yields under no-stress conditions.

8.3.1.1 General Trends in Yields Over Past 50 Years

Figures 8-6 to 8-9 present historical yield summaries for Montana, North and South Dakota, and Minnesota. Values are plotted as numbers indicating the fraction of planted acreage that was not harvested (i.e., abandonment), rounded to the nearest 10% (0 = no abandonment, 1 = 10%,....., 9 = 90%, X = 100%). Abandonment data were not available for Minnesota. The data appear very noisy due mainly to weather fluctuations, so lines are shown representing five-year running means, plotted at the mid-year of the interval. Several features are common to each curve: 1) markedly low yields in the mid-1930's, 2) yield maxima in the early to mid-1940's, 3) moderately lowered yields in the late 1940's to early 1950's, and 4) a general increase in yields from the mid-1950's through the early 1970's. The first three of these features are clearly associated with cyclical weather patterns,

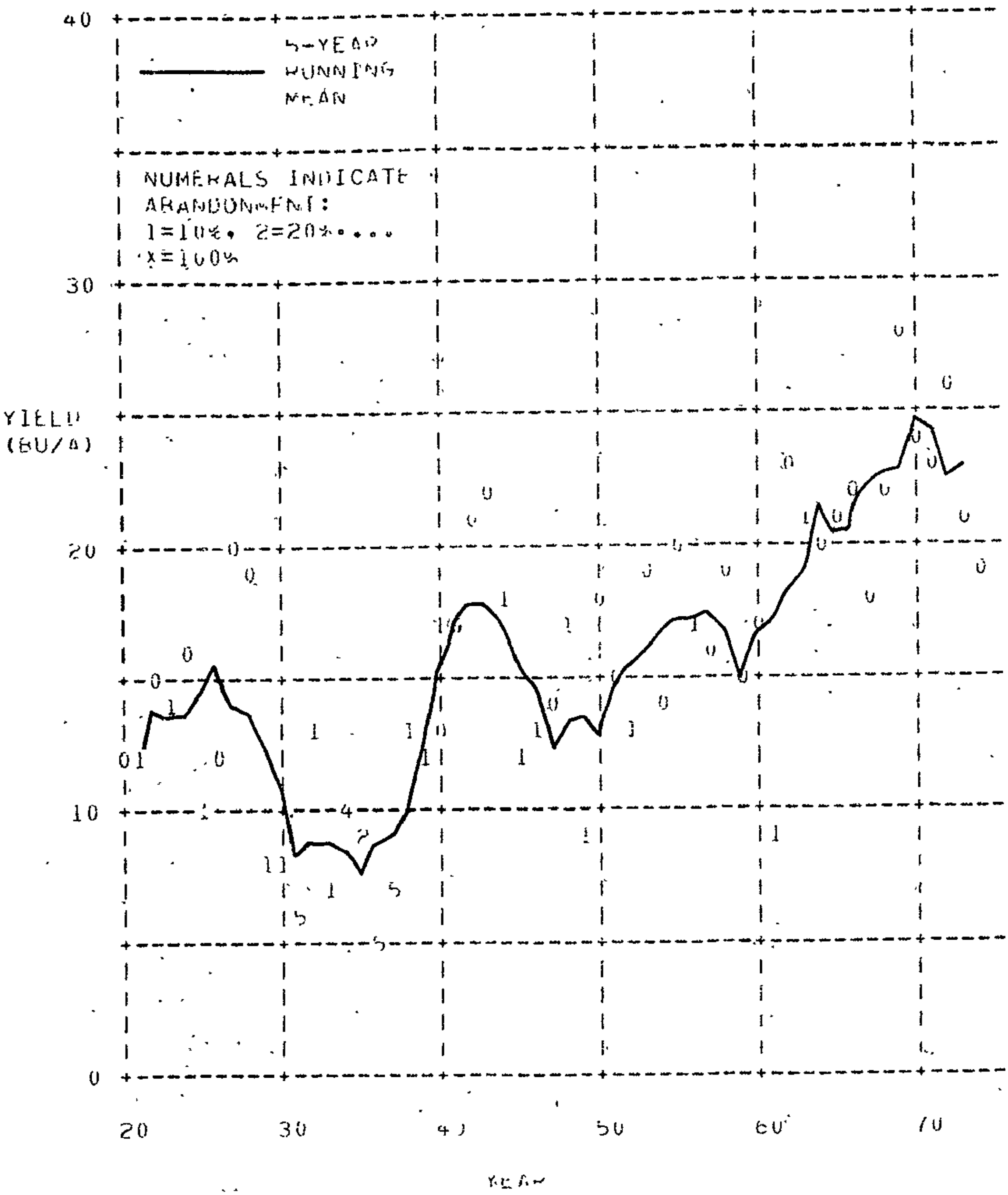

Figure 8-6: Historical yields - Montana.

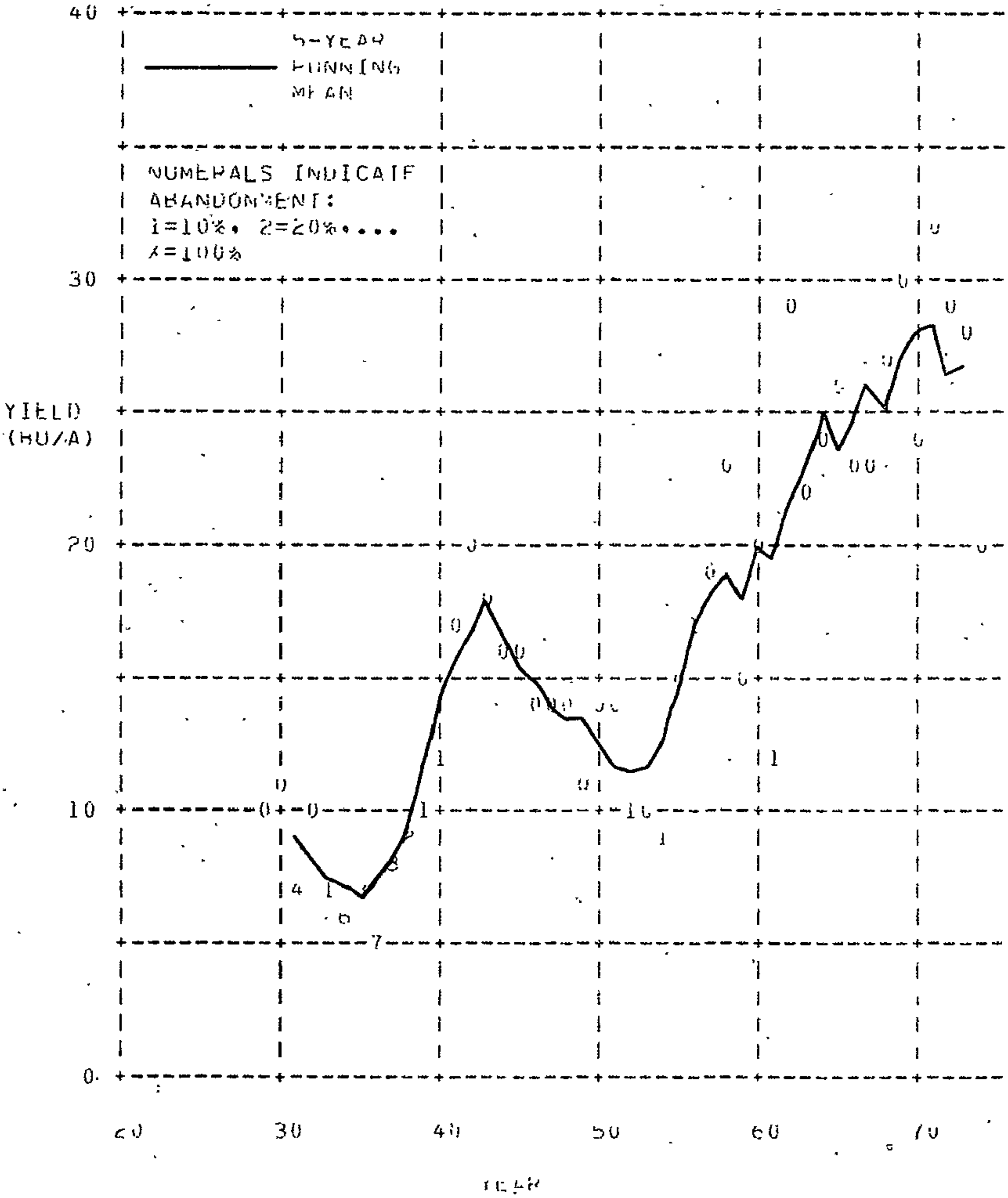

Figure 8-7: Historical yields - North Dakota.

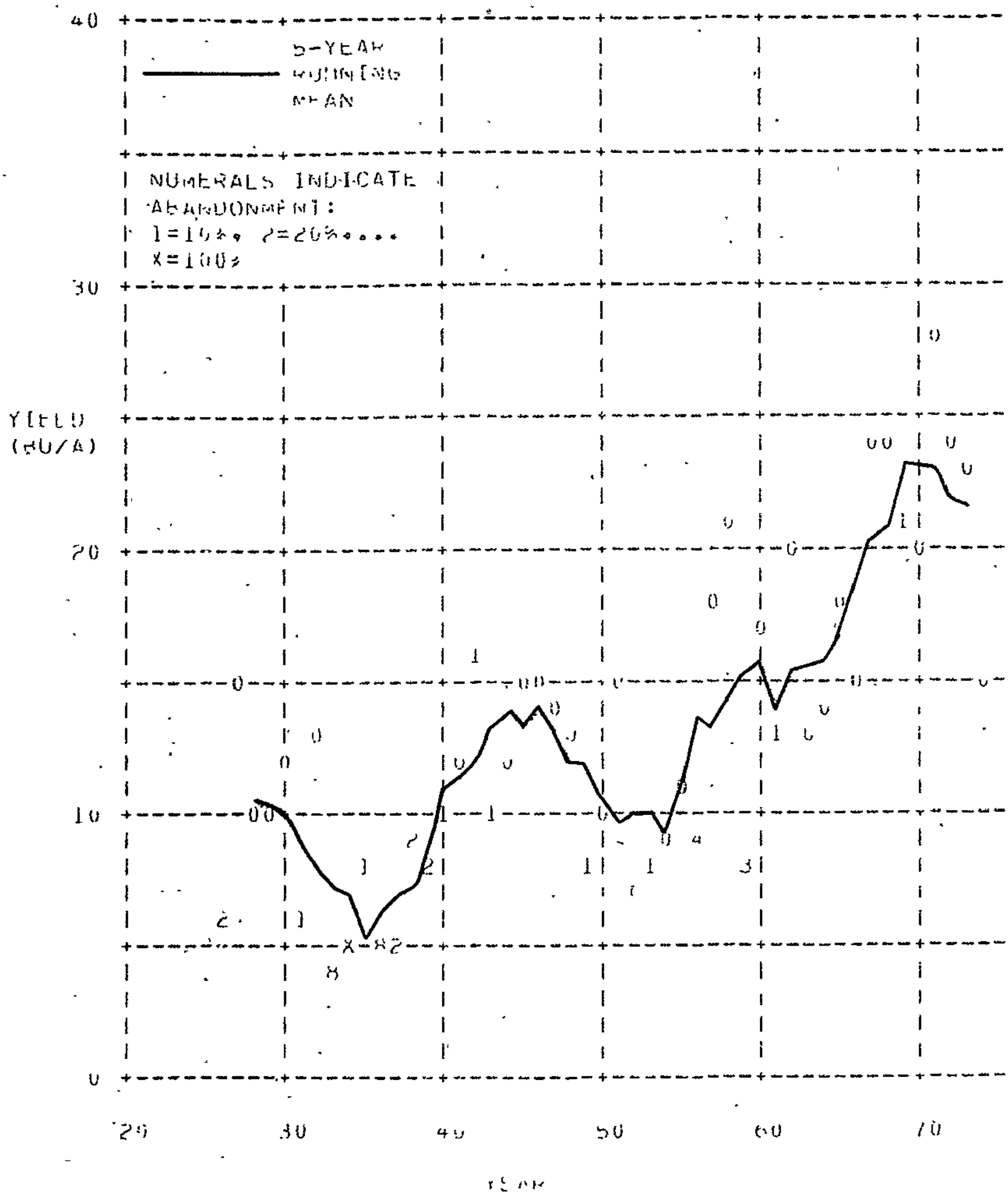

Figure 8-8: Historical yields South Dakota.

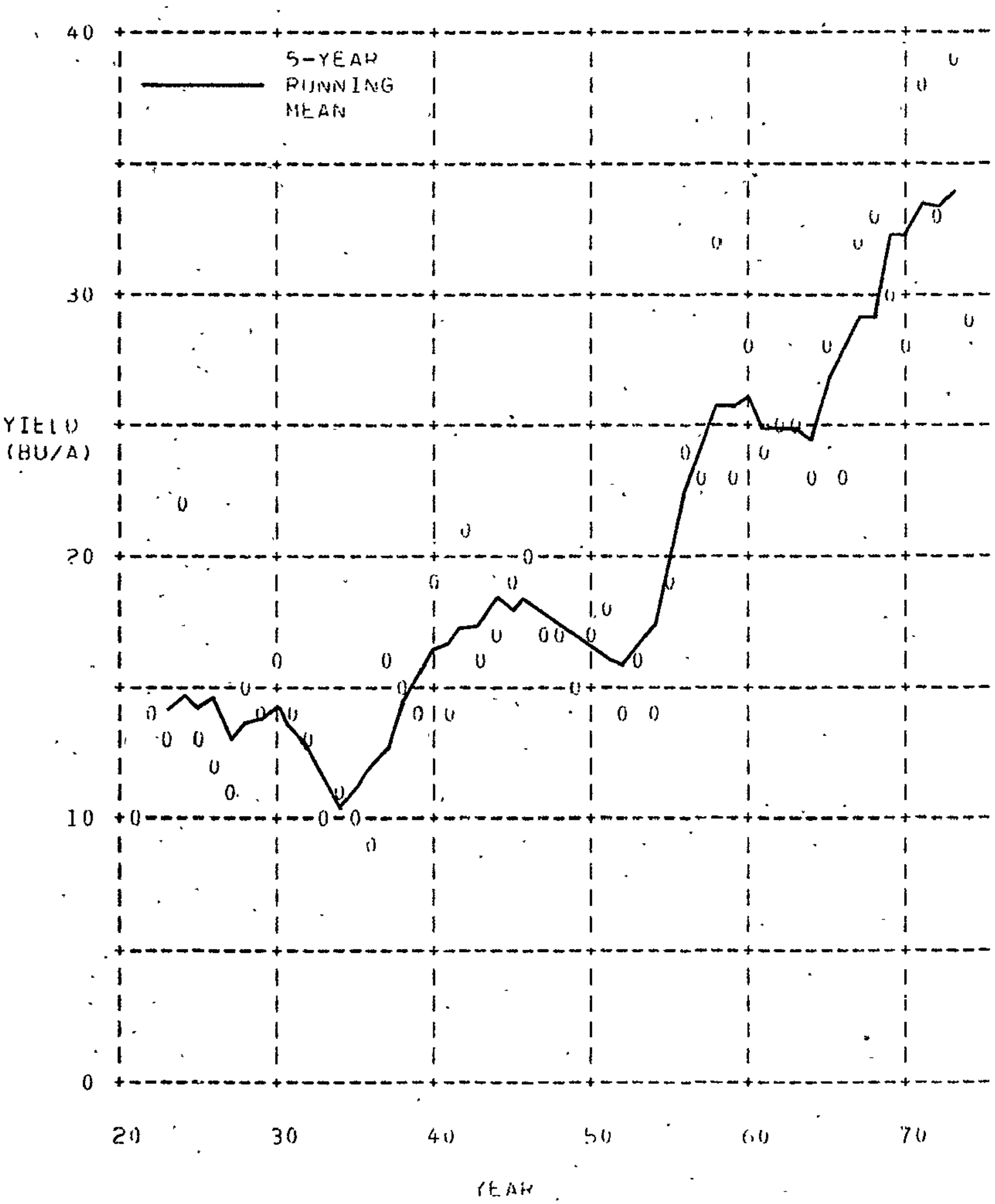

Figure 8-9: Historical yields - Minnesota.

while the latter is mainly due to technological change. The rise has been most rapid in Minnesota, which has the more favorable climate and a higher fraction of quality land. The rise has been slowest in Montana where rainfall is marginal and soils are generally shallower. This merely demonstrates that application of technology boosts yields the most in regions and years of adequate or superior weather, and is much less effective in unfavorable years. Since about 1970, there is a tendency for yields to have leveled-off or even decreased due in part to unfavorable weather, but a significant portion of this may be a reflection of such items as increased acreage or the inflated fertilizer prices discussed earlier.

8.3.1.2 Approach to Trend Line Determination

If all the weather effects could be removed from the historical yield data for a given region, the remaining function could likely be well approximated by a few connected straight line segments. Generally, a constant value would be expected up to the early 1950's, followed by a steady increase, which might be followed by a line of lesser slope in more recent years. Subjective construction of such an approximation is difficult due to the great amount of weather-induced variation in the basic data. Analytic techniques, in which the weather effects are removed through regression, offer the greatest promise and will likely result in solutions which are more geographically consistent. The major problem is that the data sets are relatively small, a slope and starting year are required for each line segment, and several parameters will be needed to adequately model the weather effects. This reduces the degrees of freedom to unacceptable values.

The problem is simplified when it is noted that only the most recent line segment need be defined for extrapolation to the current year. So the approach taken here was to define a single line segment from the most recent year back through as many years as possible without seriously compromising the standard error of prediction of the selected line and the weather parameters.

It is first necessary to define the regions over which the data are to be aggregated. The crop reporting district (CRD) is the obvious choice; the state is too large, containing too many weather regimes and too much variation in agricultural conditions; while the county is subjected too much to local effects such as hail, windstorm damage, local flooding and the like, which cannot be readily reflected in a limited number of weather parameters. Next comes the selection of the weather parameters themselves. This is more difficult since it is desirable to minimize the covariance among the selected parameters, while defining a set which can adequately depict the major effects on yield. Because of the year-to-year variations in planting date and speed of crop development, parameters having too fine a time resolution must be avoided because the growth stage of the plants could differ greatly within the individual time frame, introducing spurious effects on the regression coefficients. Monthly averages of temperature and rainfall departures from normal are readily available at the CRD level. At this time interval, certain types of adverse weather conditions, such as brief, severe heat waves or dry periods extending over parts of two months, will not be properly accounted for, but it is a reasonable compromise between the two extremes. A preliminary analysis showed that the four most useful, relatively independent parameters were:

1. June temperature departure
2. July temperature departure
3. May plus June rainfall departure
4. July rainfall departure

Of course, there will tend to be a negative correlation between temperature and rainfall within a given month, particularly in regions where widespread cloud systems tend to produce the rain. Figure 8-10 is a map of the correlation coefficient for July temperature with rainfall for the period 1954-1974. Only in Montana are the values high enough to be of any concern. These four parameters do not allow modeling of the interactive effect between temperature and rainfall (i.e.,

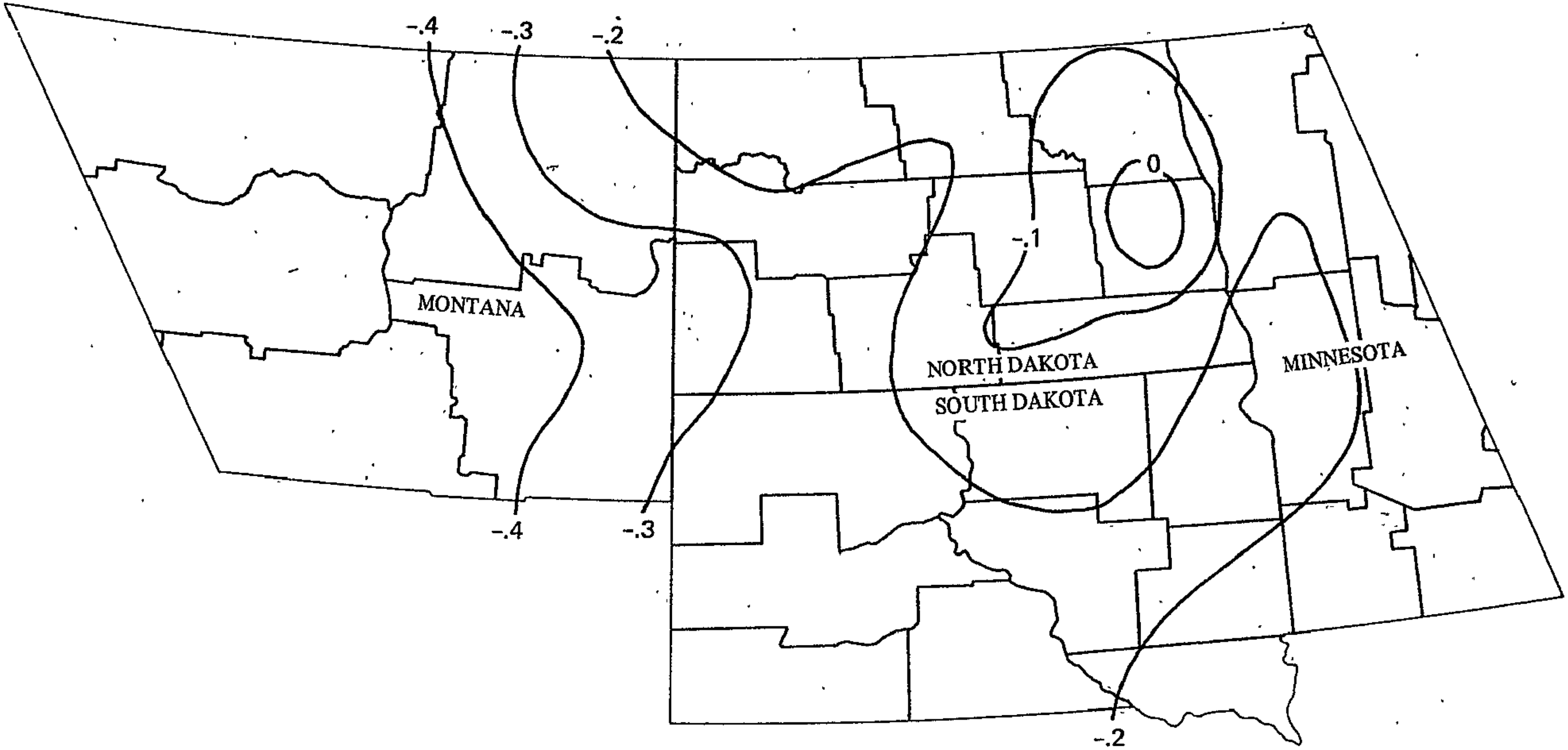

Figure 8-10: Correlation between July temperature departure and July precipitation departure, 1954-1974.

high temperature in concert with low rainfall would produce a greater effect than the simple sum of the two individual effects). Definition of an adequate coupled parameter is not straightforward and, since it would further reduce the degrees of freedom and introduce multicolinear effects, it was not undertaken.

A computer program was devised which performs the following sequence of operations:

1) The major loop begins by including the data set for 1954-1974. On each succeeding pass, the data for the first year is eliminated. The last pass is for the data set 1967-1974.

2) A trend slope optimization loop drives the stepwise regression starting with an initial trend slope value and trend increment. The trend slope value is used to compute a base yield and residual for each year in the data set. The coefficients resulting from the stepwise regression are used to compute a standard error of estimate (SEE). If the SEE is less than that resulting from the previous pass through the loop, then the trend increment is added to the trend slope for the next pass. If SEE is greater than previous, then the trend increment is reduced in magnitude and its sign is

changed before being added to the trend slope. After 25 passes, the coefficients and trend slope corresponding to the minimum SEE (optimum slope) are returned to the major loop.

3) The regression loop performs a basic stepwise regression by screening the variables in turn and selecting the one which gives the greatest reduction in the remaining variance of the dependent variable. One exception is taken, however. Since the regressions are linear, there is no justification for negative coefficients of rainfall or positive coefficients of temperature. If such a coefficient would result from the variable selection criteria, then that variable is passed over.

From a tabulation of the results for each CRD, a subjective choice is made of the best year for the trend line to begin. In most cases, this is a clear-cut choice near the minimum SEE value, where lower values of SEE are achieved only through the loss of several degrees of freedom (i.e., more recent starting year).

It is recognized that possibly very recent effects on trend will not be detected by this approach, but even though intuitive reasons exist to support a recent decrease in trend slope, no statistical significance can be attached to such a small sample.

8.3.1.3 Results of Trend Analysis

The trend analysis discussed above was applied to the 1954-1974 data set for 22 of the 29 CRD's in the region of interest. The starting dates for the selected trend lines varied from 1956 to 1962. The results showed good geographic consistency, not only in the trend line slopes, but in the regression coefficients and standard errors of estimate as well. Figure 8-11 shows the geographic variation of the trend line slope. These are highest in the east where the climate is most favorable and the soils the deepest. Relatively low slopes in much of North Dakota are likely a reflection of the sandier soils with their poorer holding power. The local maximum in southeast Montana is produced by the fertile Yellowstone River valley where most of the wheat is grown.

In 20 of the 22 CRD's analyzed, the most significant of the four weather variables was the July temperature departure. Figure 8-12 shows the distribution of the coefficient for this variable. Only in north central Montana was this variable not among those selected. July temperature and rainfall have their highest correlation here (see Figure 8-10), and once rainfall had been selected, temperature became ineffec-

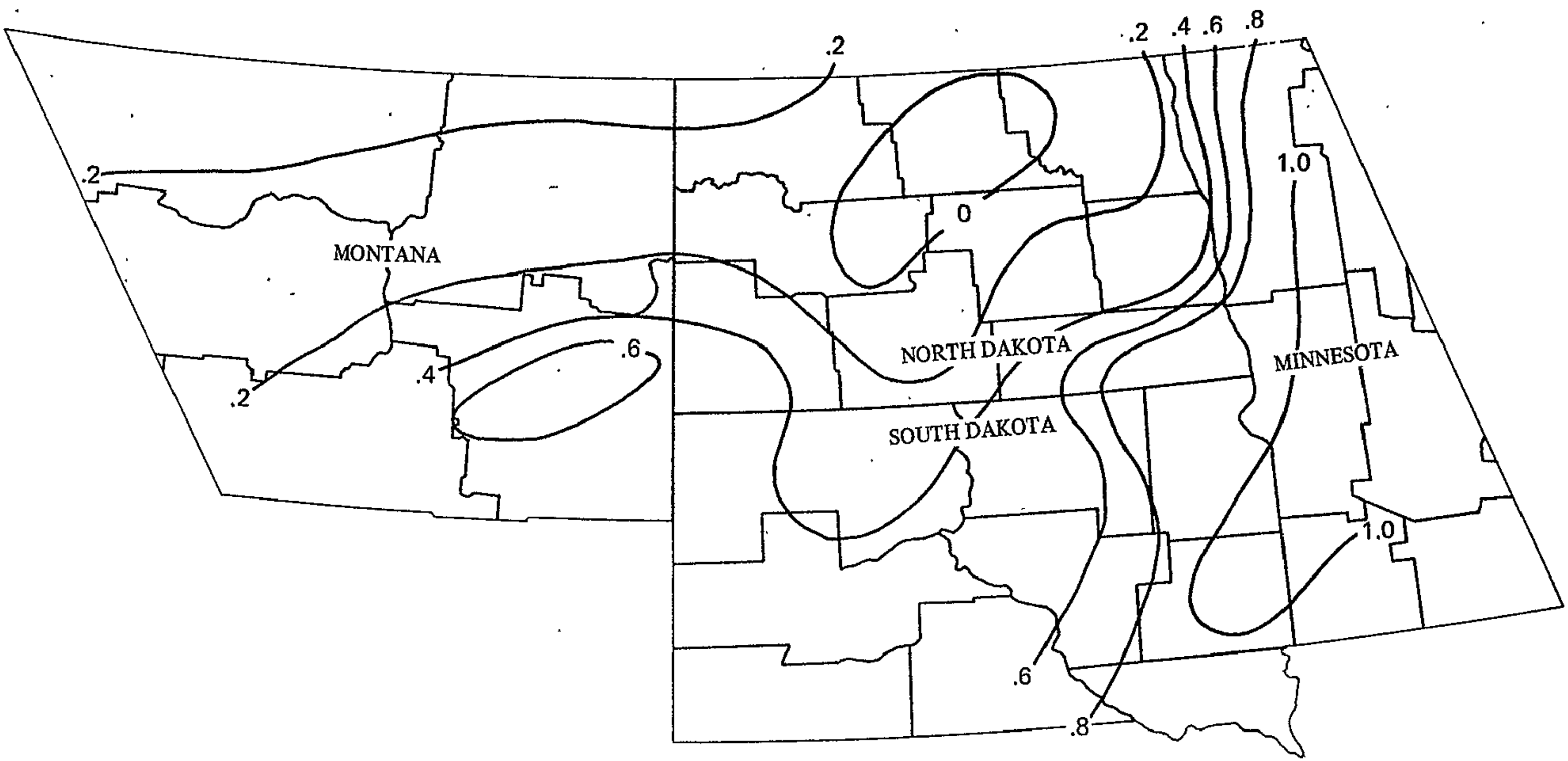

Figure 8-11: Slope of base yield trend line (Bu/acre per year).

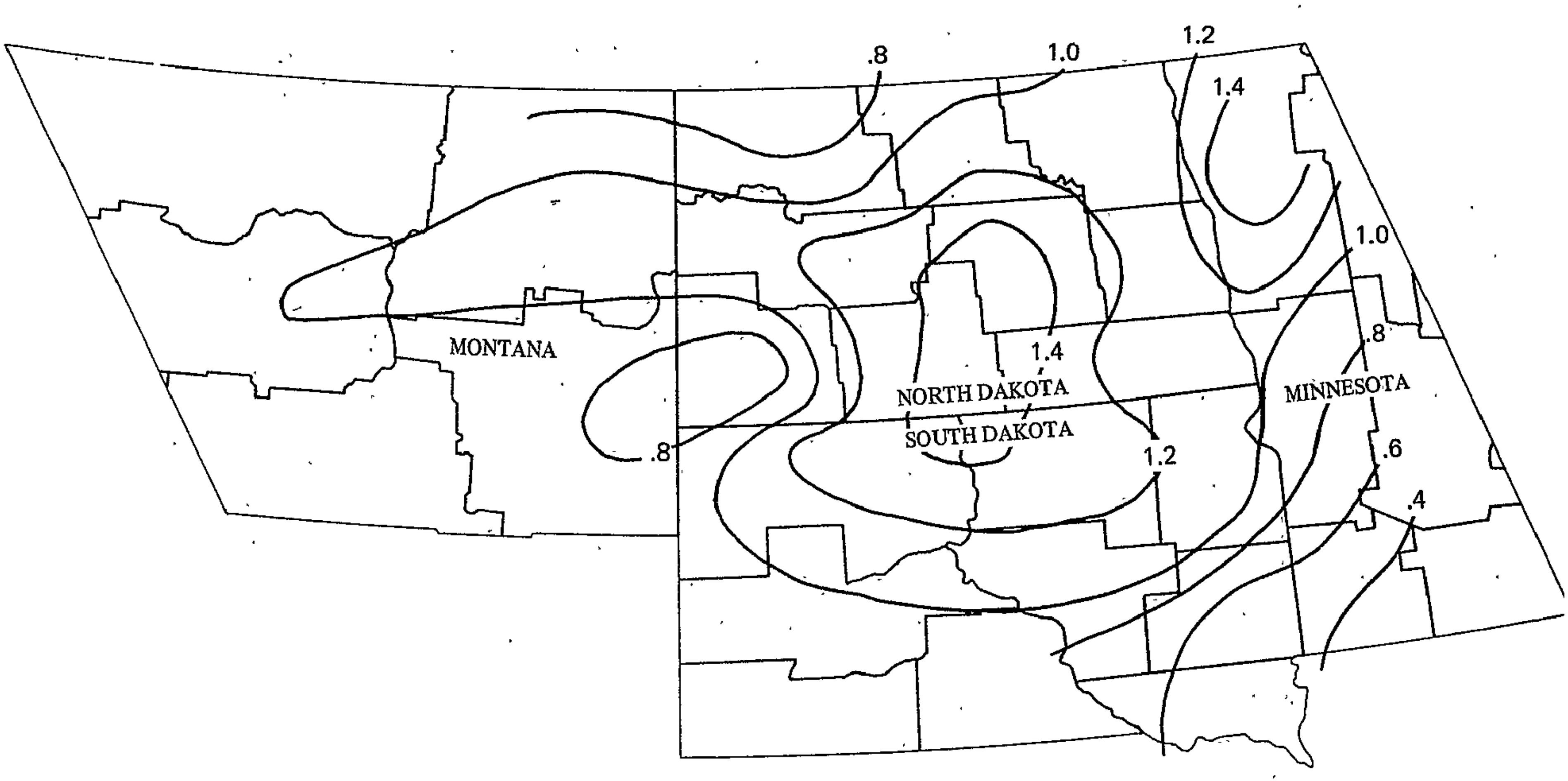

Figure 8-12: Sensitivity of yield to July mean temperature departure from normal (Bu/acre per degree F).

tive in providing additional reduction of variance. Figure 8-13 presents the coefficients for July rainfall departure for those CRD's where that variable was selected. These are confined to the northern portions of the area with a decrease in sensitivity from west to east. Figure 8-14 presents the standard error of estimate for each CRD for which a trend line was determined. The SEE is less than 2.0 bushels per acre over a broad region, rising to as high as 3.5 only in the northwest and southeast.

Since the EarthSat yield model uses a subtractive approach from maximum possible yields, the nominal trend line for each CRD must be raised to more closely represent optimum weather conditions. For a given CRD, the standard deviation of the actual yield values about the nominal trend line was determined. The base (optimum) yield line was then taken to lie above the nominal line by some multiple of the standard deviation. This multiple was subjectively chosen based on the average annual rainfall for the CRD, as indicated in Figure 8-15. The multipliers ranged from 0.5 for the wetter regions to 2.0 for the drier, reflecting the exceptional nature of optimum weather in the drier regions (truly optimum yields do not appear in the data sets for these regions).

Figures 8-16 through 8-37 present the historical yields for each of the 22 analyzed CRD's. The

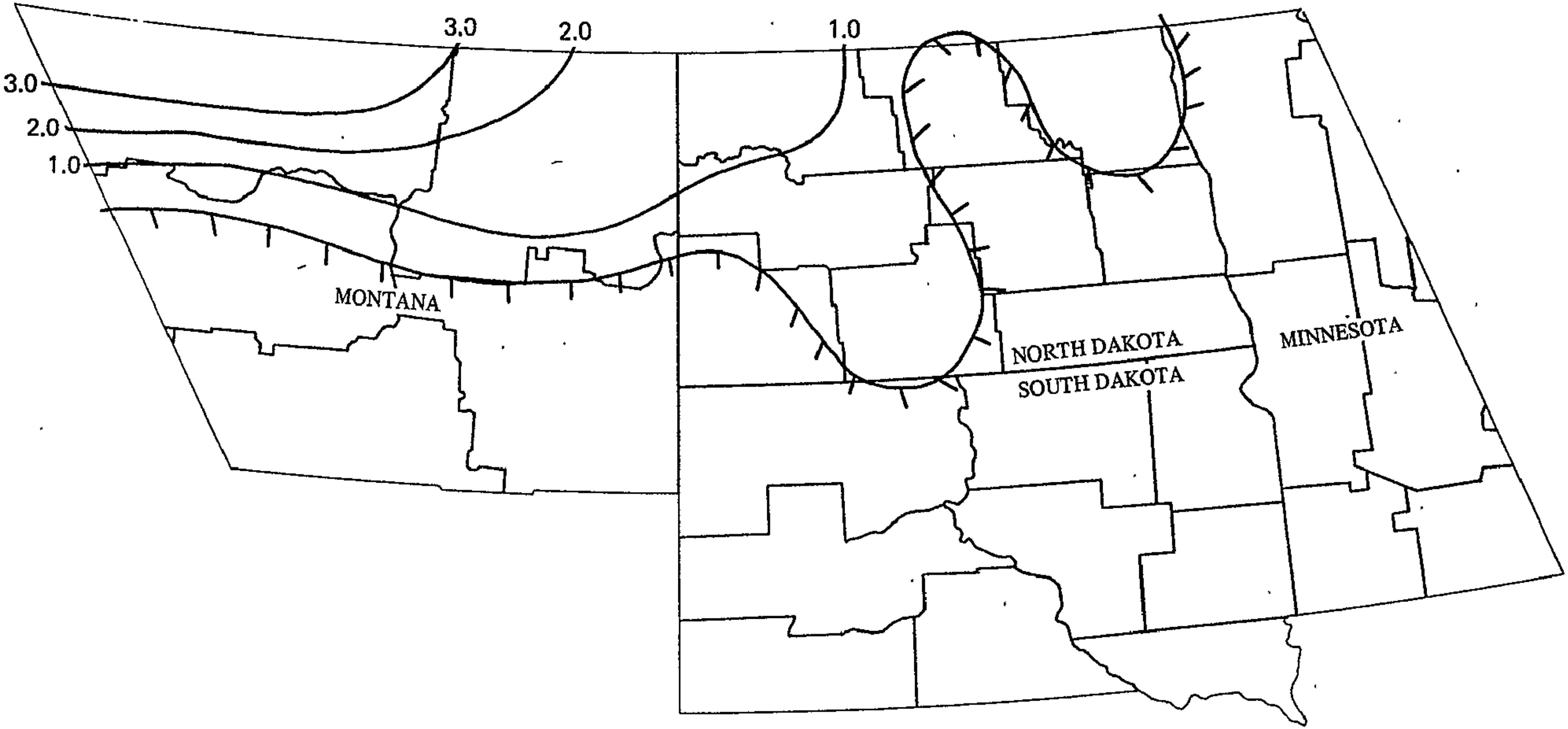

Figure 8-13: Sensitivity of yield to July precipitation departure from normal (Bu/acre per inch).

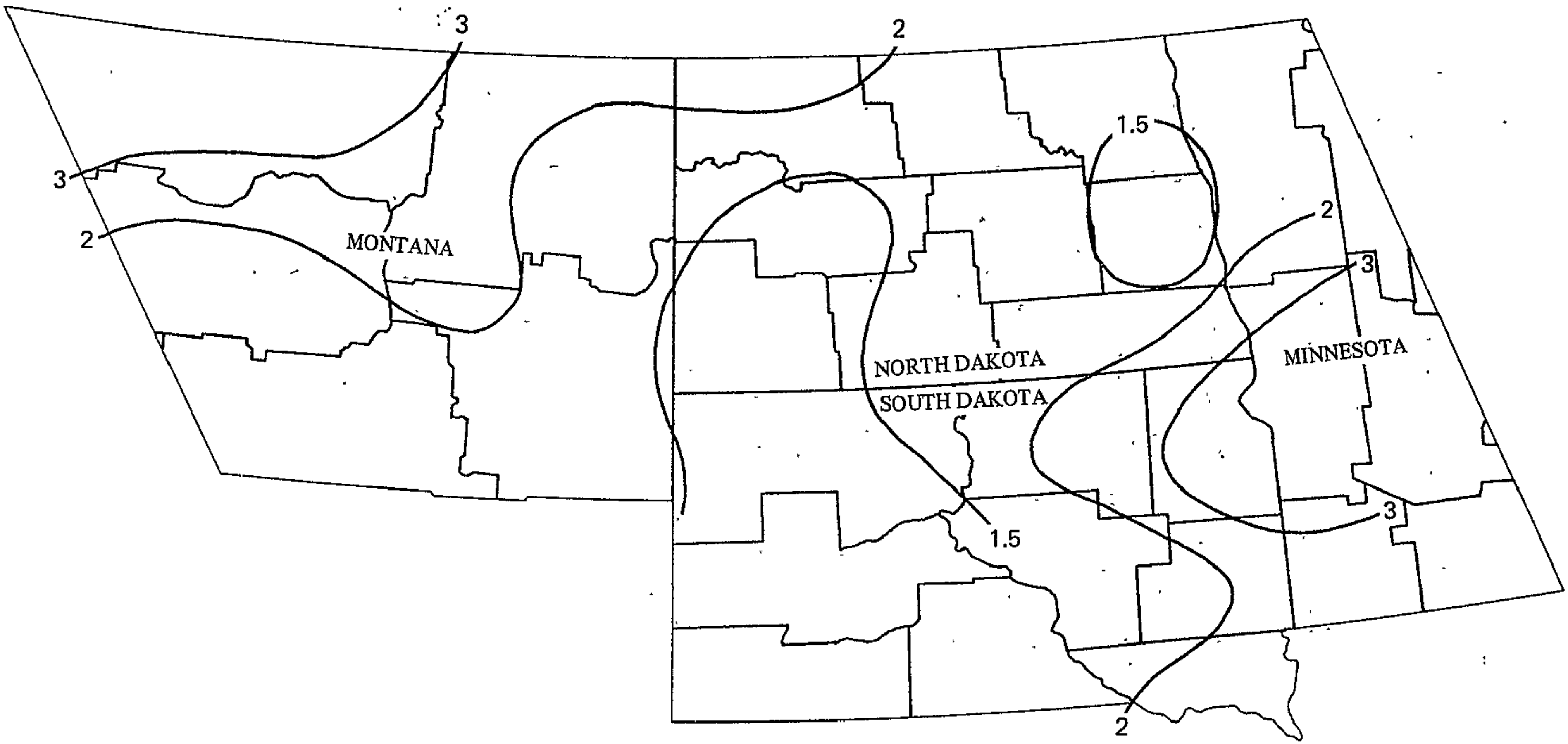

Figure 8-14: Standard error of estimate in yield using optimized trend line with monthly weather parameters (Bu/acre).

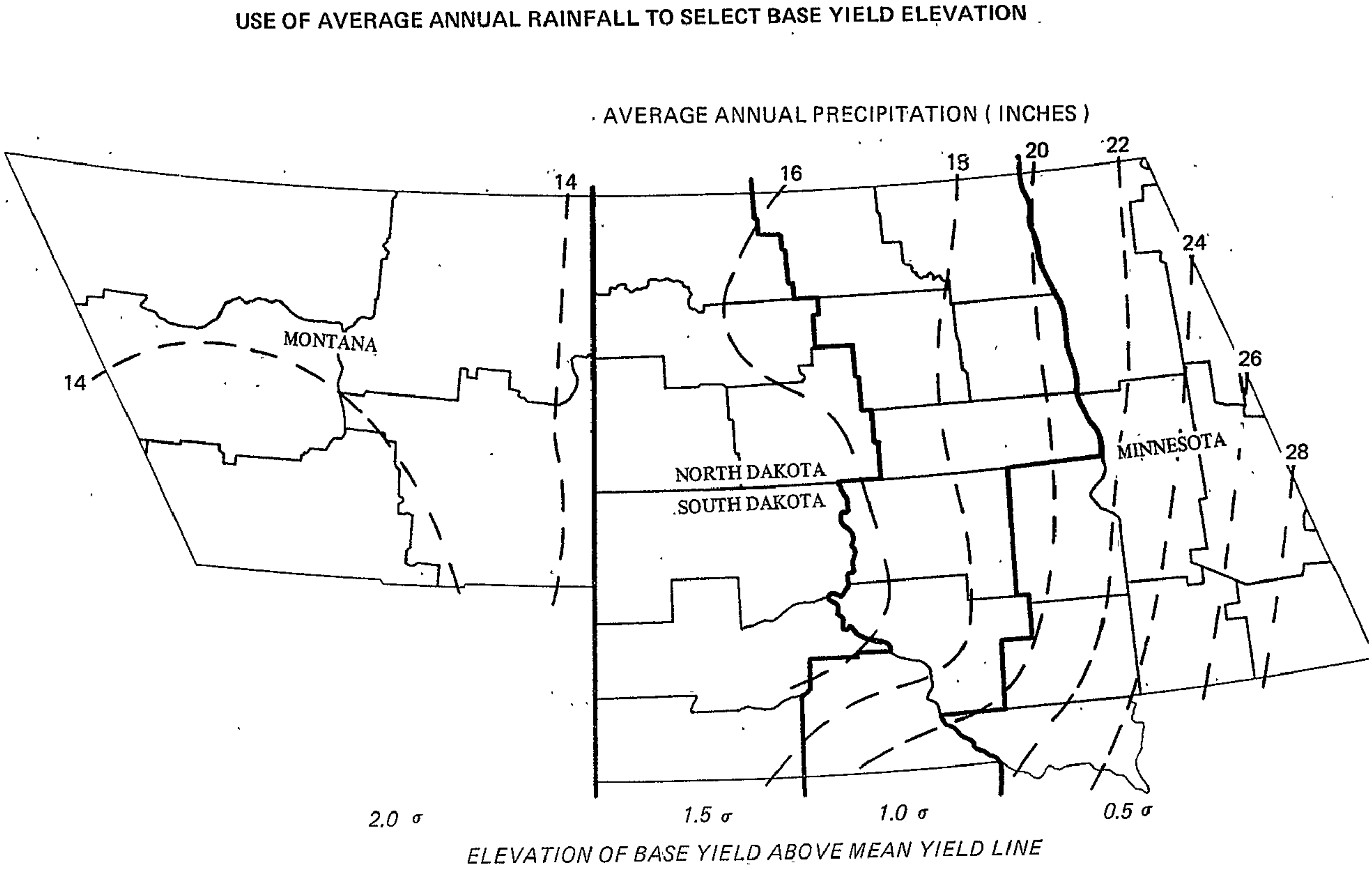

Figure 8-15: Use of average annual rainfall to select base yield elevation.

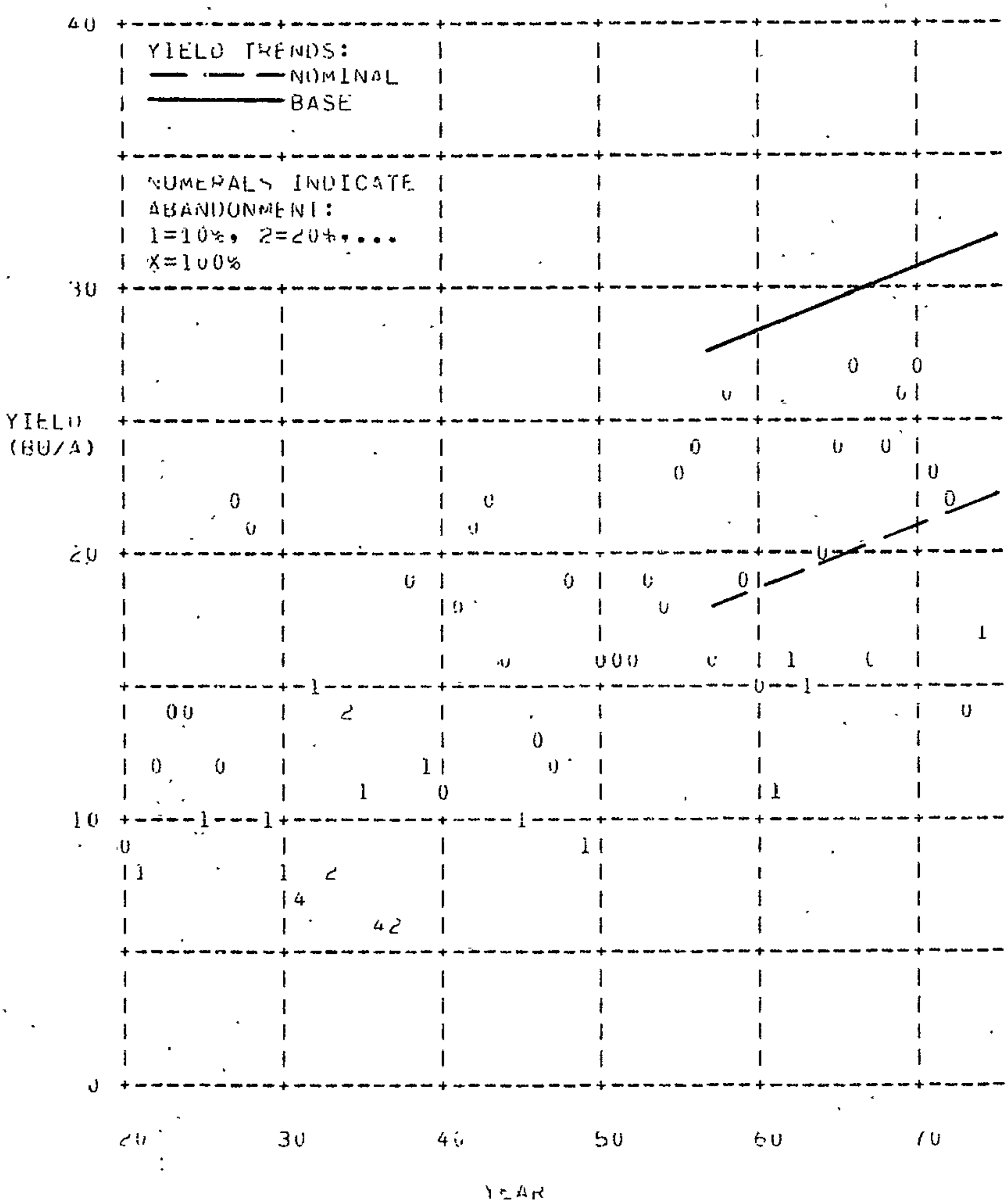

Figure 8-16: Yield history for north central Montana.

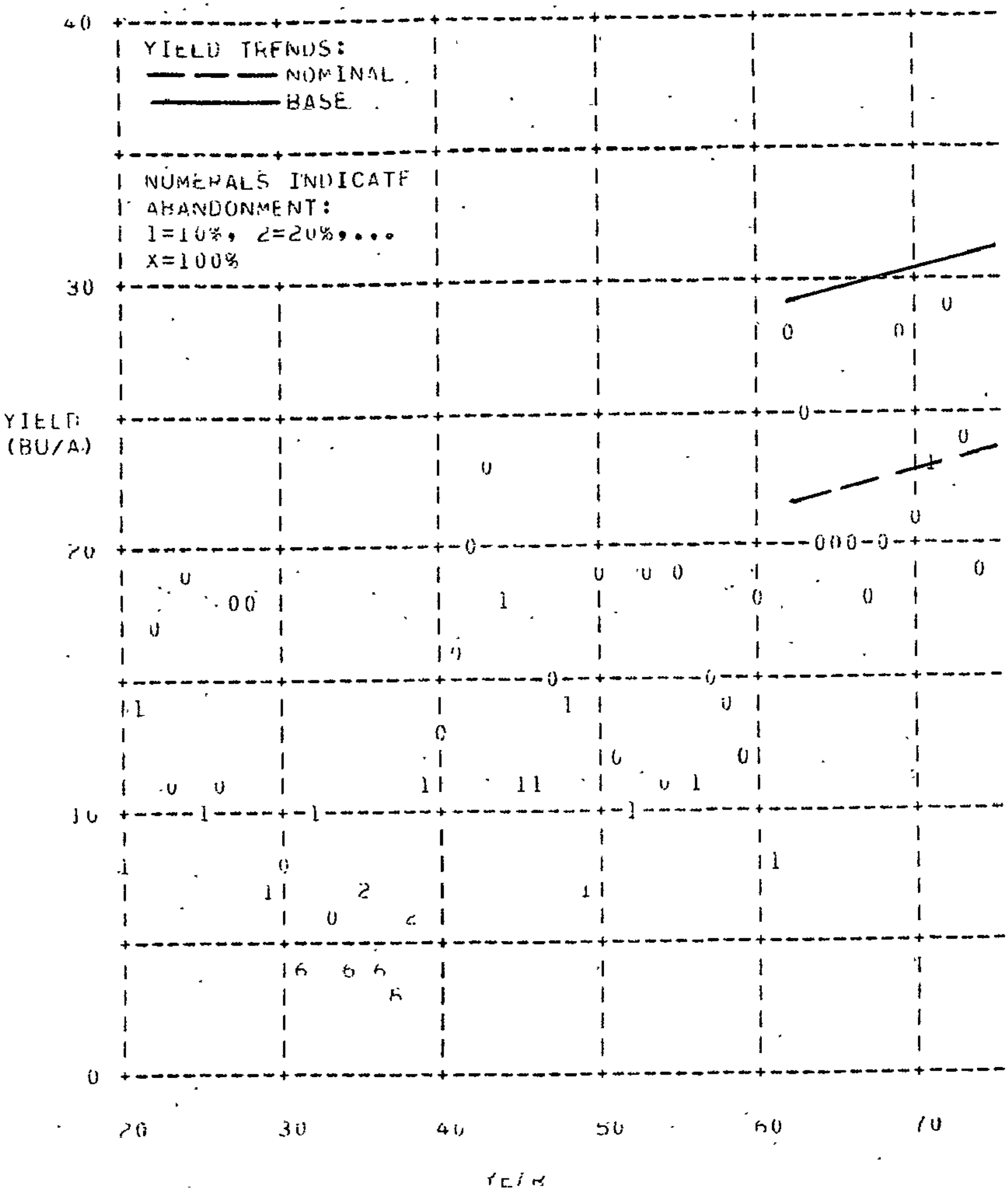

Figure 8-17: Yield history for northeast Montana.

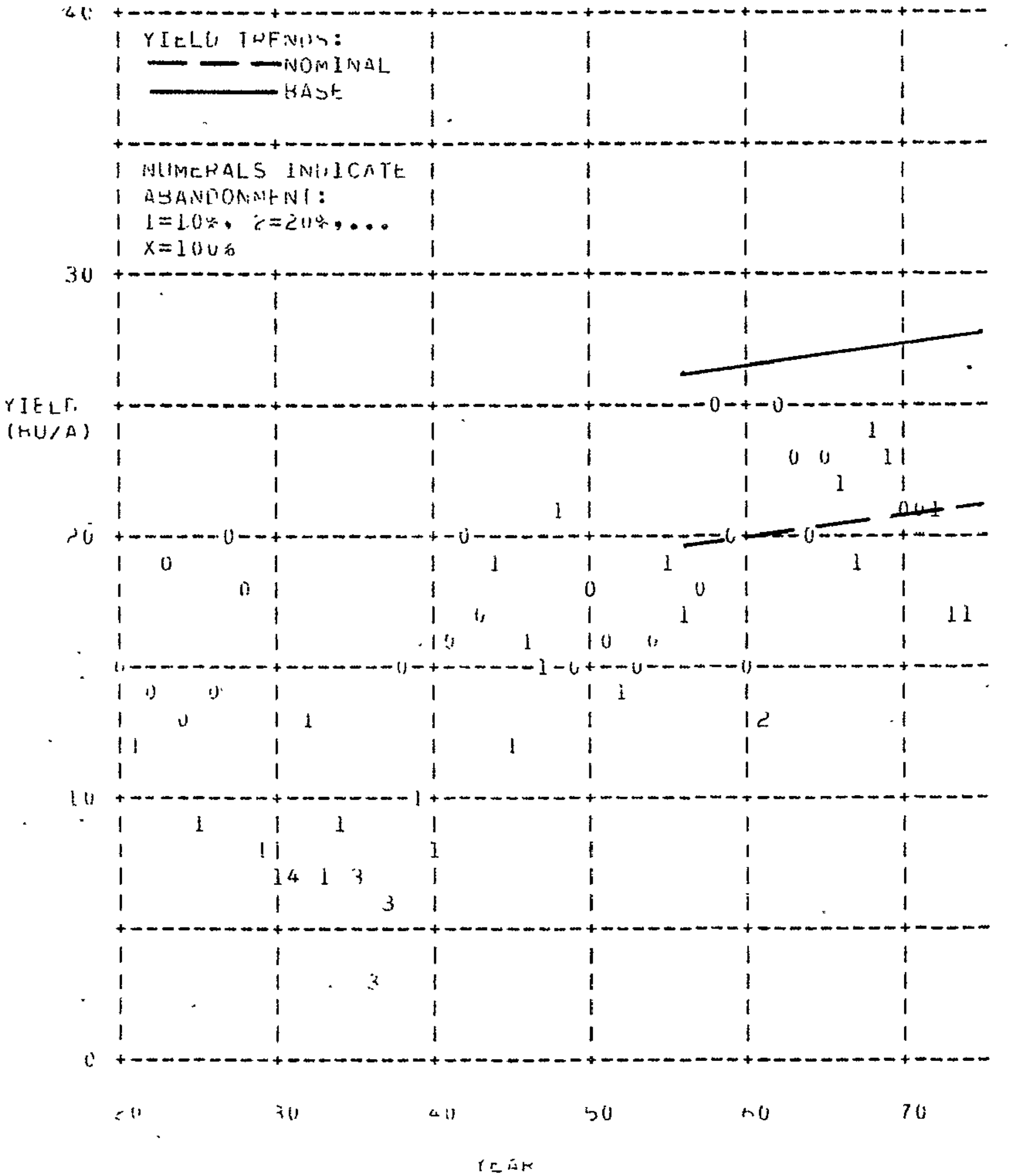

Figure 8-18: Yield history for central Montana.

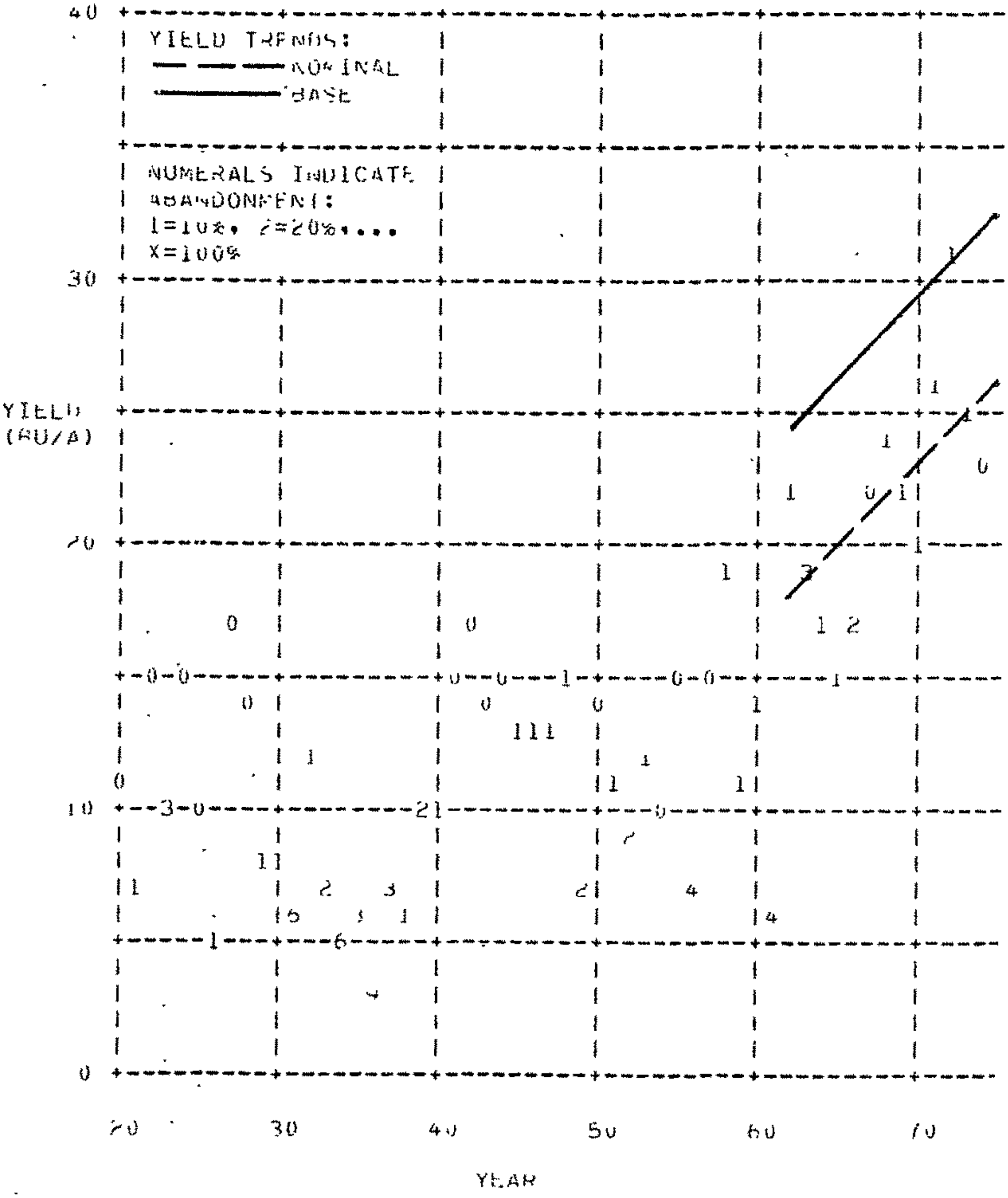

Figure 8-19: Yield history for southeast Montana.

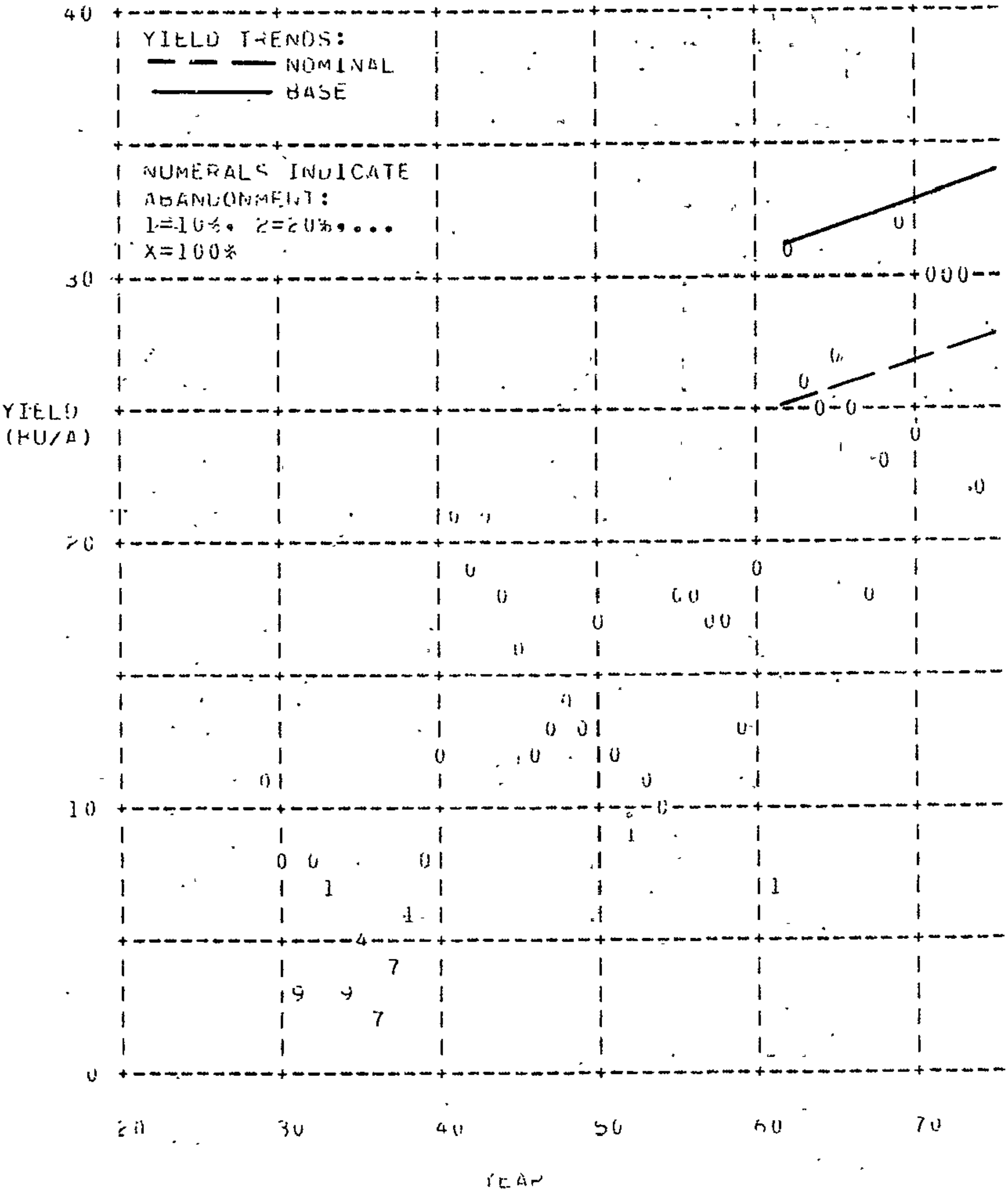

Figure 8-20: Yield history for northwest North Dakota.

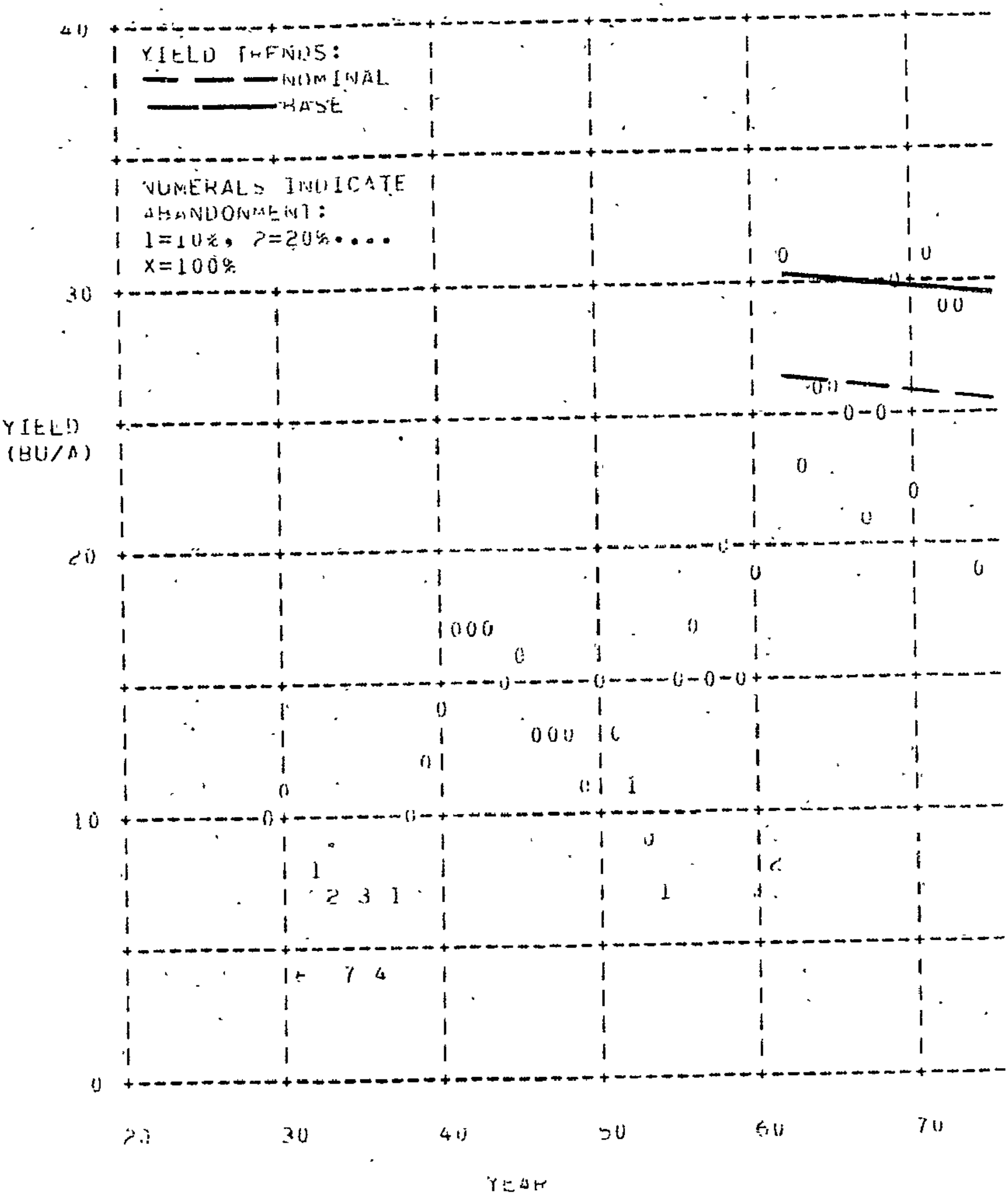

Figure 8-21: Yield history for north central North Dakota.

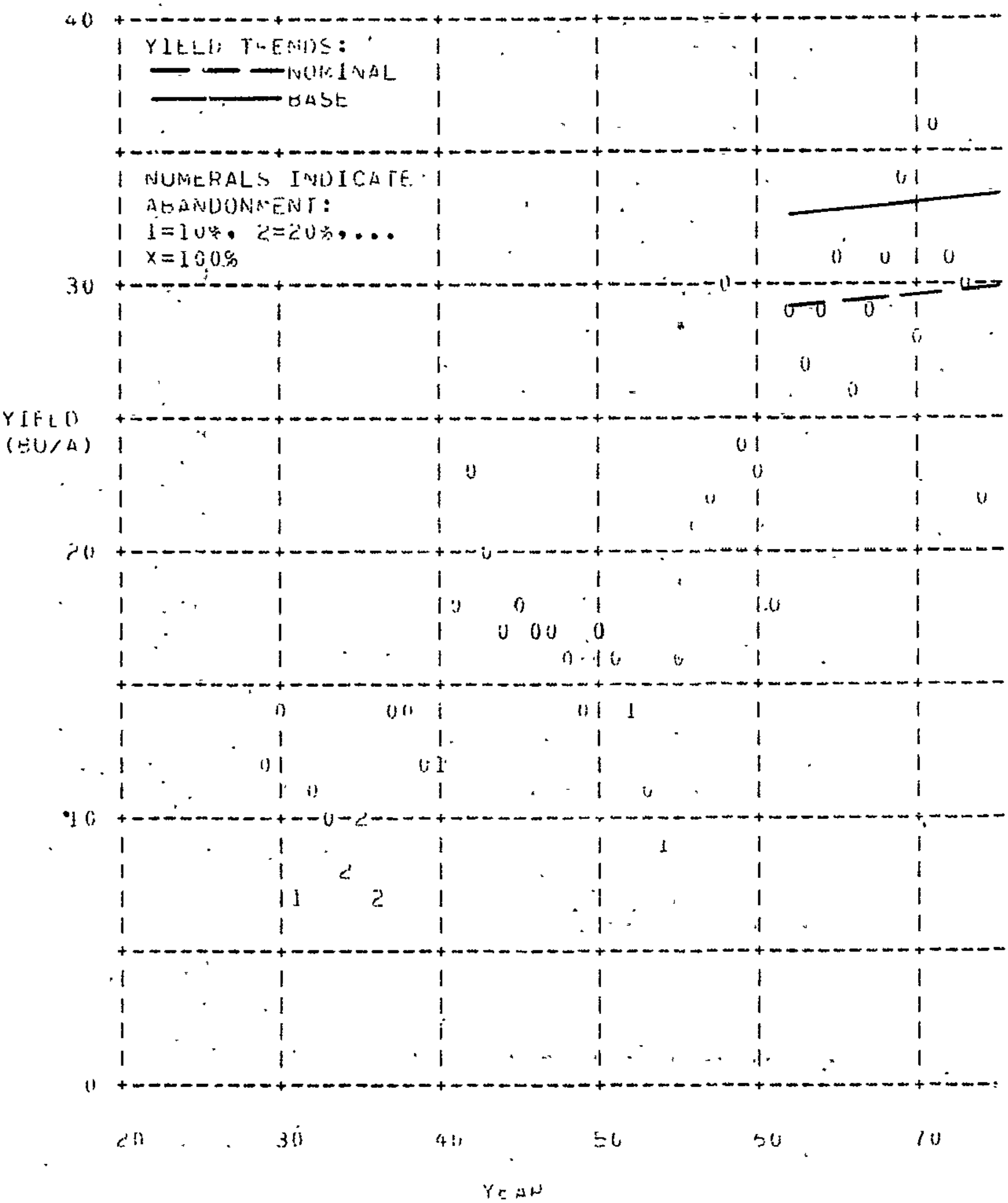

Figure 8-22: Yield history for northeast North Dakota.

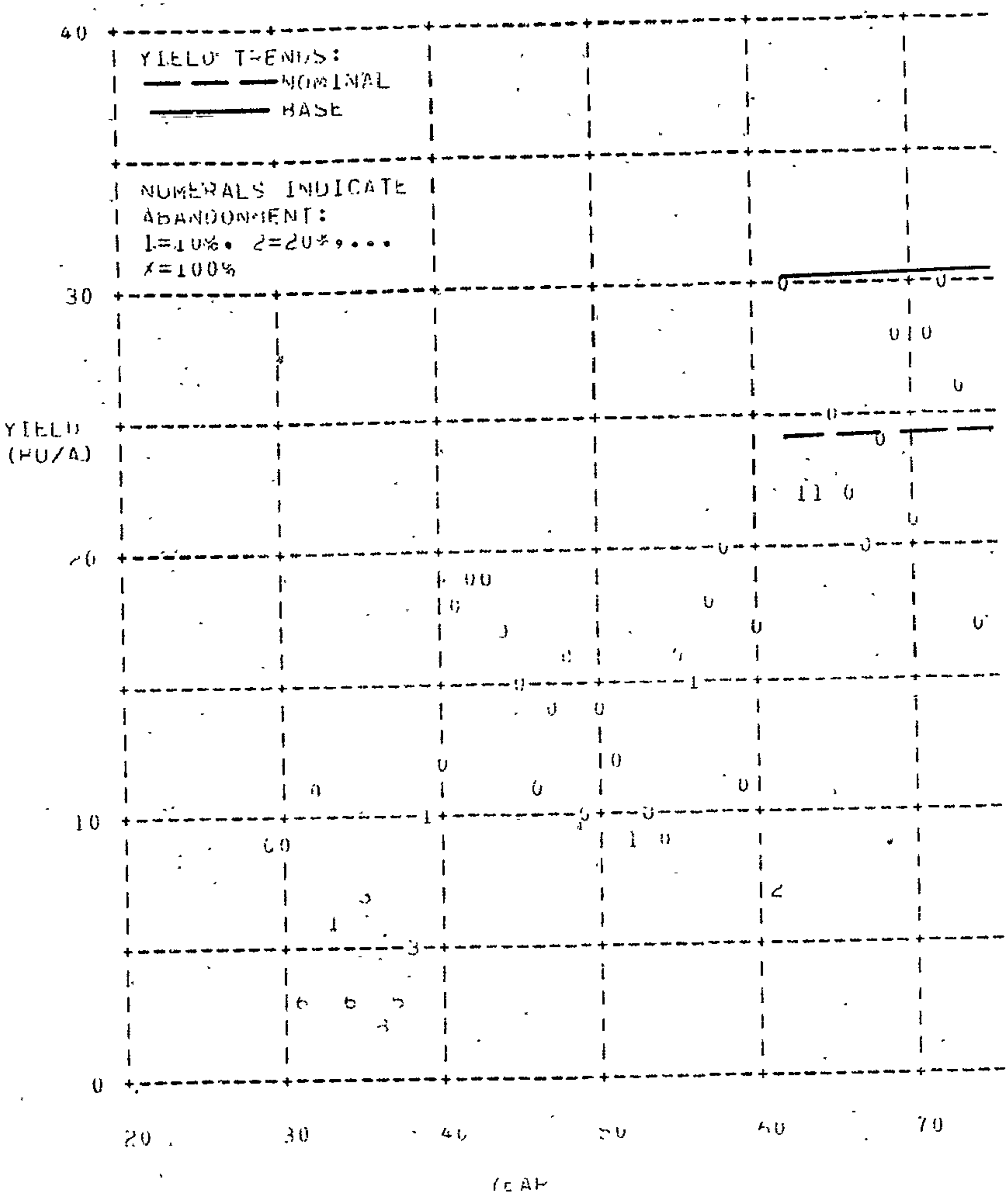

Figure 8-23: Yield history for west central North Dakota.

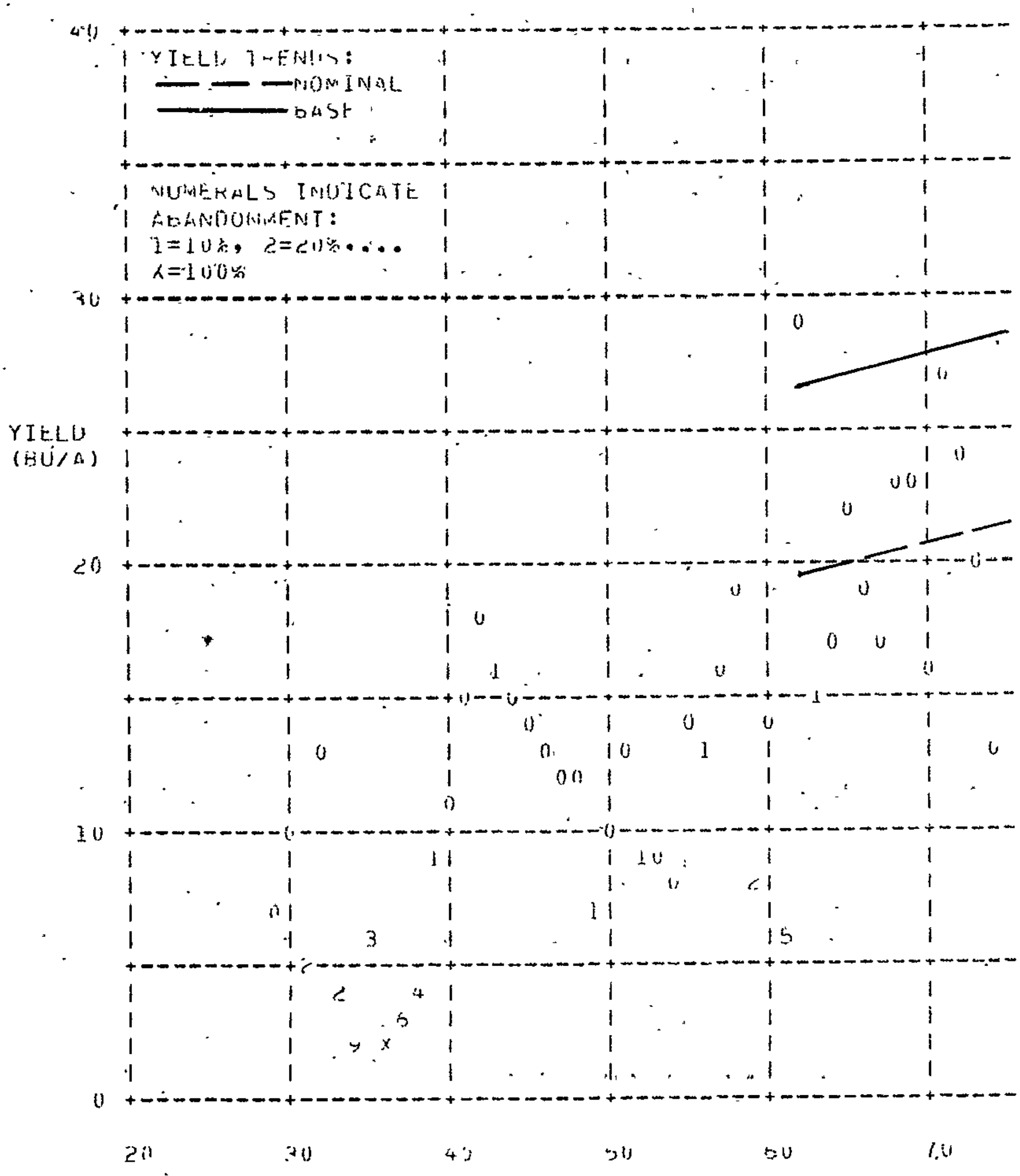

Figure 8-24: Yield history for central North Dakota.

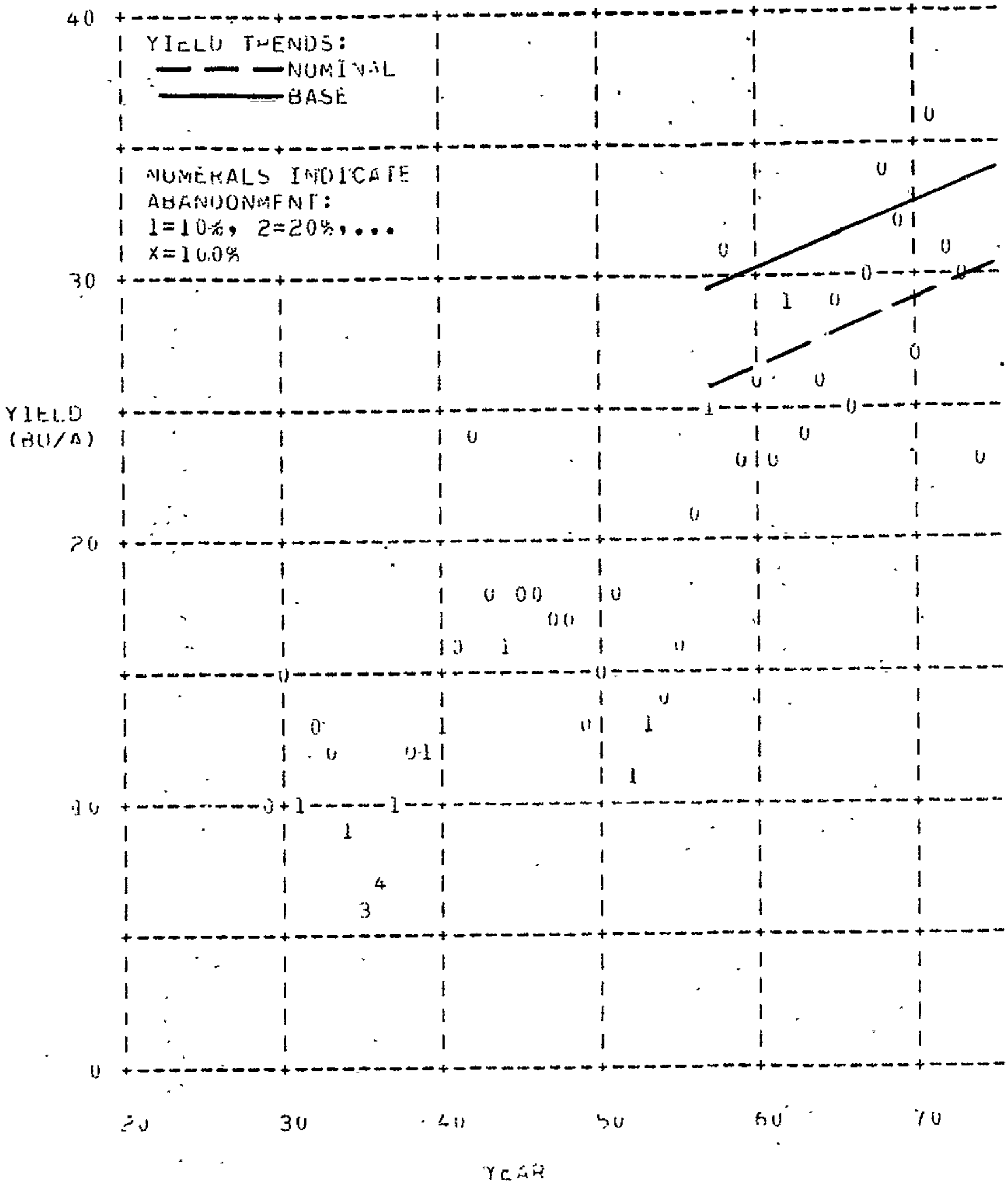

Figure 8-25: Yield history for east central North Dakota.

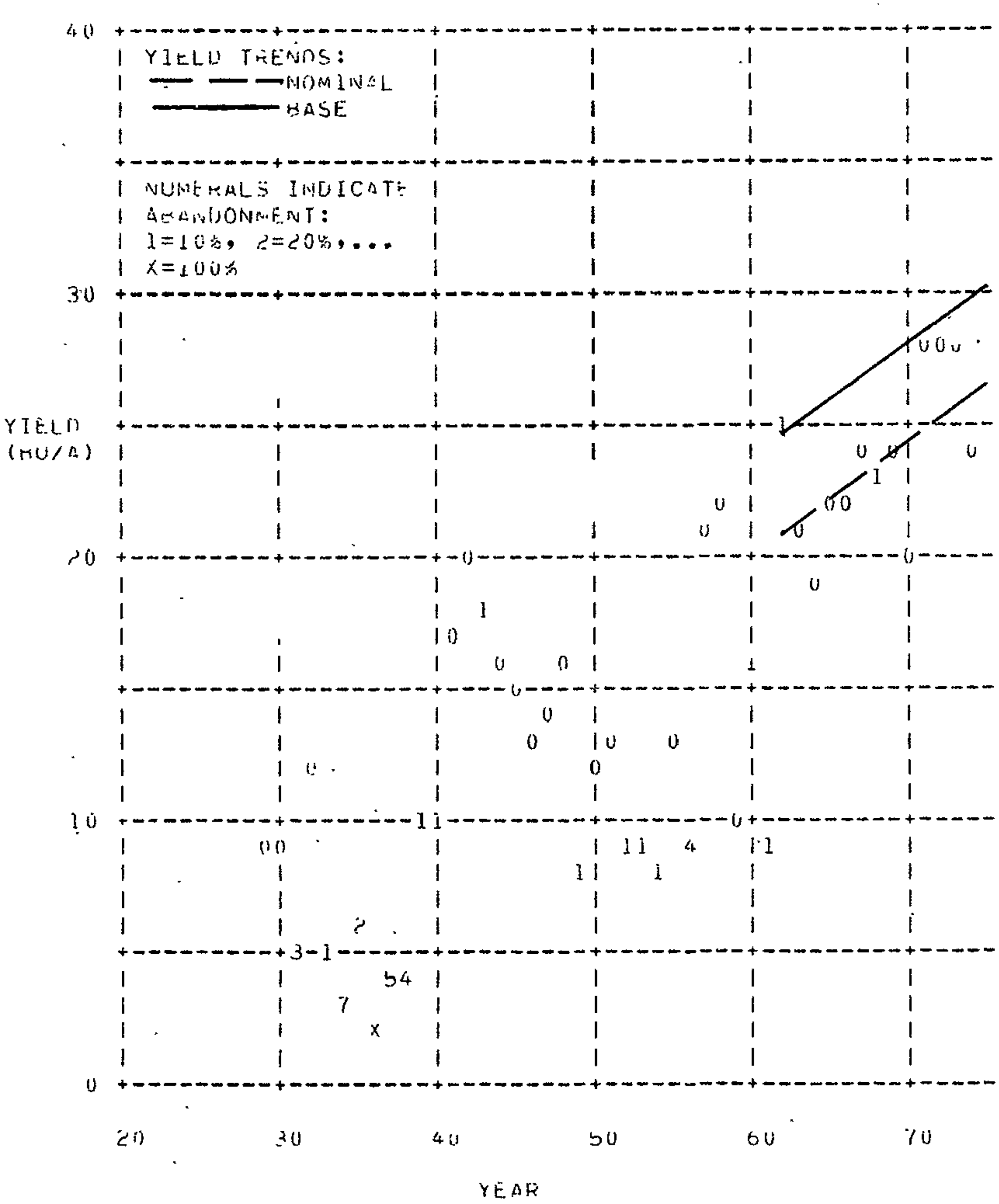

Figure 8-26: Yield history for southwest North Dakota.

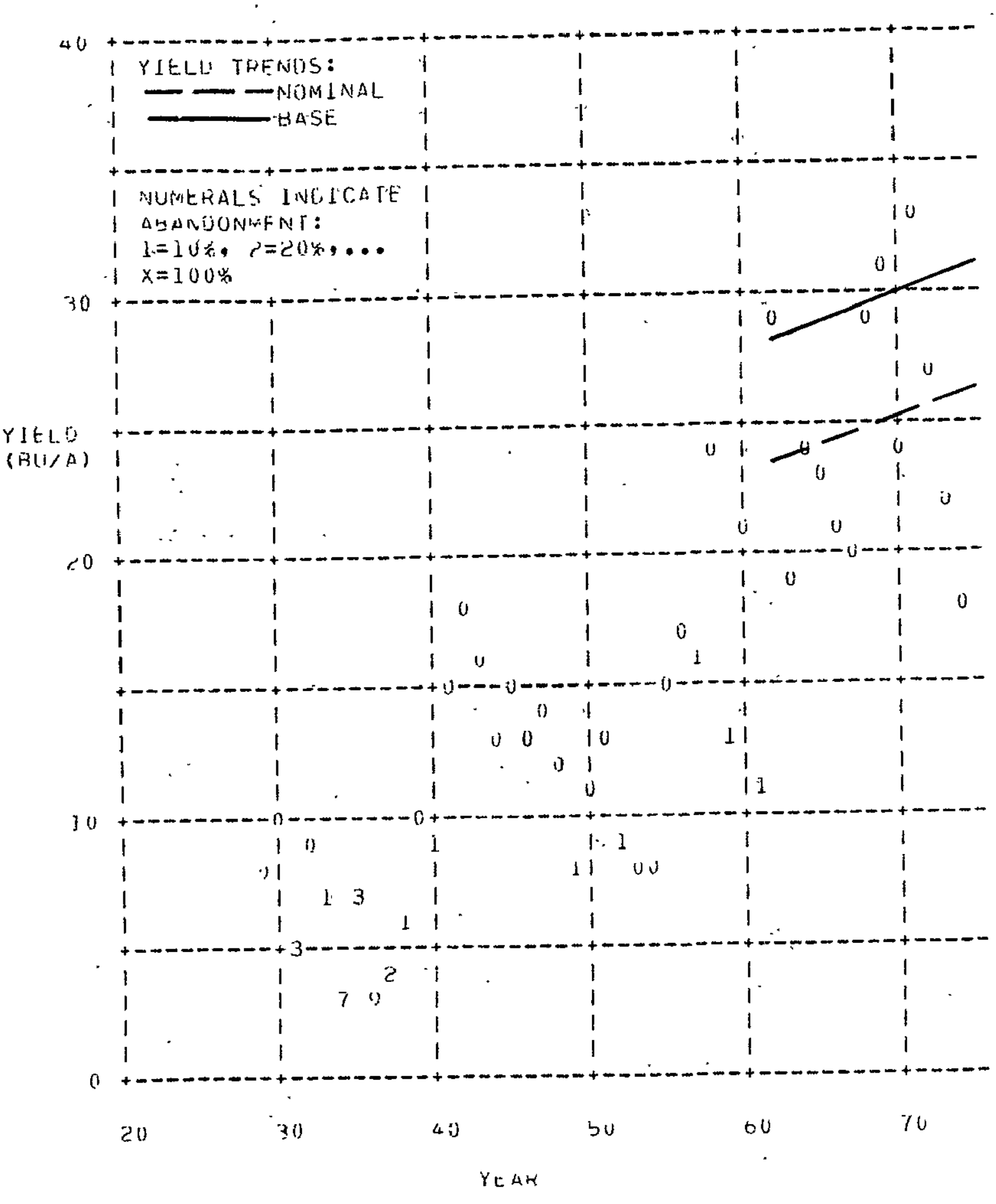

Figure 8-27: Yield history for south central North Dakota.

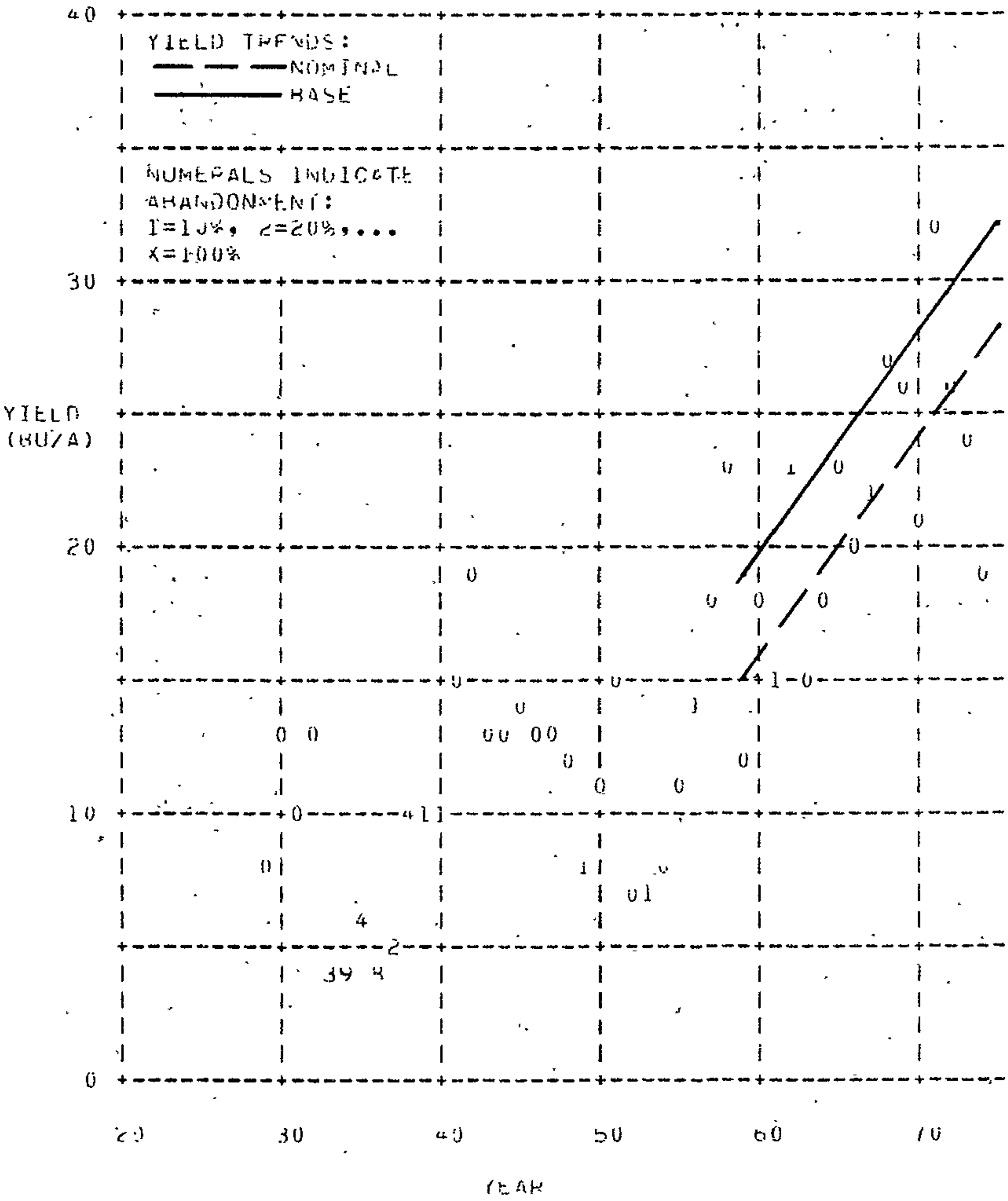

Figure 8-28: Yield history for southeast North Dakota.

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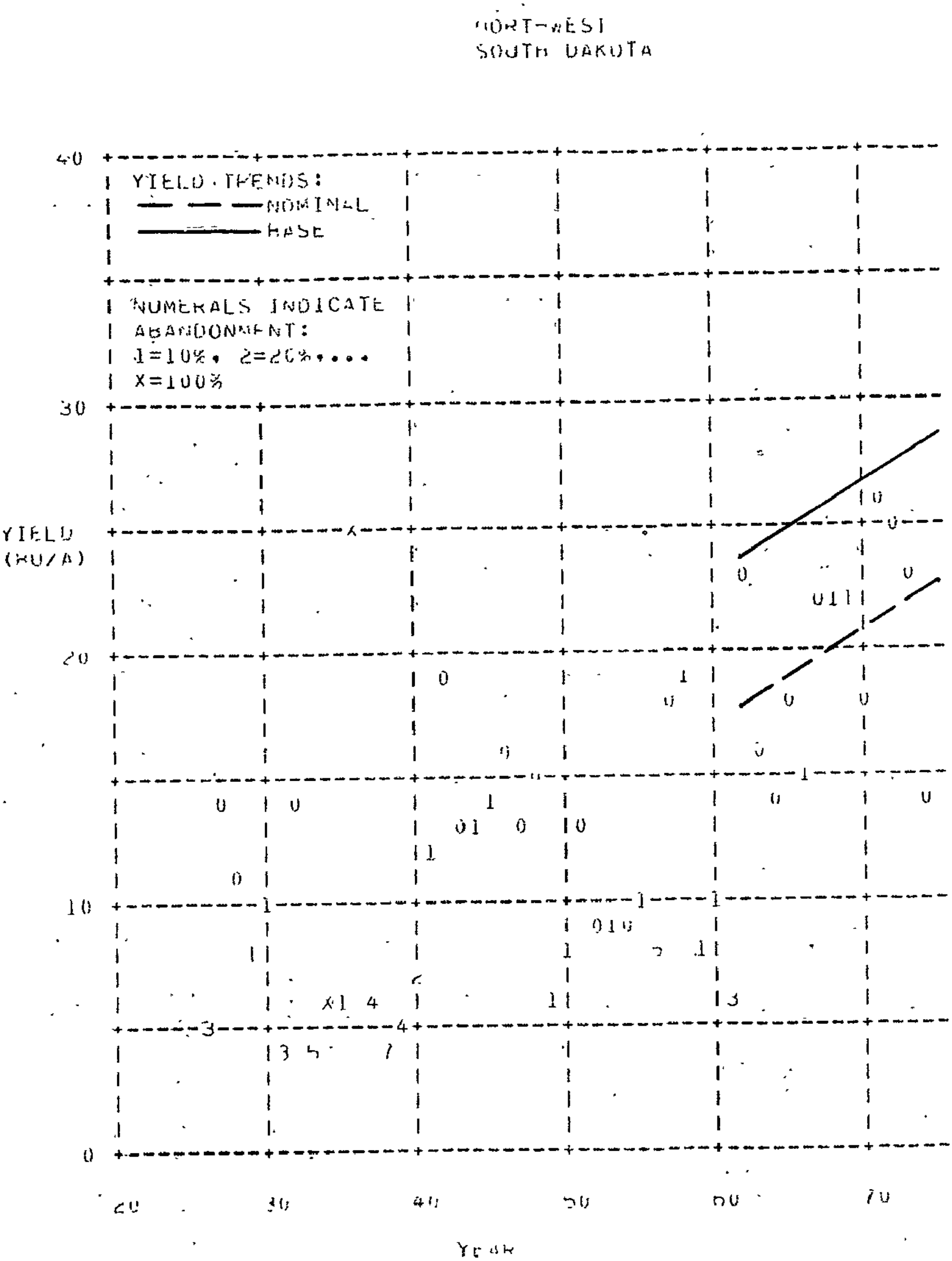


Figure 8-29: Yield history for northwest South Dakota.

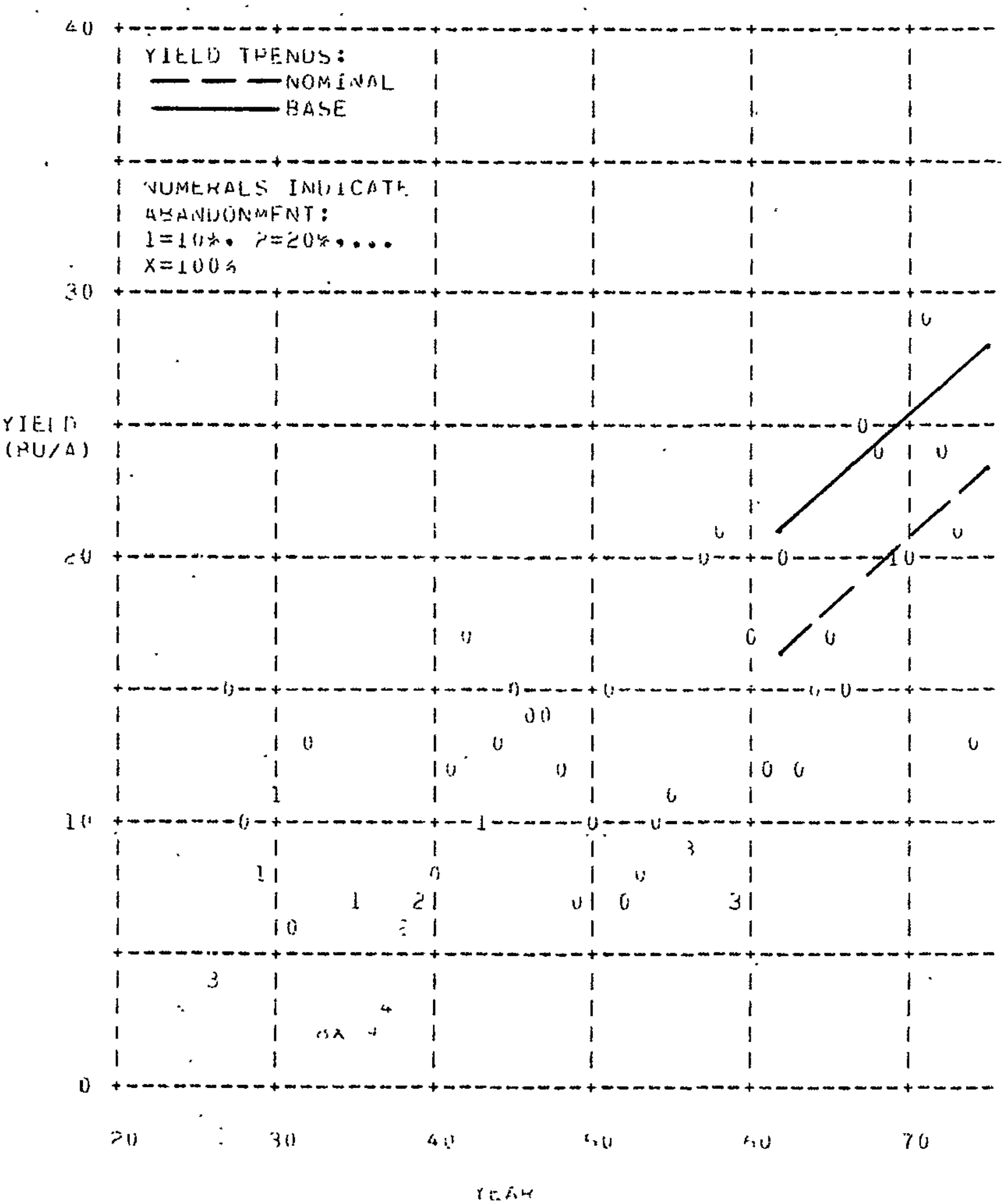


Figure 8-30: Yield history for north central South Dakota.

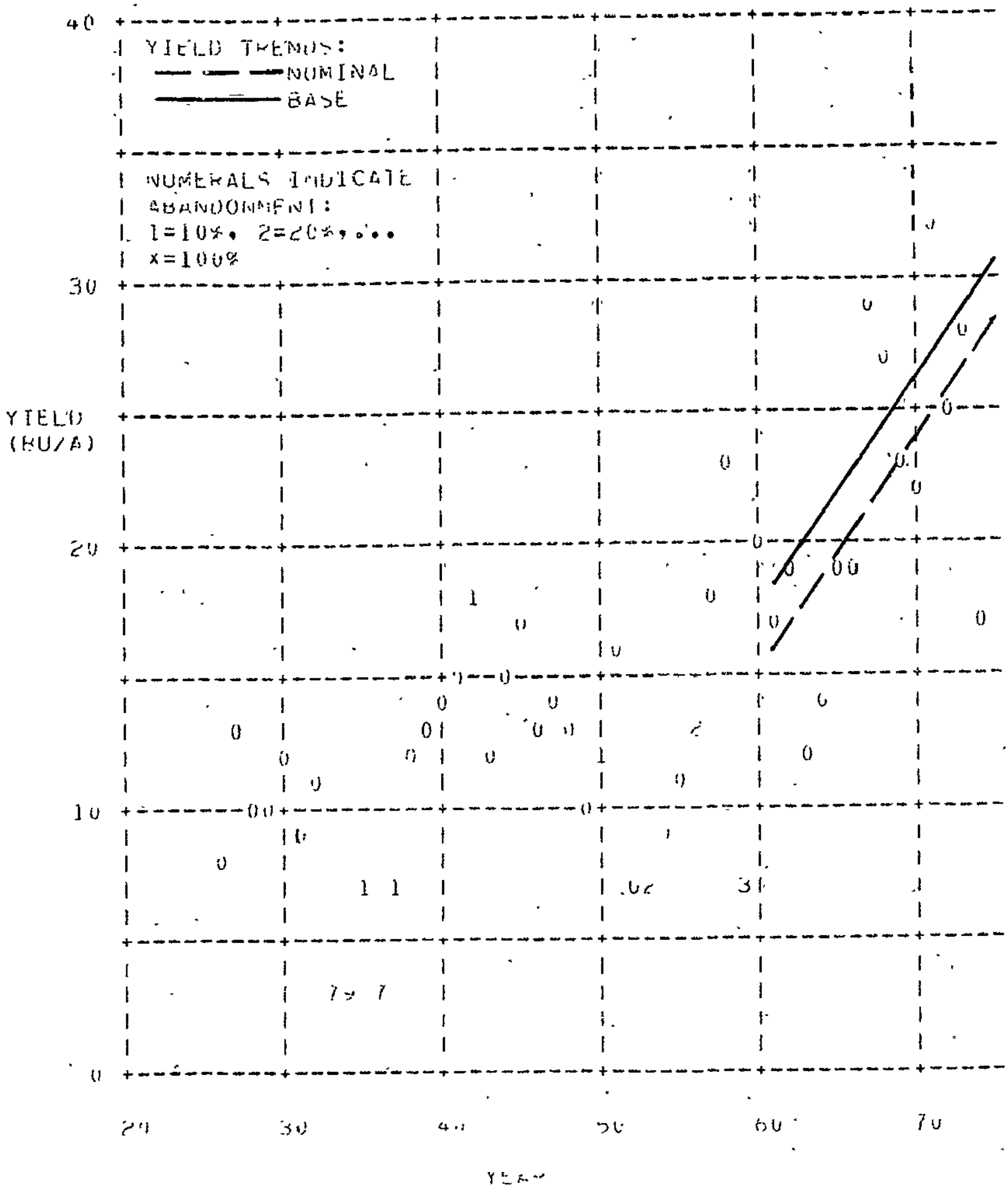


Figure 8-31: Yield history for northeast South Dakota.

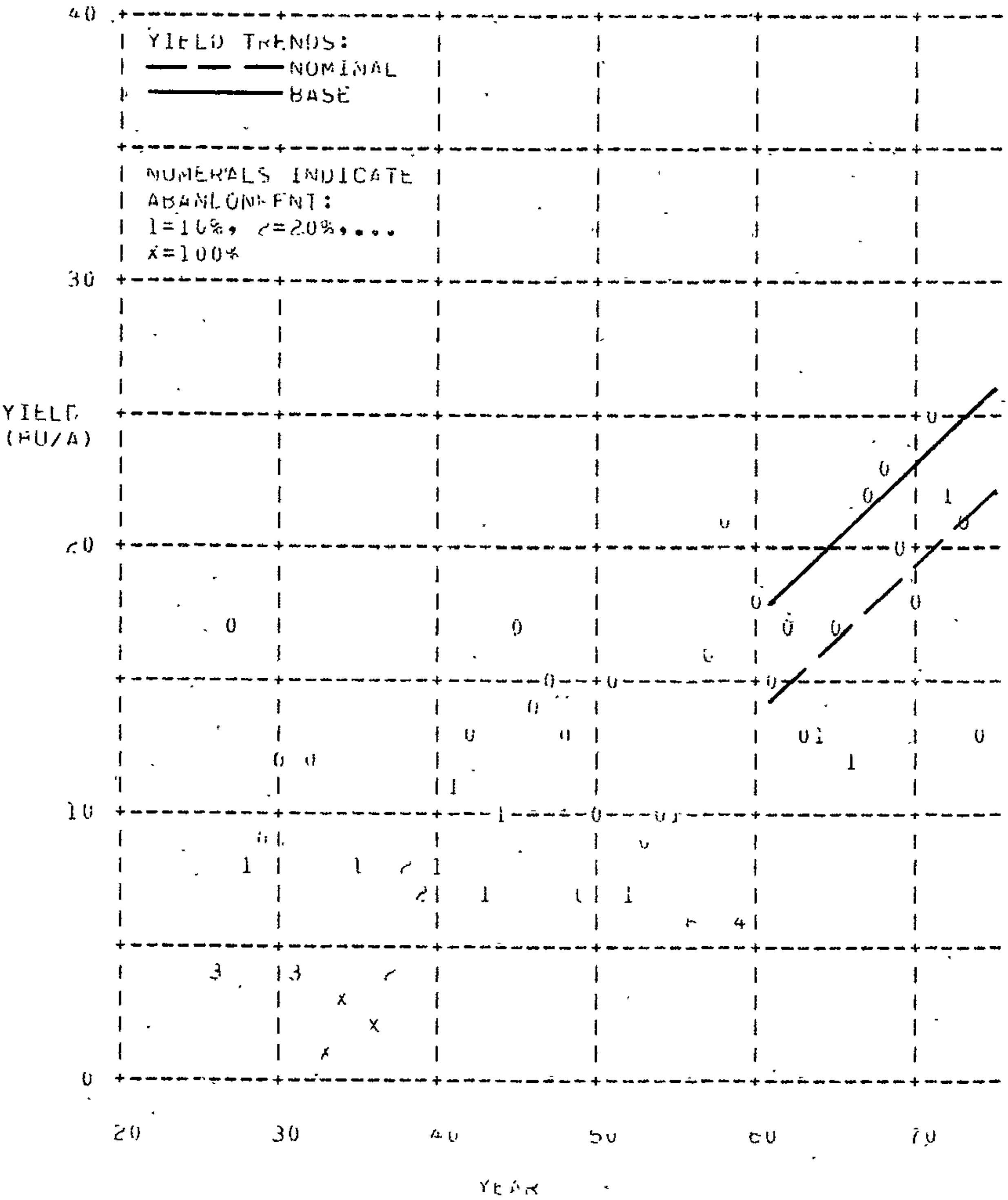


Figure 8-32: Yield history for central South Dakota.

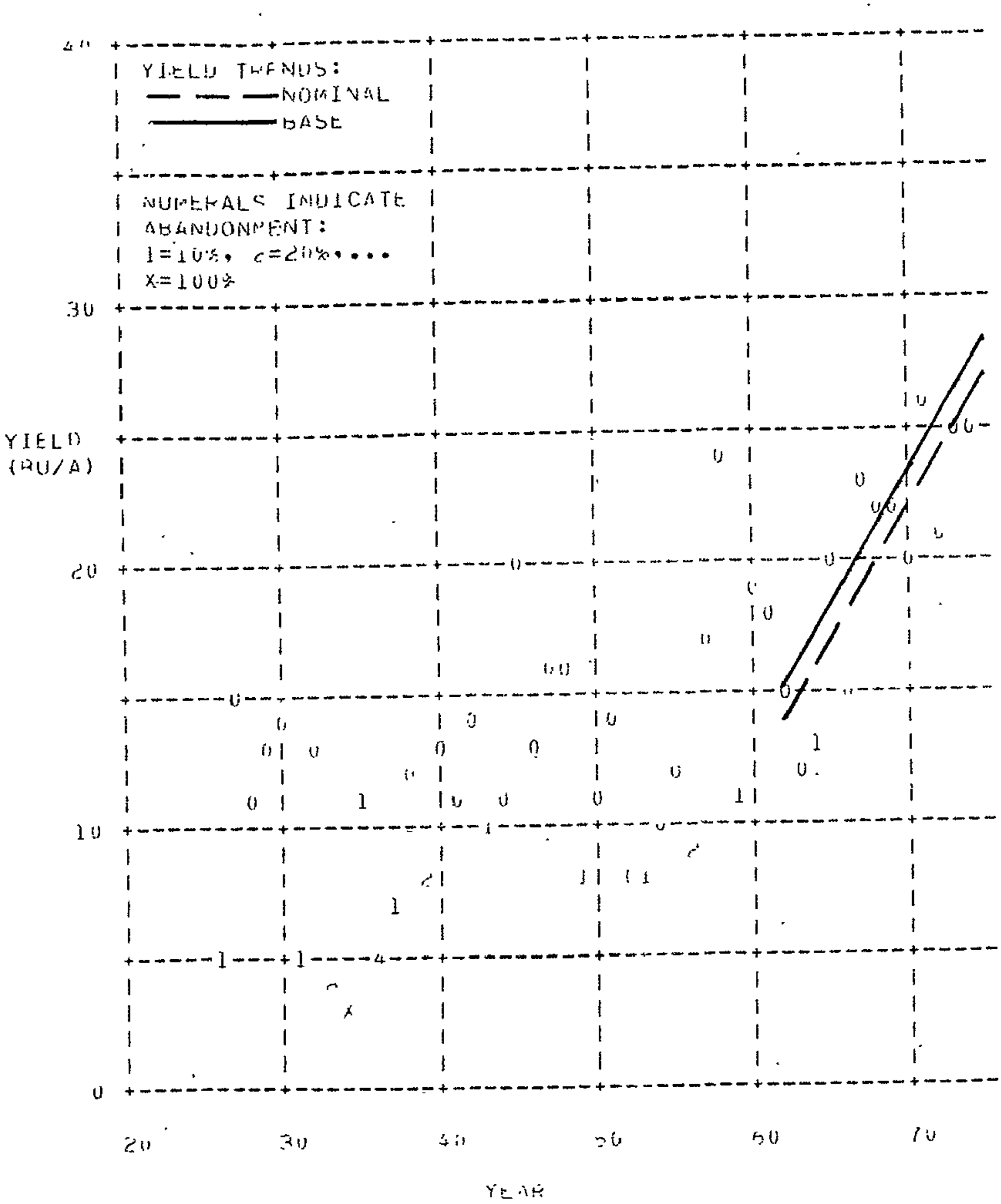


Figure 8-33: Yield history for east central South Dakota.

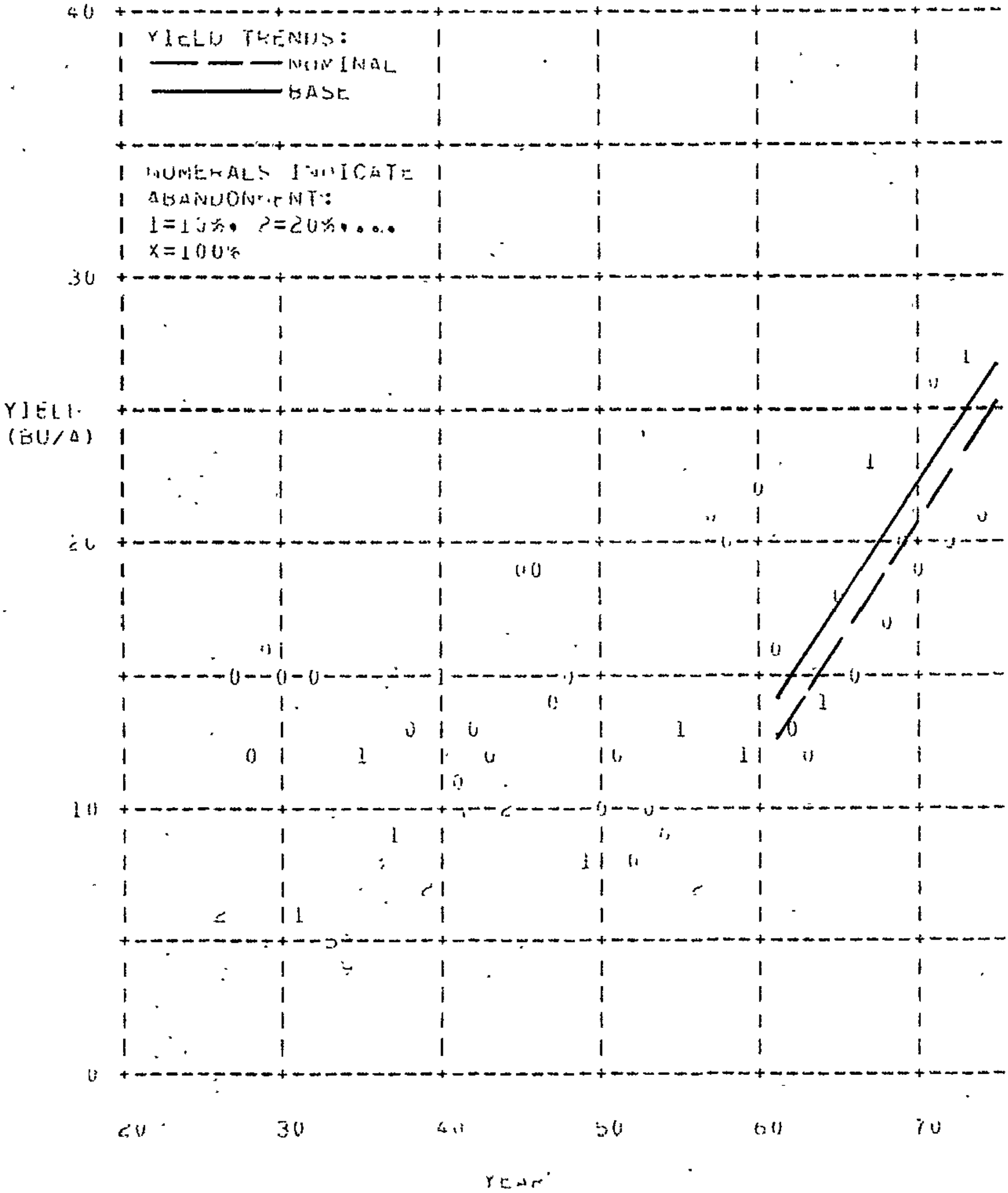


Figure 8-34: Yield history for southeast South Dakota.

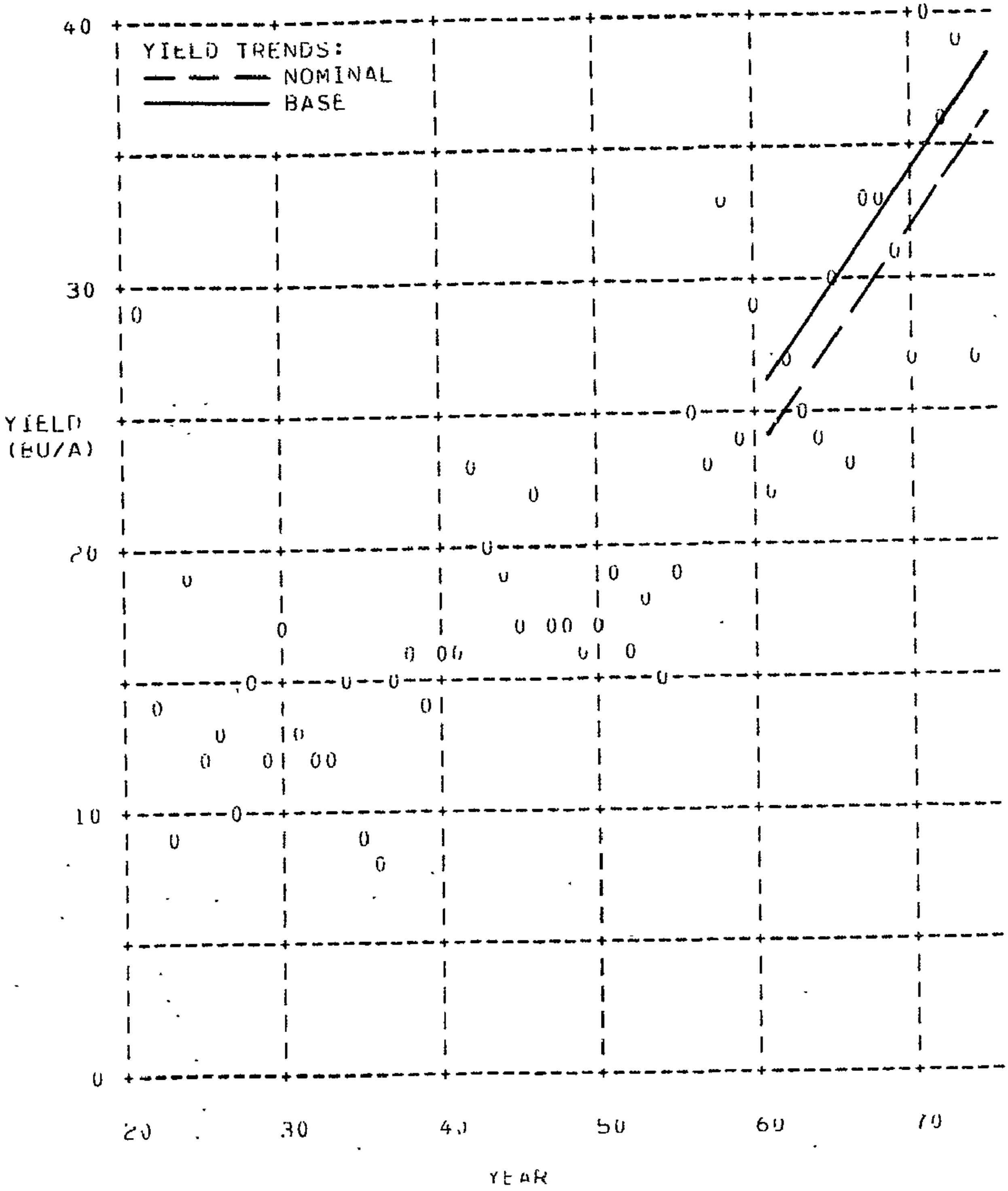


Figure 8-35: Yield history for northwest Minnesota.

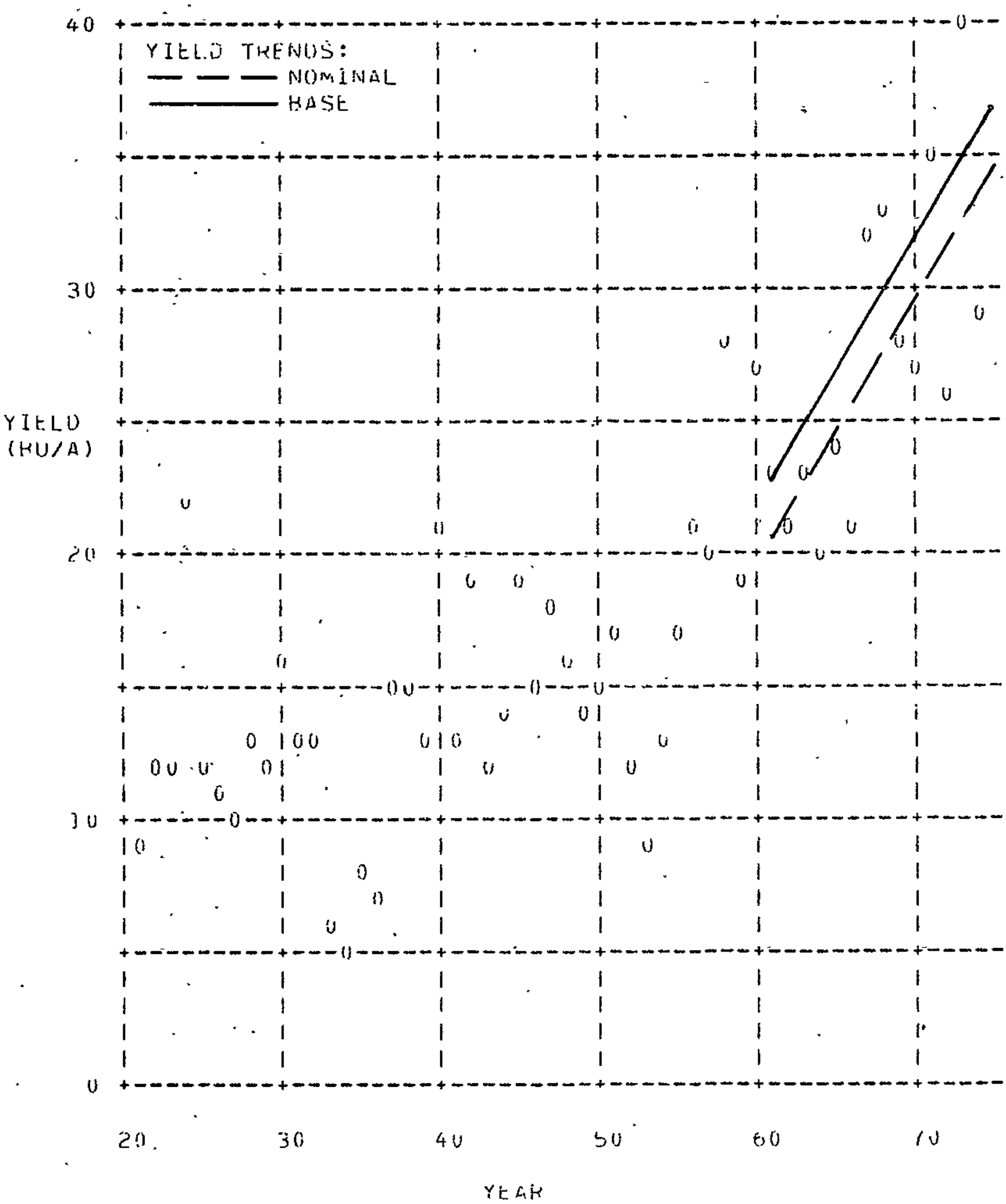


Figure 8-36: Yield history for west central Minnesota.

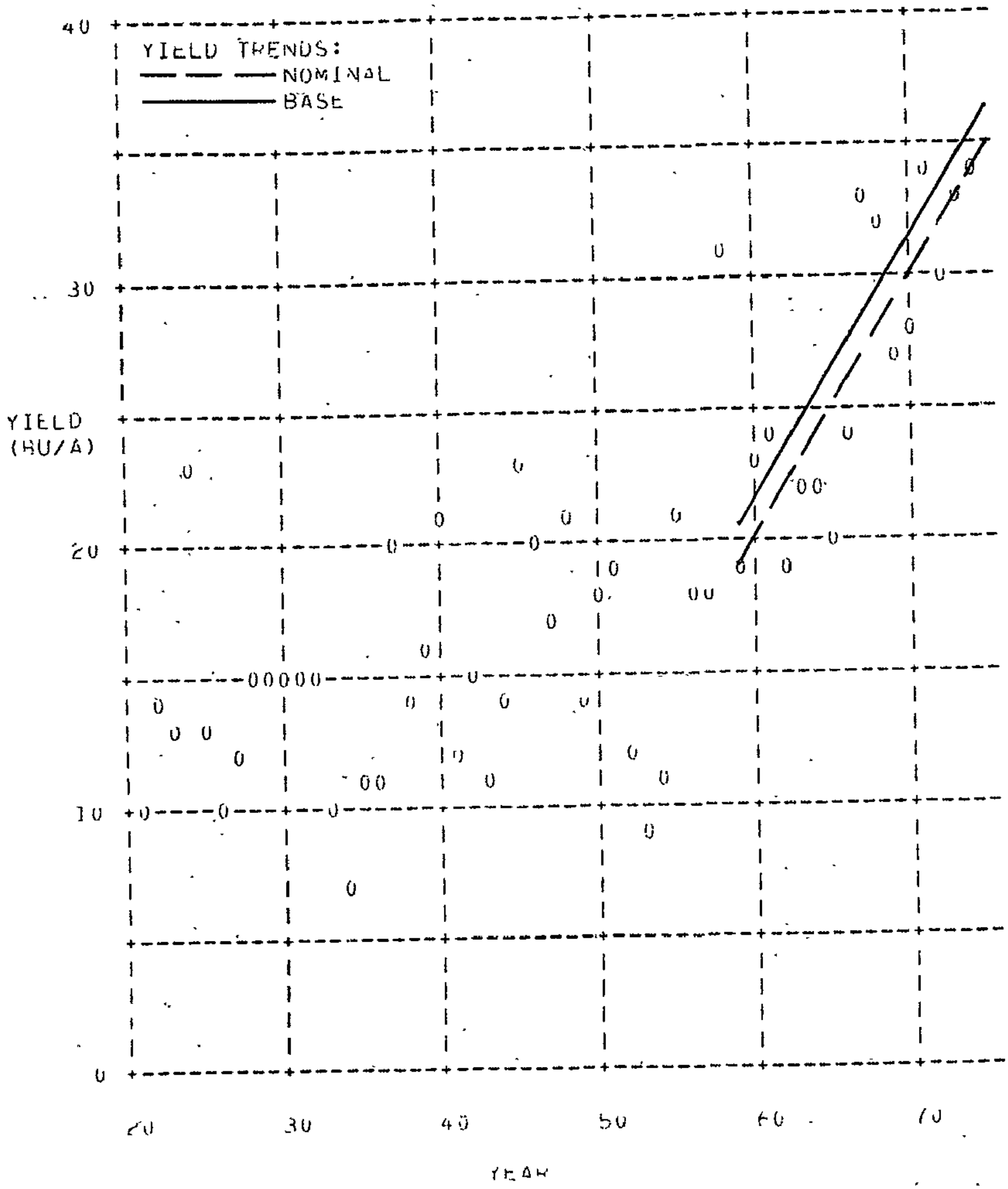


Figure 8-37: Yield history for southwest Minnesota.

dashed line is the nominal trend line, while the solid represents the base yield trend line.

An attempt was made in a few of the crop reporting districts to further reduce the standard error of estimate by including planted acreage as a fifth candidate variable for regression. In all cases, however, this variable proved not to be significant despite the intuitive notion that acreage increases involve introduction of marginal land which ought to lower the yield.

8.3.1.4 1975 Base Yields

Figure 8-38 represents the chief end item of this task - a definition of the 1975 base yield for each CRD. These values are used in Sections 8.3.4 and 8.3.5 to assign a best-estimate yield to each cell. The geographic distribution of the base yields seems quite reasonable, in that these should not reflect climate influences, but rather soil quality and level of technology.

8.3.2 Stress Coefficient Re-evaluation

As reported above (Section 8.2) the 1975 operational yield model was developed based on data from three North Dakota counties (66 location-years), and was used over the entire spring wheat study area. The appropriateness of this extension has been examined by conducting additional regressions in South Dakota and Montana. The approach used was the same as

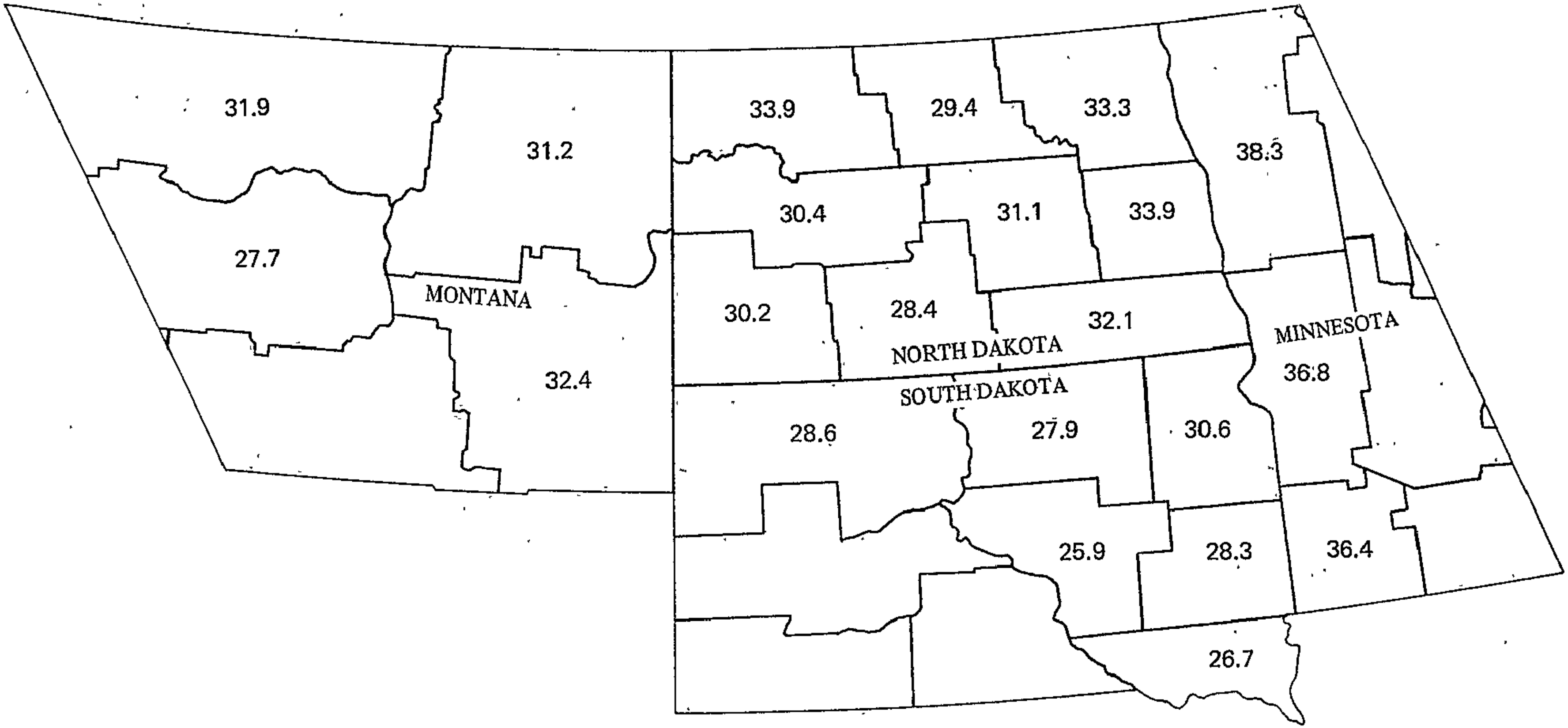


Figure 8-38: 1975 base yield values (Bu/acre).

that which had been applied to the North Dakota data. Three counties were used in South Dakota (52 location-years) and two in Montana (42 location-years). The resulting yield expressions were:

South Dakota

$$Y = -14.783 + 0.60296 \cdot YR - 31.731(\overline{S})^2 \qquad [8\text{-}5]$$

Montana

$$Y = 8.0852 + 0.34365 \cdot YR - 31.333(\overline{S})^2 \qquad [8\text{-}6]$$

The coefficients for the stress term are virtually identical to the one in the North Dakota equation [8-1]. This is to be expected, since it is primarily a function of the physiological properties of the plant. The terms attributable to trend are quite different, especially in Montana where the slope is much less. This is consistent with the results of the detailed trend analysis of Section 8.3.1. The following table compares the yields for the four states as determined by the 1975 operational model with the latest available estimates from the SRS:

	1975 oper. model	SRS	percent error
Minn.	28.9	31.0	-7
Mont.	22.8	25.8	-12
N.D.	26.5	25.9	+2
S.D.	25.7	18.0	+43

The results for North Dakota are very close, as would be expected. For the other states, much of the difference can be explained by differing trend line values.

8.3.3 Temperature Effect on Yield

As the 1975 growing season progressed, it became apparent that yields in South Dakota were going to be considerably below those being projected by the model despite the fact that soil moisture was generally adequate. The cause of this yield reduction was a period of hot weather at a critical time in the crop development cycle - namely during the time from heading to soft dough. For example, at Aberdeen, S.D., the interval from heading to soft dough spanned 18 days, from June 29 through July 17. During this period, the daily maximum temperature reached or exceeded 35C (95F) on 12 days with an extreme of 40C (104F) while the daily minimum exceeded 21C (70F) on 9 days. Since it is known that high temperatures adversely affect the wheat plants at any moisture stress level, a factor needed to be included to account for such high temperature events. A measure of the average temperature during some plant phenological interval is the number of days spent in that interval. This is true because the biometeorological time (BMT) parameter used by the model is driven at a rate proportional to the daily mean temperature and day length. Therefore, short intervals are produced by high temperatures. Since the plant is most vulnerable to high temperature during the heading (BMT = 3) to soft dough (BMT = 4) stage, regression analyses were performed introducing $\langle 20-ND_{34} \rangle^2$ as a parameter, where the $\langle\rangle$ notation means that negative values are set to zero, and ND_{34} is the number of days from BMT = 3 to BMT = 4. The quantity is squared because the temperature effects are felt to be non-linear.

A regression analysis was performed on a historical South Dakota data set containing 44 station-years. Seventeen of the data points had ND_{34} less than 20. The coefficient for the temperature parameter was -0.63. Application of this parameter with its coefficient was made on an independent data set for Montana. The result was that the standard error of estimate (SEE) for the entire 42 data points was reduced from 3.27 to 3.03 Bu/acre. For the 12 data points having $ND_{34} < 20$, the SEE was reduced from 4.01 to 3.03 Bu/acre. (In other words, a subset of the data which had shown greater variance that the "population", had its variance reduced to the population's value by inclusion of a temperature-sensitive variable.)

8.3.4 Post-Operational Yield Correlations

The 1975 operational model was, as previously stated, a North Dakota model with trend developed for that state. The obvious fact that errors were observed in Montana, Minnesota, and South Dakota was, in a way, heartening since we would not expect the North Dakota trend to be applicable in the other states except by chance. We did, however, anticipate that the stress coefficient would show little change since it is primarily related to plant physiological response to water stress.

The post-operational yield evaluations incorporated the results from the trend analyses in 22 crop reporting districts (Section 8.3.1), the stress coefficient evaluations (Section 8.3.2) and the temperature effect analysis (Section 8.3.3). Figure 8-39 presents an isopleth map of estimated yield at the county level generated based on the above considerations.

Figure 8-40 presents the corresponding latest reported county yields from the SRS. (Data from South Dakota were not yet available.) A rather large discrepancy in noted in the Red River valley region of southeastern North Dakota. This is a manifestation of serious flooding which occurred there, significantly lowering yields. The predicted yields in Montana are generally low. This is likely a result of using a too-restrictive soil dry-down curve (designated "D-project") in this moisture critical region (see detail discussion in Section 7). Elsewhere there are no major discrepancies.

Figures 8-41 and 8-42 present similar information where the isopleths are based only on yield at the CRD level. This serves to remove the "noise" of the county data, while preserving the broad-scale variations. In both figures there is a general decrease from east-to-west into eastern Montana, reflecting the distribution of rainfall and soil quality. Increasing yields farther to the west in Montana are reflections of the very favorable 1975 weather in that state.

It was anticipated that aggregation to larger areas would improve the correspondence between estimated and actual yields. To this end, correlation coefficients were calculated at the state, CRD, and county level and also at intermediate-sized regions consisting of from two to five counties. The results of these analyses appear in Table 8-2. In the case of sub-areas, only those accounting for three percent or more of the state acreage were included. This significantly increased the correlation in Montana where small acreages are often associated with marginal or irrigated land. The improvements

Table 8-2

Correlation Coefficients-Actual vs Predicted Yields

	Drydown Curve D-Project	Drydown Curve E-Normal
MONTANA		
CRD's	0.567	0.897
sub-areas	0.865	
counties	0.433	
NORTH DAKOTA		
CRD's	0.742	0.790
sub-areas	0.723	
counties	0.549	
MINNESOTA		
CRD's*	0.720	0.742
sub-areas*	0.804	
counties*	0.450	
4-STATES	0.920	0.956
all CRD's*+	0.755	
all sub-areas*+	0.607	
all counties*+	0.427	

* Only in most productive CRD's
\+ Excluding South Dakota

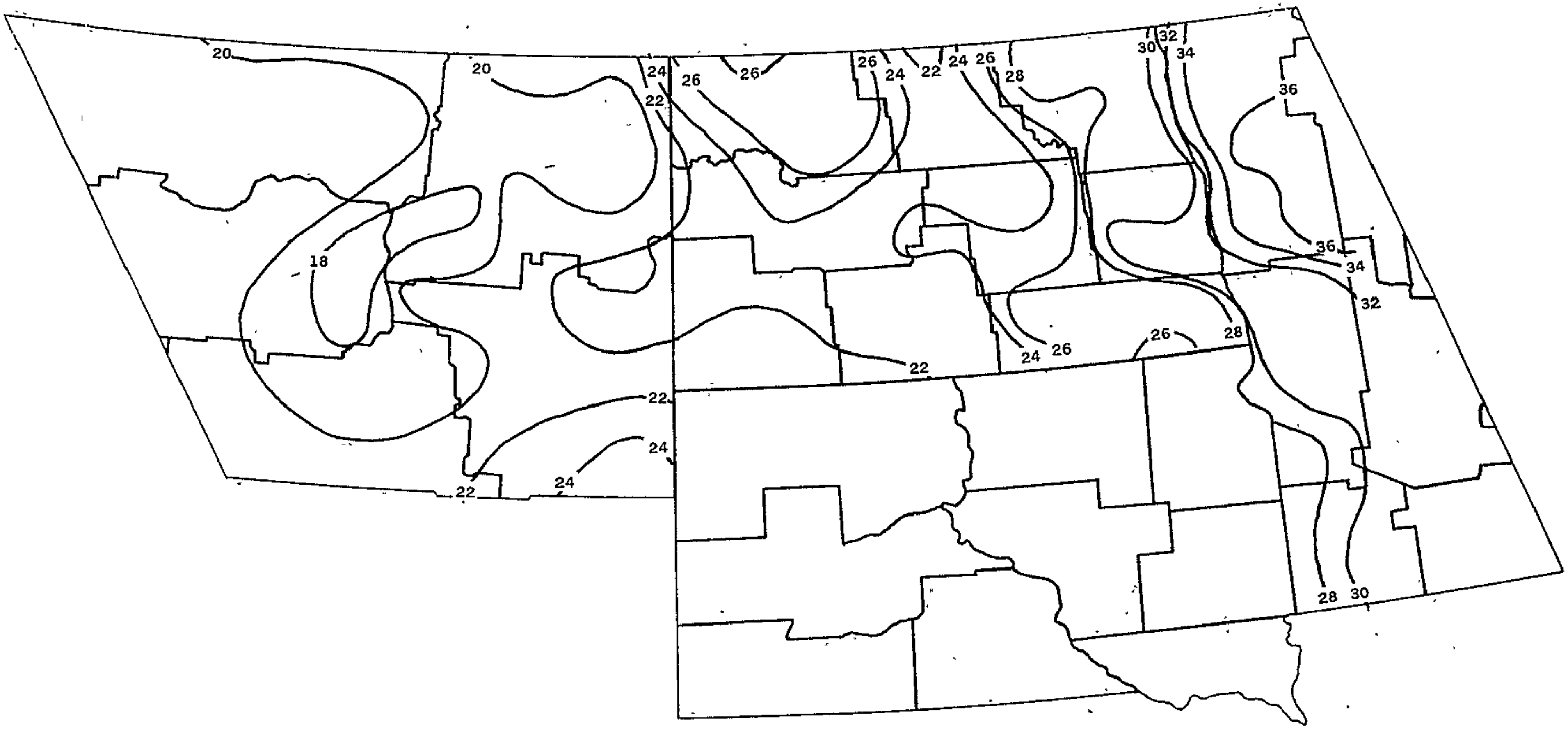


Figure 8-39: Estimated 1975 yields (Bu/acre) - counties.

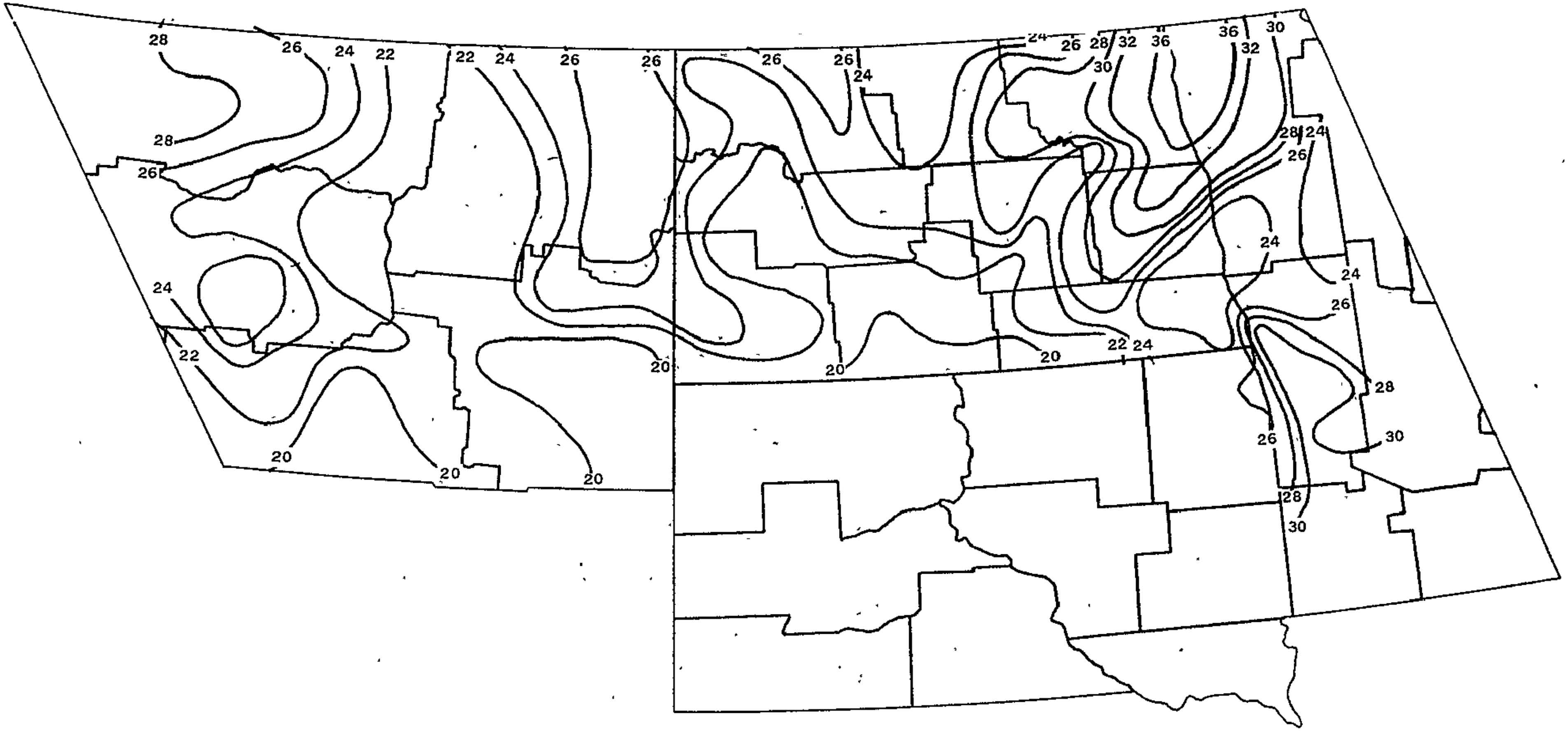


Figure 8-40: SRS actual 1975 yields (Bu/acre) - counties.

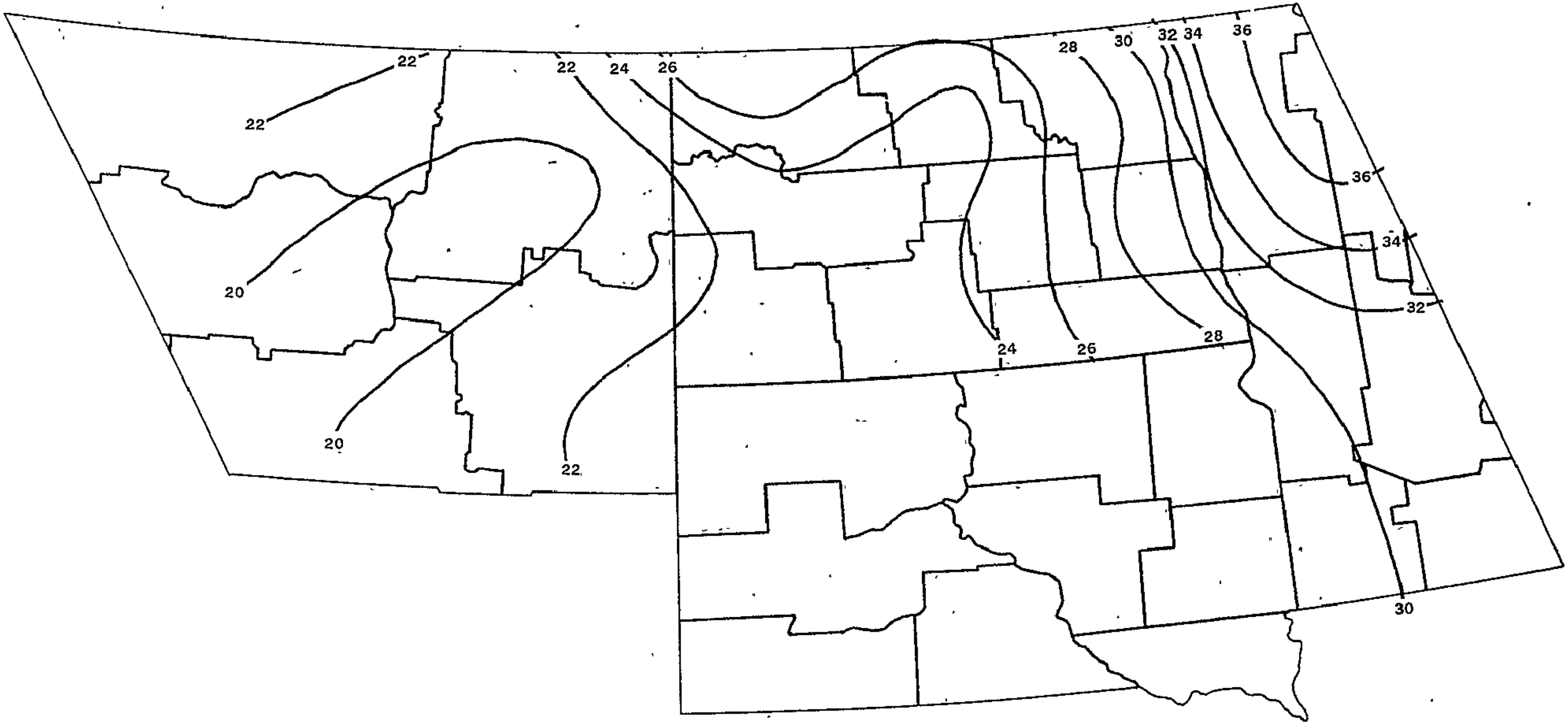


Figure 8-41: Estimated 1975 yield (Bu/acre) - CRD's.

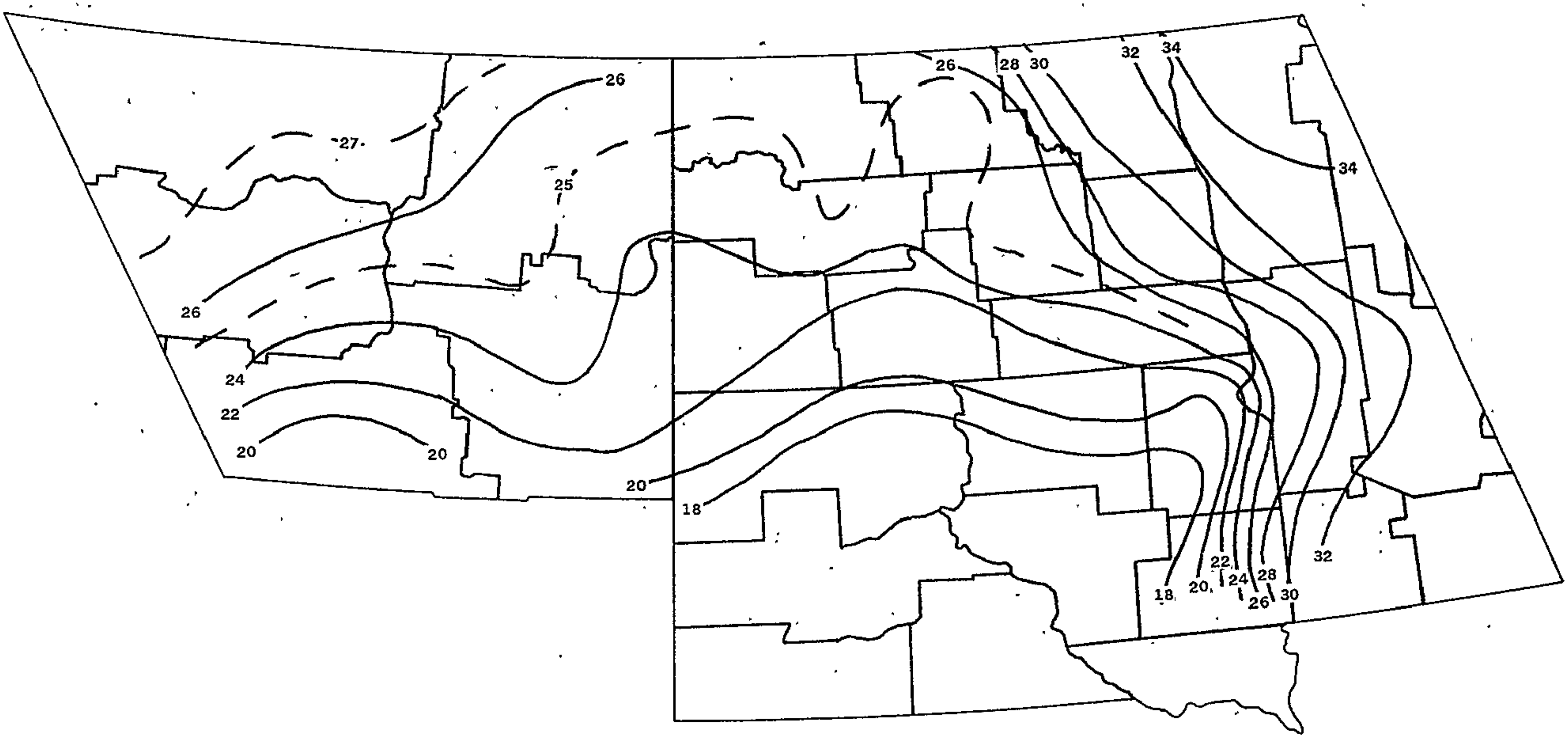


Figure 8-42: SRS actual 1975 yields (Bu/acre) - CRD's.

in North Dakota and Minnesota were negligible. Calculations using the improved E-normal dry-down curve (Section 7) showed improved correlation at the CRD level, particularly in Montana.

Figure 8-43 displays the results for the complete set of each area class analyzed. The trend to increasing correlation with increasing areas is unmistakable. Correlations above 0.5 occur for areas slightly larger in size than the county.

8.3.5 1975 Simplified Final Yield Estimates

In keeping with the desire for simplifying the system, it has been determined that suitable accuracy in yield estimation at the CRD or state level can be achieved by considering a limited sample of carefully selected cells. A sample of 61 cells was defined by selecting one representative cell in each CRD corresponding to each soil class existing in that CRD. Yield at the CRD level is then determined by aggregating each of the cells weighted by the proportion of its soil class within the CRD. Aggregations to higher levels are based on reported 1974 planted acreages.

The most refined estimates of 1975 yields using the EarthSat model incorporated the following features:

1. Sampled cell aggregations.
2. Best estimate 1975 yield trends at CRD level (Section 8.3.1).
3. High temperature modifier (Section 8.3.3).
4. E-normal dry-down curve (Section 7).

in regards to point 4, it was found that the function defining the ability of the soil to give up its moisture (dry-down

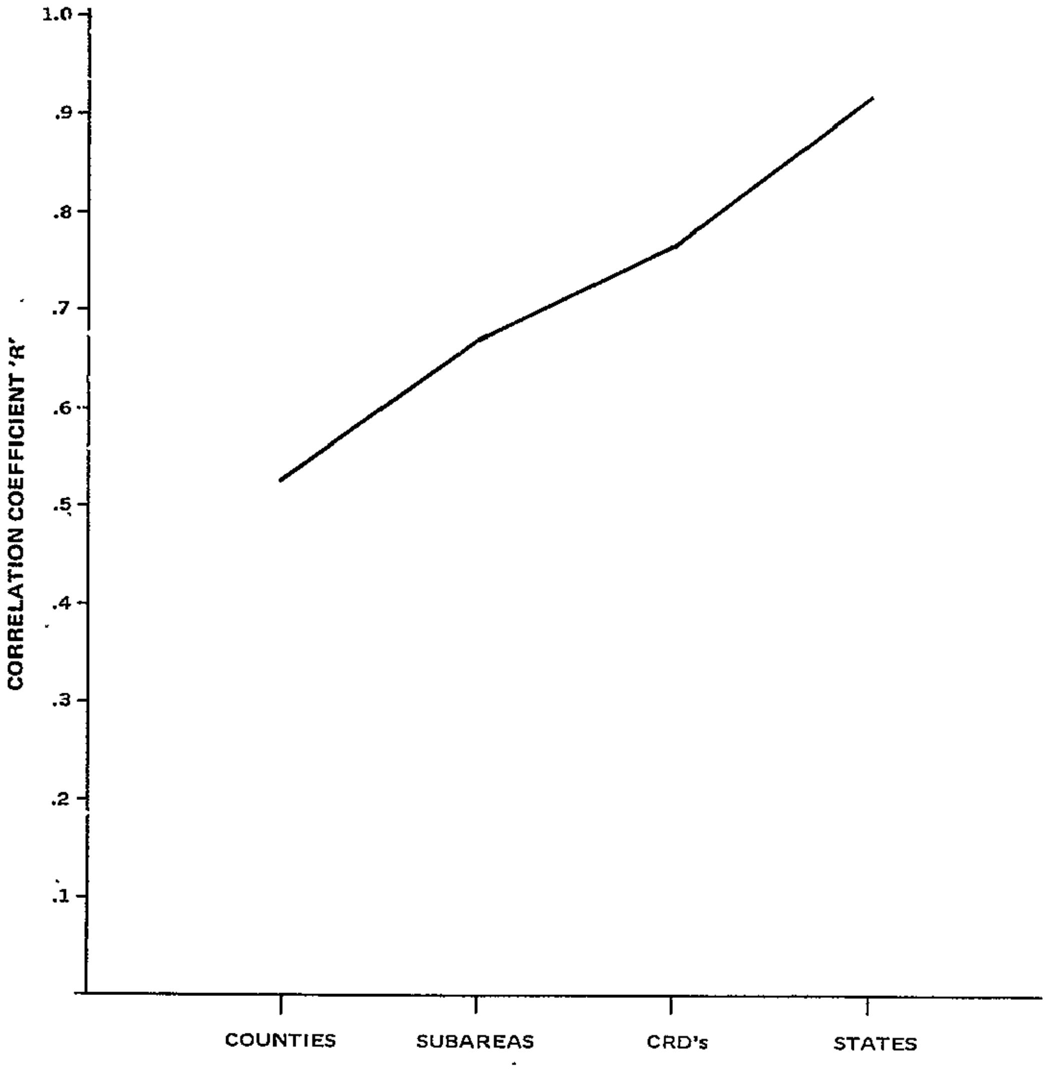


Figure 8-43: Effect of aggregation size on correlation of estimated vs. actual yields.

curve) was much too restrictive in the operational model used during 1975. As discussed in detail in Section 7, comparisons of model output with field soil moisture measurements showed that the less restrictive "E-normal" curve gave more realistic results.

Table 8-3 presents the final 1975 yield estimates for each state and its more productive crop reporting districts. Also shown for comparison purposes are the estimates from the operational model and the latest estimates from the SRS. North and South Dakota were within about one bushel per acre, Montana about two and Minnesota between two and three. North Dakota would have been even closer, but severe flooding affected parts of the east central and southeast CRD's, destroying up to 25 percent of the crop in some counties. Since the acreage lost was the most fertile, the resulting yields were lower than would have otherwise occurred. This effect of course is not accounted for in the model. The four-state aggregate yield differs from the SRS value by only 0.6 Bu/a.

8.3.6 Historical Yield Estimates

Figure 8-44 presents historical yield data for four locations in Montana and South Dakota. There is a general upward trend to the yields, somewhat less in Montana, but the year-to-year variations are substantial. The estimated yields using the North Dakota model are shown. Where temperature effects were important (i.e., ND_{34} less than 20), the estimate including the temperature adjustment is also shown. In 18 out of the 26 cases this improved the yield estimate. The estimates

Table 8-3
1975 Yield Estimates

	Operational Model	Final Model	Latest SRS
North Dakota	26.5	27.1	25.9
northwest	24.5	25.6	24.9
north central	27.0	26.2	24.4
northeast	27.3	29.7	31.0
central	26.7	26.7	25.5
east central	28.0	30.7	28.8
southeast	28.2	28.3	22.8
South Dakota	25.7	17.0	18.0
northwest	24.1	18.7	17.4
north central	26.5	15.9	19.0
northeast	25.9	17.3	19.4
Montana	22.8	23.7	25.8
north central	23.4	25.0	27.5
northeast	22.2	23.3	25.0
Minnesota	28.9	33.7	31.0
northwest	28.9	36.2	33.7
west central	28.9	29.5	27.0
4-State aggregate	26.2	26.0	25.4

(A) Montana

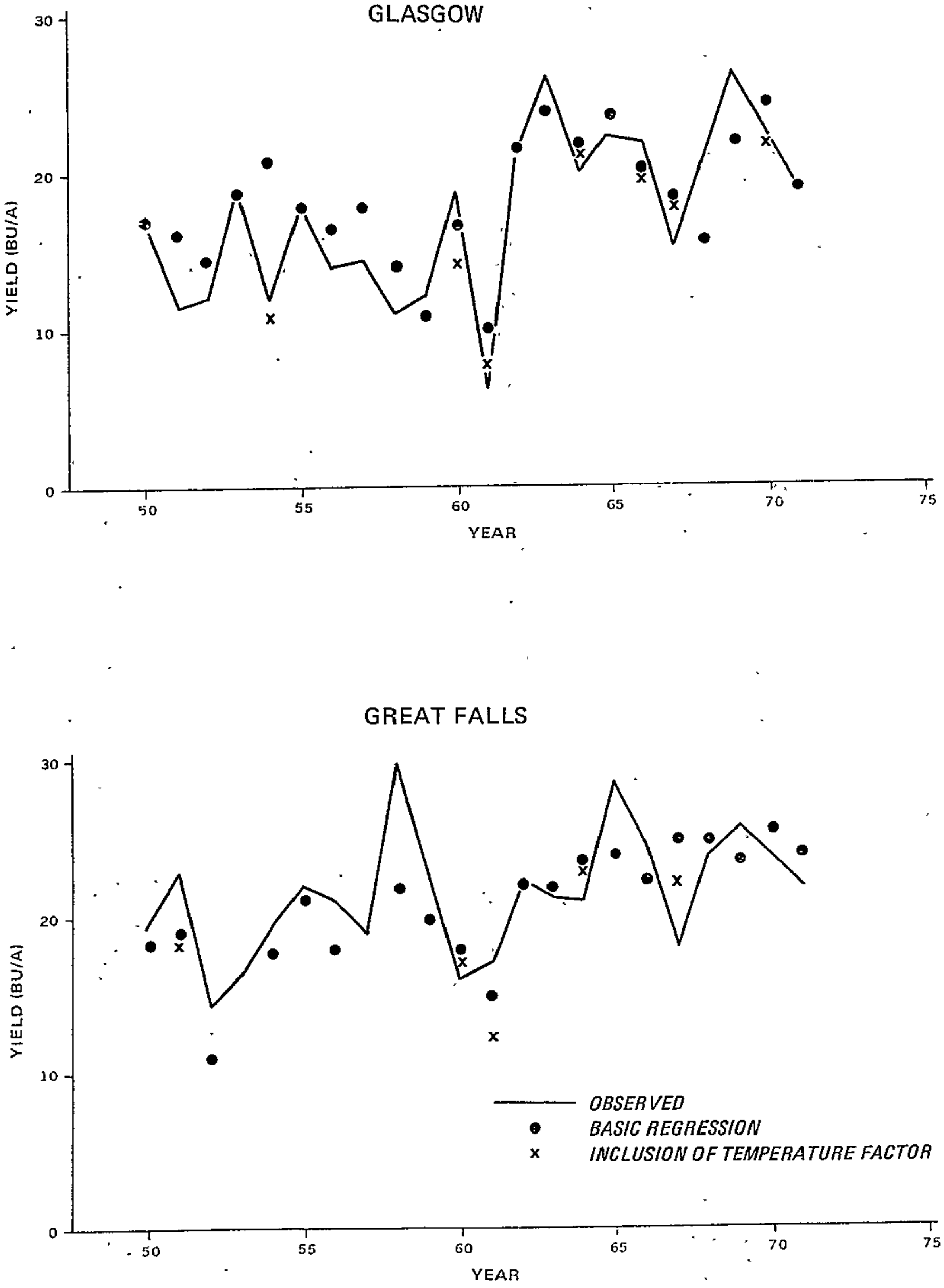
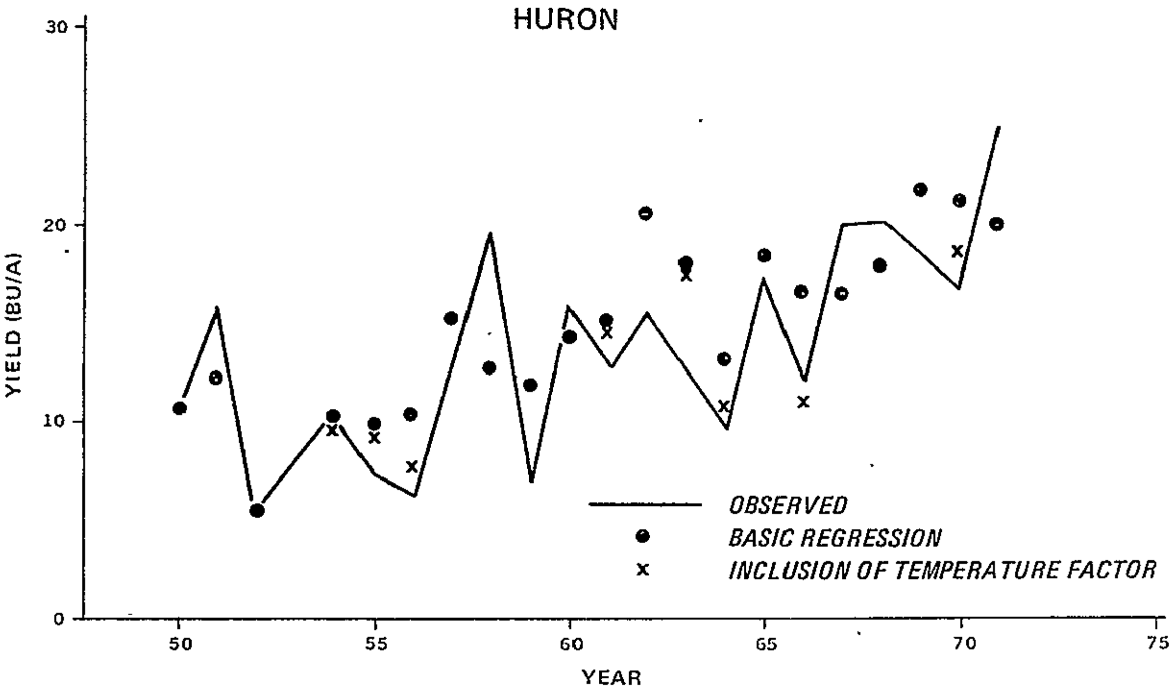


Figure 8-44: Comparisons of observed with regressed yields.

(B) South Dakota



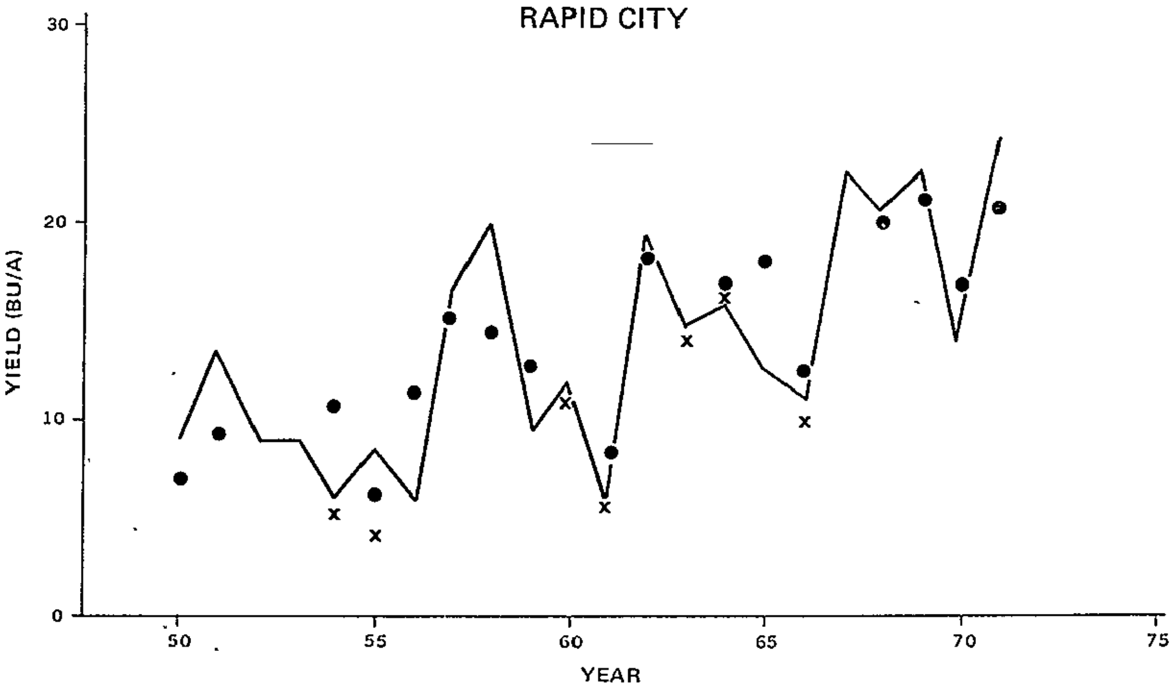


Figure 8-44: Continued

track the observed values rather well, but there is a tendency for the estimates to fluctuate less widely. The aggregated standard error of estimate is about three bushels per acre.

8.3.7 Daily Stress Weighting

It is a well established fact that the effects of significant moisture stress on plant vitality vary with the stages of growth, a phenomenon not accounted for in the 1975 EarthSat system. The major influence of water stress is manifest in the plant shoots. Stem elongation and growth is reduced for a stressed plant. The most important stage of growth relative to water stress is at pollination and flowering; water stress at this growth stage can produce significantly reduced yields in spring wheat.

Spring wheat is tolerant to light and moderate stress conditions and only small amounts of yield reduction will be seen for such stress except around the flowering to soft dough period where moderate stress will cause significant yield reductions. High stress will cause yield reduction at all growth stages but will be most important in the flowering to soft dough interval.

Transformation of the diagnosis of water stress from the EarthSat system requires the establishment of a reasonable relationship between stress and yield reduction and specification of a maximum yield potential (trend).

The transformation of daily moisture stress to yield percent reduction has been examined in North Dakota by Bauer. This relationship is shown in Figure 8-45. Note that the

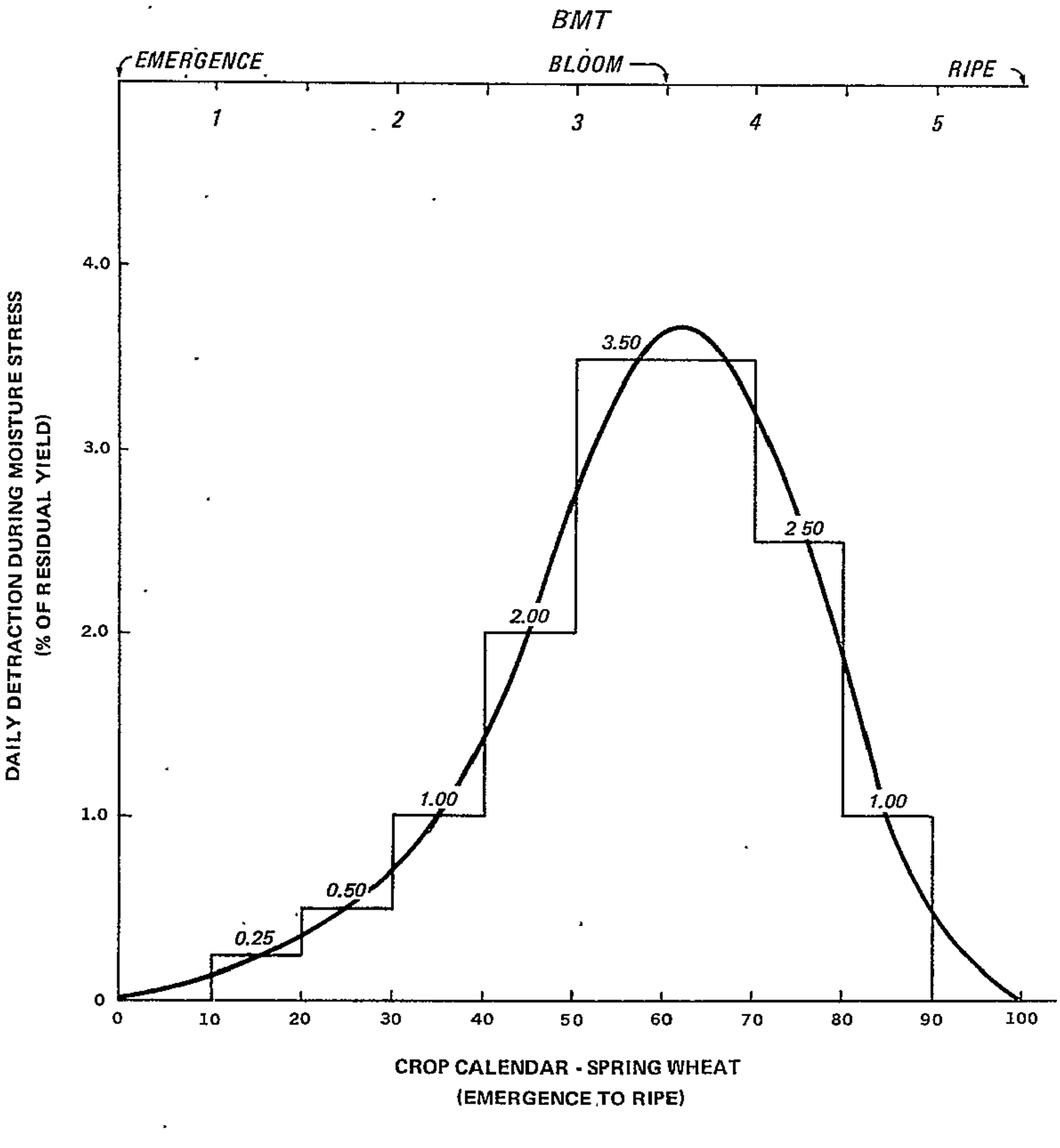


Figure 8-45: Daily moisture stress yield detraction.

maximum daily percentage reduction in excess of 3.5% per day of moisture stress occurs at the blooming (flowering) stage. The definition of moisture stress provided by the EarthSat system appears to be a reasonably promising approach. Figure 8-46 presents a graph showing the daily stress, the yield percentage reduction as a function of growth stage and the summations of the daily yield reduction for a 12.5 x 12.5 n.m. cell included in the Glacier County, Montana test site. The final yield value is estimated at 53.4% of the maximum value. Assuming a 38 bushel/acre maximum value which is reasonable for this small area of north central Montana a yield of 20.29 Bu/a is estimated. Observations taken by the Montana State team for the fields containing the neutron probes in Glacier County indicate an average of 21 Bu/a.

Regression using a historical data set for Huron, South Dakota, showed that the original approach using the square of average daily stress gives a standard error of estimate (SEE) of 3.15 Bu/a. Use of this daily weighted stress model reduces SEE to 2.43. This is representative of the reductions in SEE obtained at other locations in the growing region.

8.3.8 Monte Carlo Simulation

One of the fundamental components of an operational weather-based yield estimating system is the so-called "future weather generator." This component must provide an estimate of the weather which the crop will experience between the current date and the end of the growing season. This can use a very simple algorithm as was the case in EarthSat's 1975

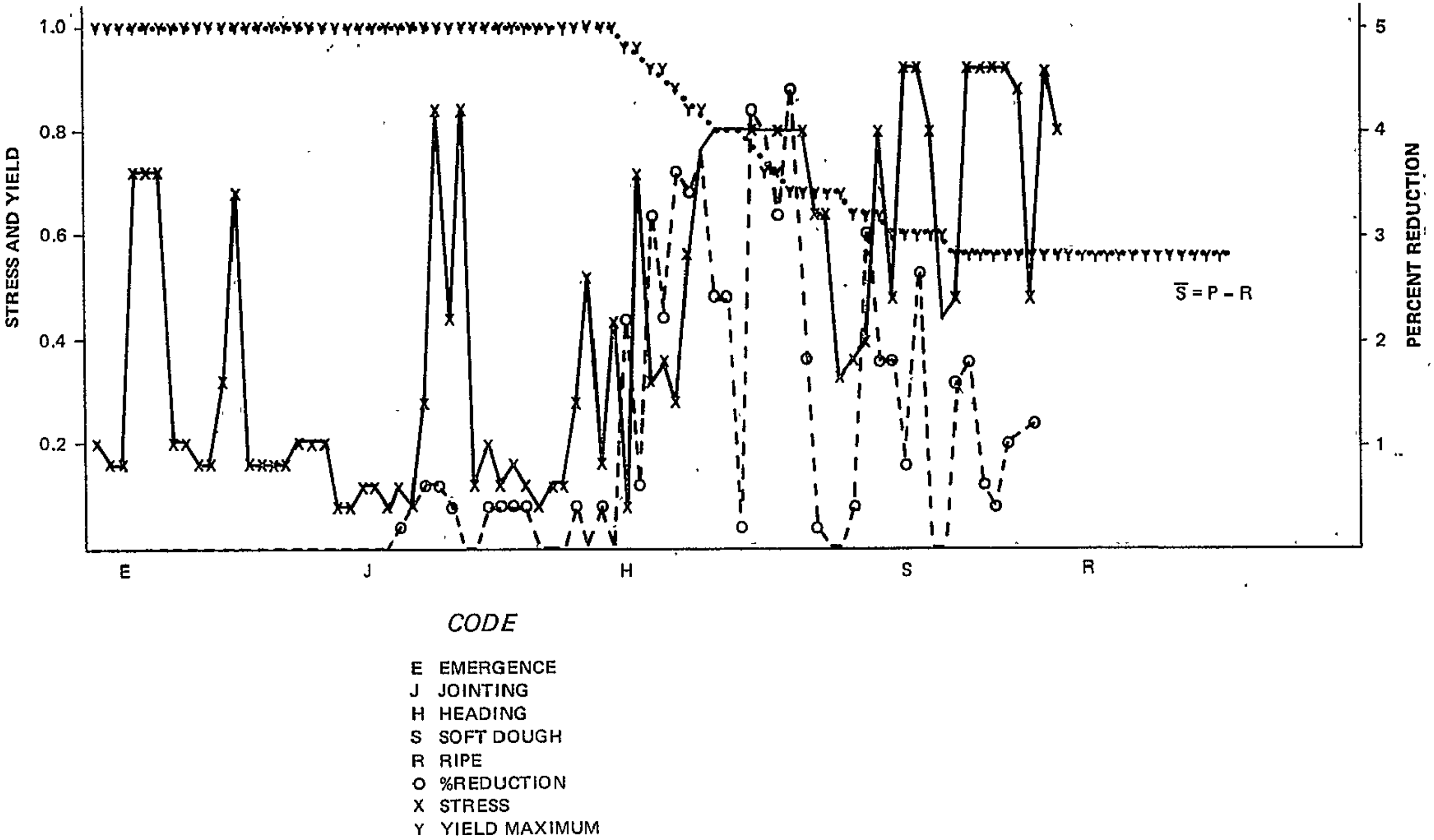


Figure 8-46: Stress reduction results for cell 206 336 A.

test. In this case the average daily stress which existed up to the date of projection was assumed to be the same as that which would exist for the entire season. The inadequacies of such an approach are obvious.

A much more sophisticated approach was developed and successfully tested for aggregation to the state level over a sample of 100 cells. This approach sought to generate a sequence of weather at the individual cell level which was based on random inputs, but which would still maintain realistic frequency distributions for rainfall. No attempt was to be made to maintain spatial consistency of weather regimes; rather, a sufficiently large number of growth-to-ripe calculations would be made at each selected sample cell, so that a mean and standard deviation of final yield could be determined to a desired confidence level. The final results should display a reasonable geographic continuity.

The key components of this system include:

a) Rainfall distribution (frequency and amount)
b) Daily temperatures
c) Daily potential evapotranspiration

These items are discussed in the following subsections.

8.3.8.1 Rainfall Distribution

The key element in the rainfall model was the generation of Markov chain probabilities of rainfall occurrence. These express the probabilities that day N will be wet (W) or dry (D) given that day N-1 was wet or dry. Data sets of about 20 years were examined for each of 13 stations in the growing region. Markov probabilities were generated for ten-day intervals in the growing season. Figure 8-47a presents the results for Aberdeen, South Dakota. For June 1 (day 152) for example, there is a 23% likelihood of rain if it rained on May 31. If May 31 was dry, however, the chance is only 12%. In the operational mode, a uniformly distributed random number between 0.0 and 1.0 is supplied. Assuming May 31 to be a rain day, if the random number is less than 0.23, June 1 will be a rain day; if greater than this it will be dry.

Once a day has been designated a rain day, the amount must be determined. The historical weather records were examined to calculate the parameters defining an incomplete gamma function which approximates the frequency distribution of rainfall amounts. These were defined for 30-day intervals in the growing season. Figure 8-47b summarizes the results for Aberdeen, S.D. In the operational mode, an additional uniformly distributed random number is used with the appropriate parameters to determine the rainfall amount for the day.

8.3.8.2 Daily Temperatures

Daily maximum and minimum temperatures are needed in the model to determine the rate of growth of the plant. Historical data was again used to generate average values and standard deviations at ten-day intervals. Recognizing the influence of cloudiness on

(A) 10-day Markov precipitation probabilities and mean temperatures.

```
INTERVAL        91-100               101-110               111-120               121-130               131-140               141-150
              D       W     TOT     D       W     TOT     D       W     TOT     D       W     TOT     D       W     TOT     D       W     TOT
           +-----------     ---  +-----------     ---  +-----------     ---  +-----------     ---  +-----------     ---  +-----------     ---
         D| 0.93    0.07    143 D| 0.91    0.09    143 D| 0.88    0.12    138 D| 0.91    0.09    141 D| 0.91    0.09    143 D| 0.88    0.12    139
         W| 0.77    0.23     13 W| 0.69    0.31     17 W| 0.73    0.27     22 W| 0.74    0.26     19 W| 0.75    0.25     17 W| 0.79    0.21     21

   TEMP      AVG     STD             AVG     STD             AVG     STD             AVG     STD             AVG     STD             AVG     STD

   DMAX      9.9     6.9            14.3     7.4            15.4     6.8            18.9     6.4            20.7     5.6            22.5     5.2
   DMIN     -2.7     4.1             0.1     5.0             1.4     4.5             3.6     4.6             4.9     4.6             7.8     4.6
           -------------           -------------           -------------           -------------           -------------           -------------
   WMAX      6.5     3.9             9.6     6.0            10.2     6.0            13.3     6.7            15.8     7.1            20.2     5.1
   WMIN      0.3     2.3             1.9     3.2             1.5     4.8             5.1     3.3             7.9     4.1            10.7     3.5
           -------------           -------------           -------------           -------------           -------------           -------------

INTERVAL        151-160              161-170               171-180               181-190               191-200               201-210
              D       W     TOT     D       W     TOT     D       W     TOT     D       W     TOT     D       W     TOT     D       W     TOT
           +-----------     ---  +-----------     ---  +-----------     ---  +-----------     ---  +-----------     ---  +-----------     ---
         D| 0.88    0.12    138 D| 0.88    0.12    140 D| 0.85    0.15    133 D| 0.83    0.17    133 D| 0.92    0.08    145 D| 0.87    0.13    130
         W| 0.77    0.23     22 W| 0.83    0.17     20 W| 0.72    0.28     27 W| 0.86    0.14     27 W| 0.93    0.07     13 W| 0.88    0.13     20

   TEMP      AVG     STD             AVG     STD             AVG     STD             AVG     STD             AVG     STD             AVG     STD

   DMAX     24.6     5.4            25.7     4.5            26.8     4.6            27.9     4.3            30.0     4.2            30.0     4.0
   DMIN      9.9     4.6            11.8     4.0            12.4     4.0            13.4     3.9            14.8     3.6            14.5     3.7
           -------------           -------------           -------------           -------------           -------------           -------------
   WMAX     22.9     6.2            24.9     3.6            25.5     4.4            28.3     4.0            28.8     4.1            28.8     2.3
   WMIN     13.1     3.3            14.3     3.2            14.1     3.4            15.1     2.3            15.9     2.3            16.3     2.0
           -------------           -------------           -------------           -------------           -------------           -------------

INTERVAL        211-220              221-230               231-240               241-250               251-260               261-270
              D       W     TOT     D       W     TOT     D       W     TOT     D       W     TOT     D       W     TOT     D       W     TOT
           +-----------     ---  +-----------     ---  +-----------     ---  +-----------     ---  +-----------     ---  +-----------     ---
         D| 0.94    0.06    146 D| 0.91    0.09    147 D| 0.93    0.07    148 D| 0.94    0.06    149 D| 0.90    0.10    144 D| 0.95    0.05    150
         W| 0.81    0.19     11 W| 1.00    0.0      13 W| 0.83    0.17     12 W| 0.82    0.18     11 W| 0.86    0.14     16 W| 0.83    0.17     10

   TEMP      AVG     STD             AVG     STD             AVG     STD             AVG     STD             AVG     STD             AVG     STD

   DMAX     29.2     3.9            29.2     5.1            29.1     4.9            26.7     5.2            23.8     5.9            20.9     5.7
   DMIN     13.4     3.5            12.8     4.5            13.3     4.6            11.0     4.7             8.3     5.1             5.1     4.7
           -------------           -------------           -------------           -------------           -------------           -------------
   WMAX     29.4     5.4            26.2     5.5            25.6     4.3            24.3     5.1            19.0     5.8            17.3     4.2
   WMIN     18.0     2.3            13.1     3.1            13.4     3.2            15.7     3.0             8.8     3.6             7.8     3.3
           -------------           -------------           -------------           -------------           -------------           -------------
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Figure 8-47: Data summary for Aberdeen, S.D.

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(B) 30-day precipitation amount analysis.

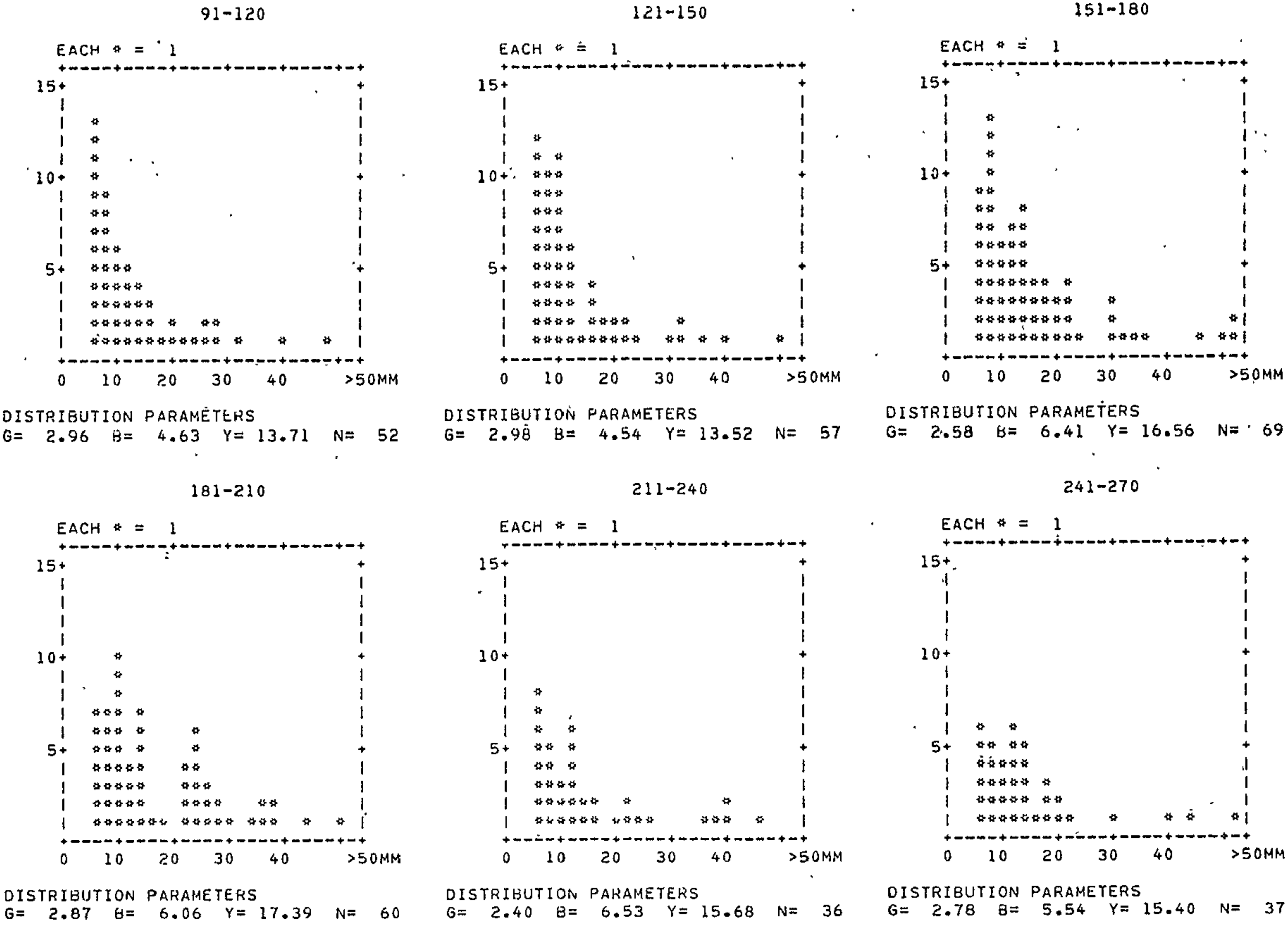


Figure 8-47: Continued

temperatures, separate averages were compiled for wet and dry days. The results for Aberdeen appear on Figure 8-47a. As would be expected, the maxima are higher and the minima generally slightly lower on dry days. For June 1, the Aberdeen average maximum and minimum are 22.9 and 13.1 wet, and 24.6 and 9.9 dry. A gaussian - distributed random number is used as a multiplier on the standard deviation and this product is added to the normal temperature value to provide day-to-day variability.

8.3.8.3 Daily Potential Evapotranspiration

In a manner analogous to the maximum and minimum temperatures, daily averages and standard deviations of potential evapotranspiration (ETP) were determined for wet and dry days at ten-day intervals. Due to the greater data requirements in evaluating ETP, this was done for only four stations across the region. For Huron, South Dakota, the June 1 average ETP is 4.89 mm wet and 7.05 mm dry. Just as for the temperature, a gaussion random number is used with the standard deviation to provide variation in the daily values.

8.3.8.4. Results of Sample Calculations

As a demonstration of the application of this method a limited exercise was conducted on a sample of 100 cells distributed throughout the growing region. For each cell, five projections were made from each projection date. Aggregations were made only at the state level, giving an effective average of 125 values for each projcetion. This approach has been designated SPRED (stochastic predictor) and the results are presented in Figure 8-48 where they are compared with the QPRED (quick predictor) results from Section 8.2.1 (Figure 8-2).

The most apparent feature of SPRED is the rapidity with which the projections converged to the final estimate. All states except South Dakota had converged to within 1.0 bu/acre of the final estimate prior to the end of June. In South Dakota, anomalously hot weather in early July decreased yields, after which the projection was virtually constant.

C-4

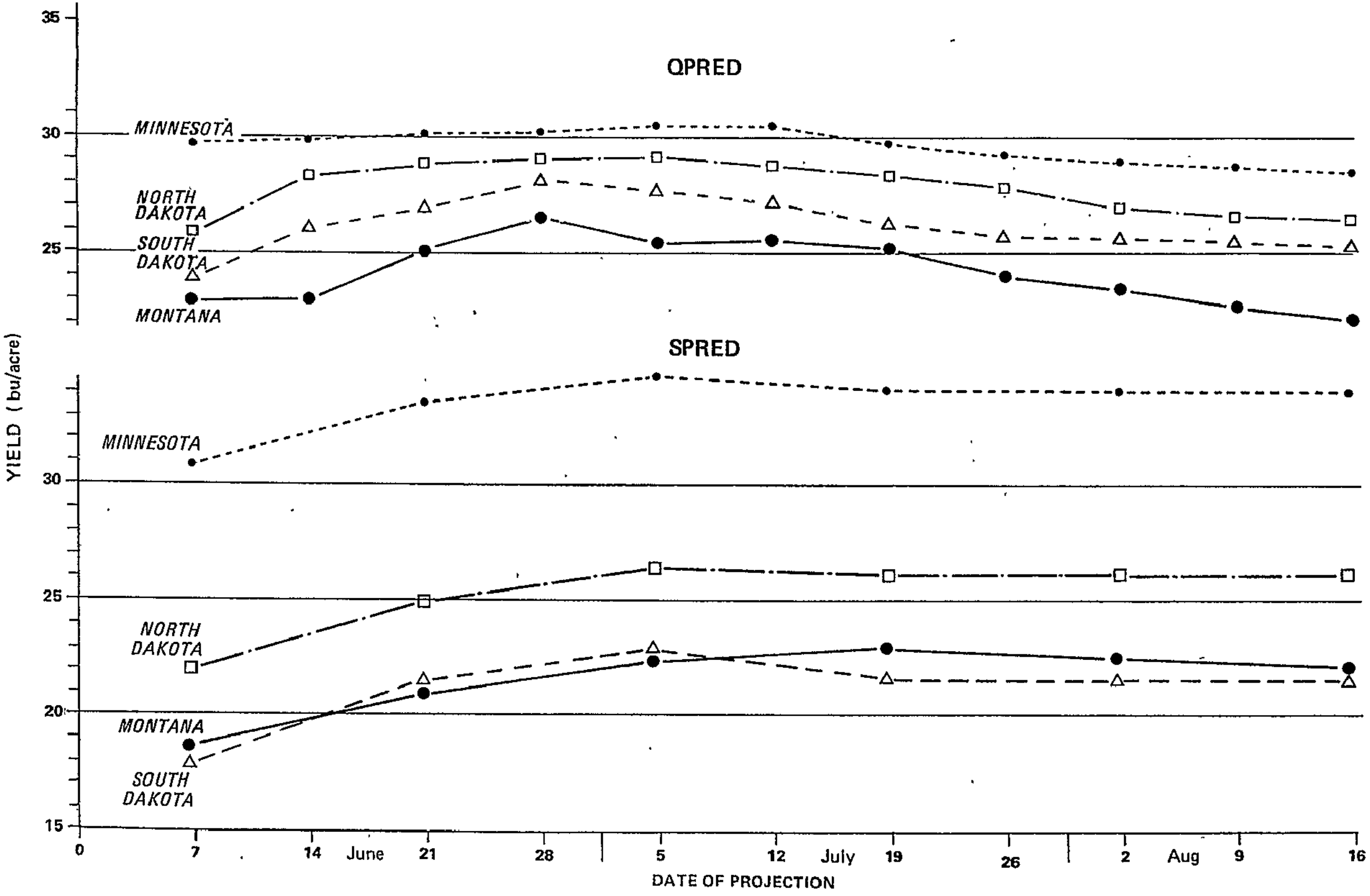


Figure 8-48: Comparison of QPRED with a cell sample developed with the Monte Carlo simulation model (SPRED).

9.0 SENSITIVITY ANALYSIS

The performance of the Plant Growth model is dependent upon two factors: the accuracy of the model and the accuracy of the data used to drive the model. Since the model is a simplification of reality and since the data is subject to error in observation or calculation, it is necessary to determine how sensitive the results of the model are to either data errors or errors caused by the mathematical construction of the model. These errors can be grouped into two categories: observational errors and definitional errors. Observations errors refer to those errors, random and systematic, derived from the measurement of physical data. Examples are errors in the measurement of precipitation, temperature, or an error in the starting soil moisture level. The second category of error encompasses errors in soil type assignment or in components of the growth model. The component section examines the BMT, ET, and stress formulas and evaluates the effects of the two error types on both the daily and seasonal levels. The system sensitivity section is concerned with the ultimate product of the system, yield, and examines the model as a whole.

9.1 Sensitivity Methodology

The techniques used in these evaluations are the classical techniques of sensitivity coefficients and Monte Carlo simulation. Where a relation between dependent and independent variables can be expressed in a differentiable equation, it is possible to derive the stability or sensitivity of the dependent variable to errors or perturbations in selected independent variables. For example, partials:

$$\frac{\partial z}{\partial x} \text{ and } \frac{\partial z}{\partial y}$$

represent the sensitivity of z to x and y respectively. If x and y are uncorrelated, then, given errors in x and y of Δx and Δy, the resultant error in z, Δz, can be approximated by:

$$\Delta z = \frac{\partial z}{\partial x} \Delta x + \frac{\partial z}{\partial y} \Delta y \qquad [9\text{-}1]$$

where the functions are evaluated at nominal values to xo and Yo.

Usually the exact error is not known, rather some parameter of the distribution of errors. Thus, equation 1 shows the error in z resulting from errors Δx and Δy. If, however, Δx and Δy vary, systematically and/or randomly, it is necessary to estimate the variance σ^2 which results from variances in x and y. The basic equation, which is derived in Bevington (1969) Chapter 4, is:

$$\sigma_z^{2} \approx \sigma_x^{2} \frac{\partial z}{\partial x}^{2} + \sigma_y^{2} \frac{\partial z}{\partial y}^{2} + 2\sigma_{xy}^{2} \frac{\partial z}{\partial x} \frac{\partial z}{\partial y} \qquad [9\text{-}2]$$

Using the assumption that x and y are independent and uncorrelated, the fluid term in equation 2 reduces to zero.

Critically important in the evaluation and use of sensitivity coefficients is the selection of representative data to be used as nominal values. This is especially true if the functional relation is nonlinear. That is, the partial derivative is still a function of the independent variable. A prime example of this is the BMT equation (eq. 28).

$$\frac{\partial \Delta BMT}{\partial T_1} = \partial T_1 + \beta \qquad [9\text{-}3]$$

Consequently, the value of the sensitivity coefficient will depend upon the value of T_1 used. The nominal values used in this section were selected as being reasonably representative of the data observed during the 1975 season.

VARIABLE	NOMINAL VALUE
Temperature (max.)	30C
Temperature (min.)	18C
Daylength (hrs.)	14
Soil Moisture	87.5mm
Soil Moisture Capacity	175mm
Average Stress	0.5
Dry-Down Curve Coefficient	1.0
k-coefficient	0.5
ETP	8.6mn
$\overline{\text{ETP}}$	8.00mn

Monte Carlo simulation assumes that some component of the system varies randomly. Repeated trials using different randomly generated numbers for each of the random components will provide measurements of performance under a variety of conditions. If the relation is unstable or highly sensitive to the input errors, the measurements will vary significantly.

To provide a base from which Monte Carlo simulations could be run, historical meteorological data for Fargo and Williston in North Dakota were analyzed. The six month season, from April through September, was partitioned into 18 10-day intervals. Precipitation, ETP, and temperature were extracted on a daily basis and the distribution parameters of each were calculated according to whether measurable precipitation was recorded or not. Thus means and standard deviations for temperature and ETP on wet and dry days were calculated. A two state Markov chain was derived for each interval. The Markov chain, or probability state matrix, contains the probability of transition from, for example, a dry day to a rain day given that the preceding day was dry. Similarly, if the preceding day was wet, then there exist probabilities, derived from observing the sequence of rain and dry days in historical data, that the succeeding day will be either wet or dry. In practice, if day 1 was dry, then the rain state for day 2 can be determined by generating a uniformly distributed random number and comparing it against the probability of a dry day following a dry day. If the random number is less than or equal to that dry-dry probability, then day 2 has no precipitation. Otherwise, day 2 will be wet and a precipitation estimate must be generated. Rain amount is drawn from the observation of historical rainfall amounts. A continuous approximation is made of the observed frequency histogram. Without going into the mathematics, a random number is generated and used to estimate a rainfall amount. Next, with the rain state determined, the temperature and ETP estimates can be calculated. [The techniques described were reported in a paper from Mississippi State University communicated to us by Dr. Charles Baker.]

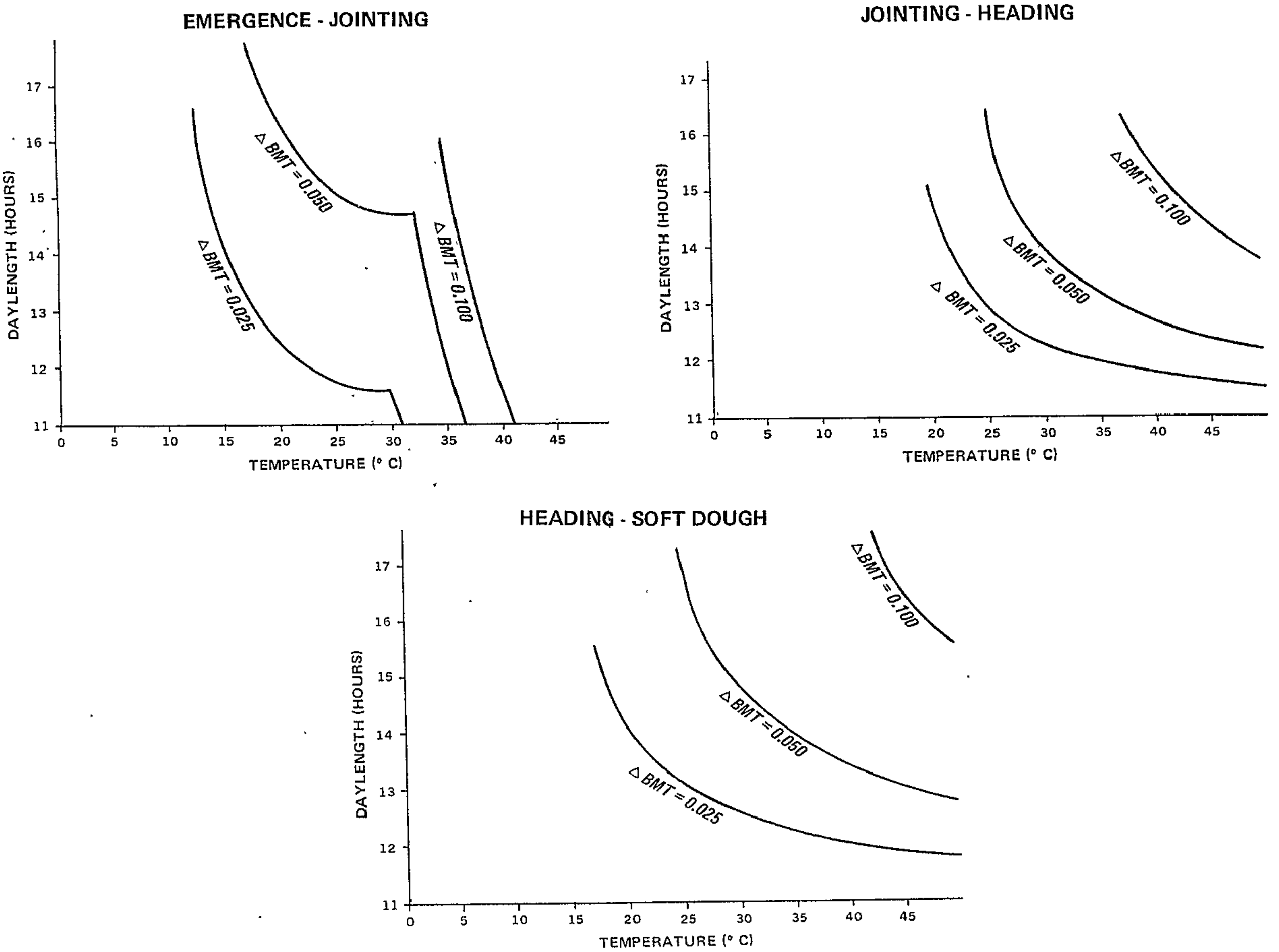
9.2.1 <u>BMT Sensitivity</u>

The equation for BMT is a triquadratic equation relating photo period and temperature extrema to the daily change in growth stage. The coefficients of the equation are unique for each growth stage and change immediately upon entering a new growth stage. Consequently, it is necessary to derive different sensitivity coefficients for each interval. Additionally, since the equation is quadratic for each of the independent variables, the value of the sensitivity coefficients will vary depending upon what nominal values are selected. A graphic explanation is that the sensitivity coefficient is the slope of the function at the point evaluated. For example, Figure 9.1 shows BMT isolines for varying values of daylength and maximum temperature (for these graphs, TMIN = TMAX-12). An error of 5°C (from nominal values of 30°C and 14hrs daylength) would effectively translate the line tangent to the BMT = 0.05 isoline to the right so that it intersected at 35°C instead of 30°C. The fraction of the distance traveled between adjacent isolines times the change in BMT rates would give an estimate of the effect the temperature error would have. In this case, the increase in the daily BMT rate is 0.0141, corresponding to a 28% speed up.

The sensitivity coefficients for the BMT intervals are listed in Table 1. Since daylength is a function of latitude and Julian date, the error in this expression is negligible. Temperature, however, is subject to estimation error. This error has been estimated to have a 0 mean and a standard deviation of 2.3°C. The net effect of this error distribution in both the maximum and minimum temperature measurements can be estimated using equation 2. Evaluating for each interval:

Figure 9-1:

BMT SENSITIVITY GRAPHS



EMERGENCE - JOINTING

JOINTING - HEADING

HEADING - SOFT DOUGH

TABLE 9-1

SENSITIVITY COEFFICIENTS

	P-E R-P	E-J	J-H	H-S	S-R
$\frac{\partial BMT}{\partial DAYLENGTH}$	0.0	7.83E-03	2.14E-02	1.15E-02	1.25E-02
$\frac{\partial BMT}{\partial TMAX(C)}$	-1.39E-02	7.79E-02	1.21E-03	1.54E-03	1.43E-03
$\frac{\partial BMT}{\partial TMIN(C)}$	1.17E-03	1.77E-04	1.61E-03	1.96E-04	7.33E-03

$\frac{\partial ET}{\partial ETP} = 0.3896$ $\qquad$ $\frac{\partial ET}{\partial DC} = 4.258$

$\frac{\partial ET}{\partial SM} = 0.00174$ $\qquad$ $\frac{\partial ET}{\partial k} = 8.516$

$\frac{\partial ET}{\partial ETP} = 0.1026$

$\frac{\partial STR}{\partial ET} = -0.125$ $\qquad$ $\frac{\partial STR}{ETP} = 0.0625$

$\frac{\partial YIELD}{\partial STR} = 31.2954$

INTERVAL	$\sigma_{\Delta BMT}$	% INCREASE OVER AVERAGE BMT RATE IN INTERVAL
P-E/R-P	0.032	32.0
E-J	0.064	128.0
J-H	0.0046	9.2
H-S	0.0036	7.2
S-R	0.017	17.0

The high value of the E-J precentage error and the "break" in the graph of Figure 9.1 is a function of the coefficients used in that growth interval. Examination shows that the growth rate is not affected by the maximum temperature until 34.16°C. Above that level, the growth rate increases drastically as can be seen in Figure 9-1. At the nominal values, the growth rate is 0.04395. Raising the maximum temperature to 40°C raises the growth rate to 0.2817 BMT units per day. Robertson (1968) reports that this phenomena is due to few data points above the critical value. Nonetheless, the temperature is not unheard of and in a delayed season may cause accelerated growth.

Since the temperature errors are random, it is reasonable to expect that the observed errors will tend to cancel each other out over time. To test this, 600 growth cycles were simulated. In the base model, 300 cycles were run using the temperature data for Williston, North Dokata. To do this, a 2nd order polynomial was fit through the mean temperature values for each of the 18 10-day intervals. Thus, for any data within the season, an average temperature could be derived. Using the standard deviation of temperatures observed for that interval, a random deviation from that day's mean temperature was generated. This was done for both the daily maximum and minimum temperatures. The season was processed and information kept as to the total length of the season and the length of each BMT interval. After this was completed, the process was repeated. This time however, after the daily temperatures were estimated, zero-mean noise with a 2.3°C standard deviation was added to each temperature measurement simulating the incorporation of observation errors of the METRUN system.

The results of the simulation are shown below. It appears that the assumption of error cancellation is valid.

	ND	ND(PE)	ND(EJ)	ND(JH)	ND(HS)	ND(SR)
WILLISTON						
MEAN	86.48	8.2	20.3	23.1	23.5	11.4
NO ERROR σ	7.22	0.86	1.89	2.01	2.06	1.15
MEAN	36.06	8.5	19.8	22.2	23.8	11.8
ERROR σ	7.39	0.86	2.01	2.29	2.12	1.20

9.2.2 ET Sensitivity

The second component under examination is ET. As discussed in Section 7.5, the primary source of error in the ET relation is definitional. That is, if the wrong dry-down curve is specified, very large errors can result. To determine the magnitude of the potential error, the sensitivity coefficients were derived and are shown in Table 9-1. Examining the magnitude of the coefficients, it is immediately apparent that ET is extremely sensitive to errors in the dry-down curve and k-coefficient. This serves to confirm the observations made in Section 7.

While the errors in k and DC terms are definitional, the remaining three coefficients are observational and related to the construction of the ET relation. ETP, soil moisture, soil capacity, and $\overline{ETP}$ are used to estimate the atmospheric demand coefficient (ADC) discussed in Section 7.1.2. Being an exponential function, this term is nonlinear and thus the sensitivity coefficients are valid only about the nominal values. To obtain a better understanding of this term, Figure 9.2 was constructed. This figure shows constant value isolines for ADC as a function of ΔETP (=ETP-$\overline{ETP}$) and the fraction of soil moisture capacity ($=\frac{SM}{SMC}$). The mathematical result of ADC is to reduce or amplify ET.* There are two regions in the figure which are sensitive to error. Near 72% of capacity (SMR 0.72), an error in the soil moisture level will cause a larger error in ADC than at any other SMR level. However, since large ΔETP's are infrequent, the impact of this error should amount to no more than 3-4% on average. More serious, however, is the sensitivity of ADC to errors in ΔETP at low SMR levels. For example:

$$\frac{\partial ADC}{\partial ETP}_{SMR=.5} = -0.024 \qquad \frac{\partial ADC}{\partial ETP} = -0.065 \quad SMR=.1$$

indicating increased sensitivity at low SMR levels. However, since the sign of the coefficient is the opposite of that of the ETP error, the ADC will tend to dampen the errors in the

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* Analysis of the work by Denmead and Shaw (1962) indicates ADC $\leq$ 1.0.

ATMOSPHERIC DEMAND COEFFICIENT ANALYSIS

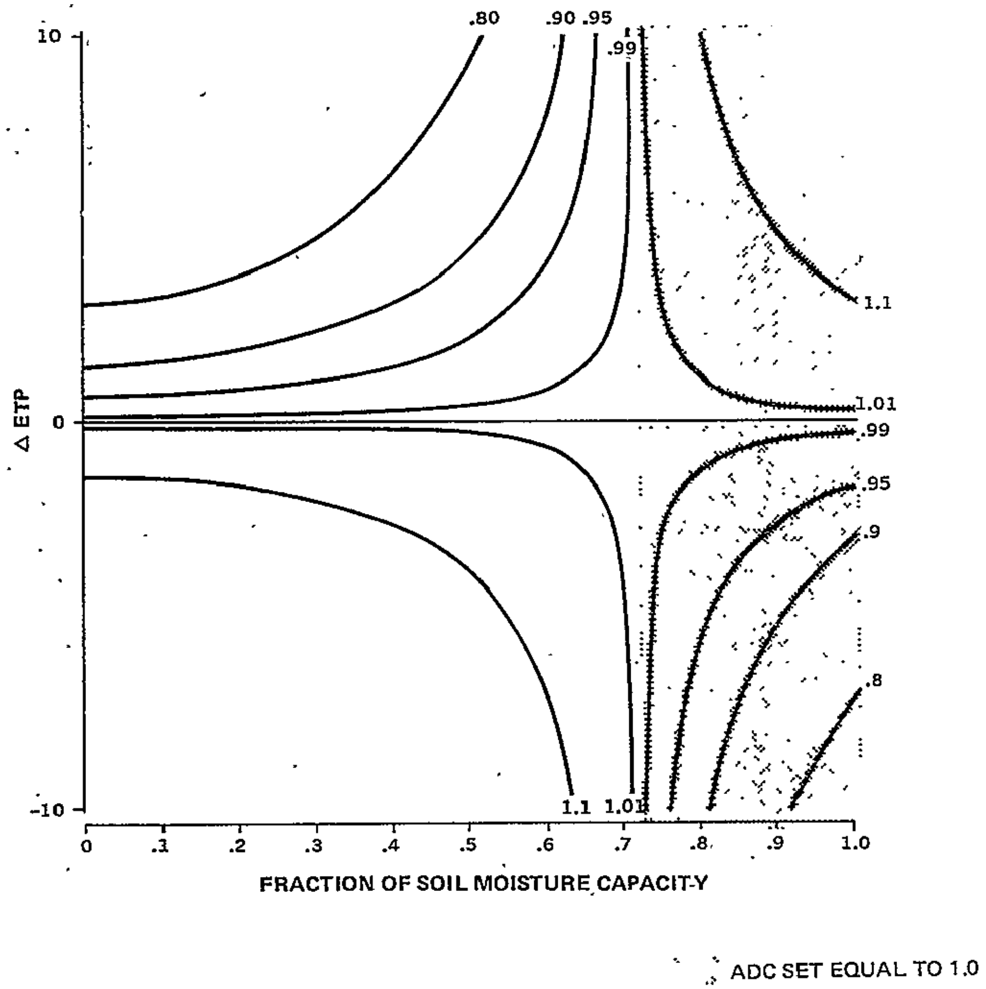


Figure 9-2:

observation of ETP. To verify this observation the sensitivity coefficient of ET with respect to ETP was recalculated using SMR = 0.10. For this case:

$$\frac{\partial ET}{\partial ETP} = 0.1966$$

The cumulative effects of errors in the components of ET is observed by errors in the soil moisture levels. As observed in the evaluation of random errors on BMT, purely random errors should cancel overtime. In the ET relation, this will apply to ETP and the ADC. The systematic overestimation of ETP will overestimate ET on a daily basis. $\overline{ETP}$ is based on historical station data, then the systematic positive ΔETP error will result in ADC's <1.0 reducing the impact of the ETP error (by 21% at ETP = 8.65 level).

9.2.3 Stress Sensitivity

The last component calculated on a daily basis, and the most important since it directly influences yield, is daily moisture stress. Given the relationship of stress:

$$STRESS = 1.0 - \frac{ET}{ETP} \qquad (3)$$

it is readily apparent that those factors affecting ET will directly impact on stress.

$$\frac{\partial STR}{\partial DC} = \frac{\partial STR}{\partial ET} \cdot \frac{\partial ET}{\partial DC} = .49$$

Thus, if the DC coefficient error is -0.5, the effect will be to raise the daily stress value by 0.246.

It is difficult to go much beyond stating the sensitivity of stress to some of its independent variables since stress, like ET, is not directly measureable. It is possible, like the ET error analysis, to eliminate as many variables and observe the remainder. To do this, a 60 day weather scenario was postulated. Each day was identical to the previous.

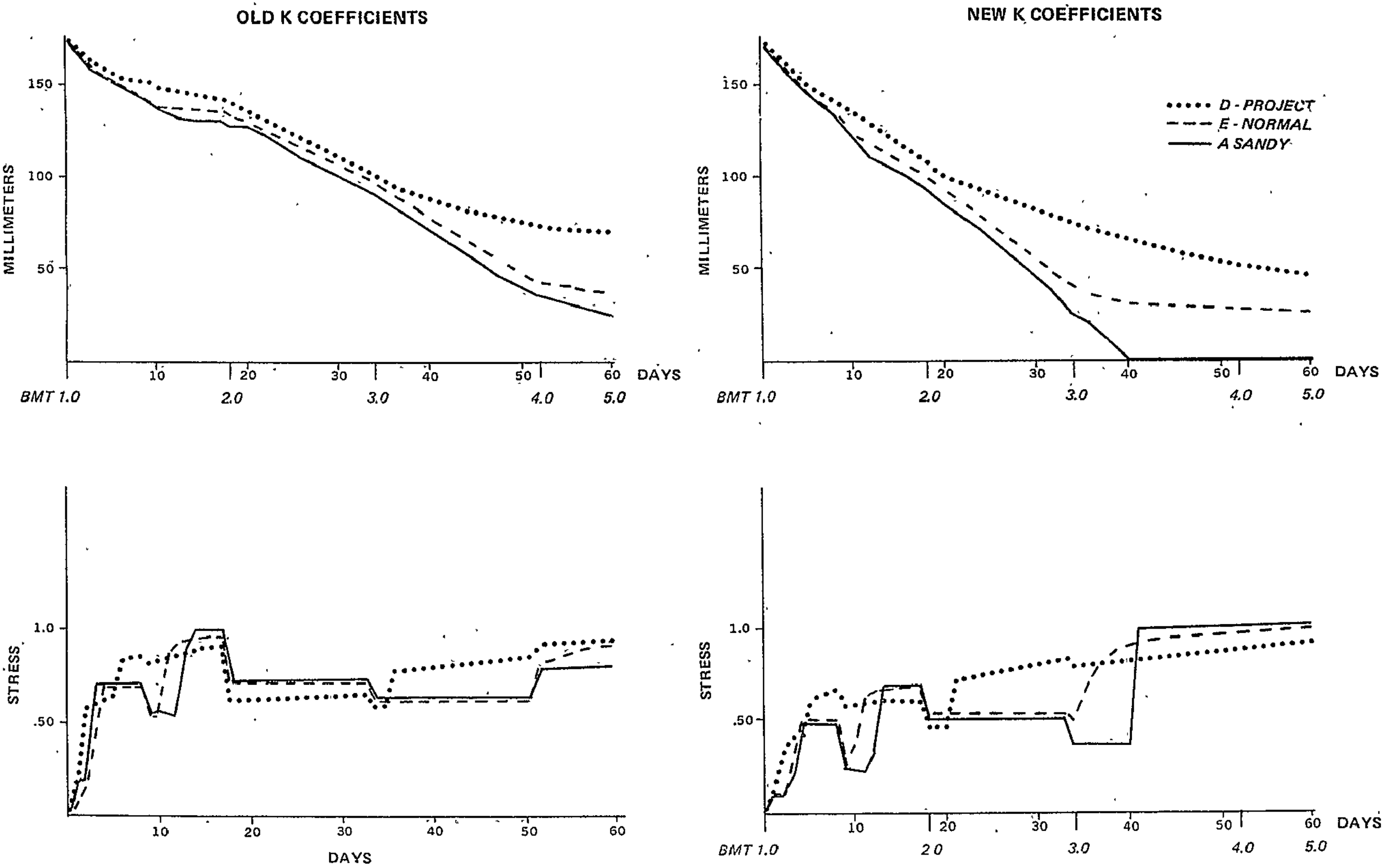
TMAX = 30°C
TMIN = 18°C
ETP = 8mm
PRECIPITATION = 0.0mm

Starting with a full soil moisture profile, the constant ETP meant that ADC = 1.0. Figure 9.3 shows the results of these comparisons for the 3 dry-down curves and 2 sets of k-coefficients.

Two conclusions result from the analysis of the curves. First, at high soil moisture levels, all 3 curves respond similarly. The main difference results from the drying of the upper layers and, when possible, extraction from lower layers (not possible with old k and BMT<2.0 since $k_3 = 0$ - all curves reach a "floor"). It is apparent, too, that the new k coefficients dry the soil profile more quickly and, consequently, reach their effective floors after about 40 days. Secondly, the impact of changing k-coefficients can be seen in the

Figure 9-3:

DRY DOWN PATTERN COMPARISON



graphs of daily stress as the growth stage changes. In essence, this must be considered noise on top of which the actual influence of moisture stress is added. Given the sensitivity coefficients of stress and the time series analysis in Figure 9.3, it appears that only moving averages of daily stress will have meaning.

9.3 System Sensitivity

The ultimate product of the Agmet system is the estimation of yield. As a result, it is necessary to relate the errors and sensitivities discussed in previous sections to yield. The yield model used in this project estimates yield from the planting-to-ripe average moisture stress. The basic yield - stress relation is shown in Figure 9.4. This analysis is divided into two parts. First, since ET is not directly observable, an alternate expression for seasonal ET is derived relating soil moisture level, precipitation, and infiltration to total season ET. As will be shown this expression can be directly related to average stress permitting examination of the influence of some observable parameters. The second section evaluates the influence of asymetric meteorological trends on average stress.

9.3.1 Evaluation of Stress and Yield

The definition of average stress used in this project is:

YIELD LOSS DUE TO PLANT STRESS

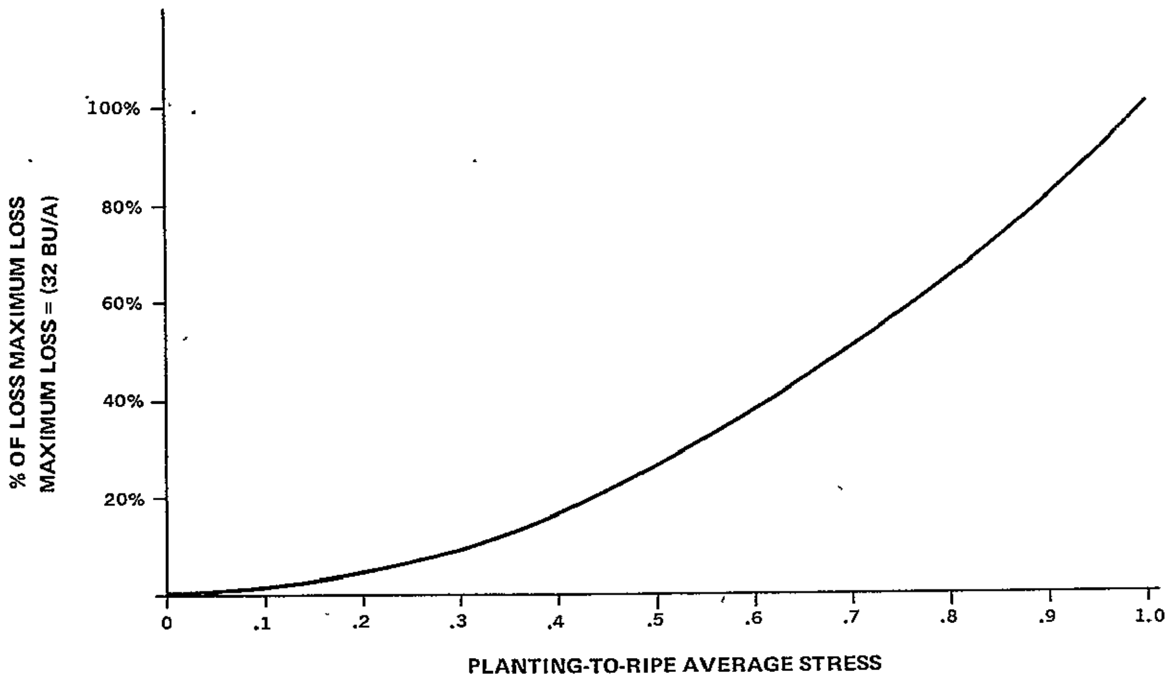


Figure 9-4:

$$\overline{STR} = \frac{1}{N}\sum_{i}^{N} STR_i = \frac{1}{N}\sum_{i}^{N} \left(1 - \frac{ETi}{ETPi}\right) \qquad [9\text{-}4]$$

$$= \frac{N}{N} - \frac{1}{N}\sum_{i}^{N} \frac{ETi}{ETPi} = 1 - \frac{1}{N}\cdot \sum_{i}^{N} \frac{\left[\prod_{j}^{N} ETPi_{\,j\neq i}\right] ET_i}{\prod_{i} ETP_i} \qquad [9\text{-}5]$$

It can be demonstrated that for large N

$$\prod_{i}^{N} ETP_i \approx \overline{ETP}^{N}$$

Thus equation 5 reduces to:

$$\overline{STR} \approx 1 - \frac{1}{N} \frac{\sum_{i}^{N} \overline{ETP}^{N-1} ET_i}{\overline{ETP}^{N}} = 1 - \frac{1}{N} \cdot \frac{\overline{ETP}^{N-1} \sum_{i}^{N} ET_i}{\overline{ETP}^{N}} \qquad [9\text{-}6]$$

$$= 1 - \frac{1}{N\,\overline{ETP}} \cdot \sum_{i}^{N} ET_i \qquad [9\text{-}7]$$

It is possible at this point to replace ΣET by

$$\sum_{i}^{N} ET_i = SM_{FINAL} - SM_{START} + \sum_{i}^{N} PRECIP_i + \sum_{i}^{N} RUNOFF_i \qquad [9\text{-}8]$$

Substituting 8 into 7 we get

$$\overline{STR} = 1 - \frac{1}{N\overline{ETP}}\left(SM_{FINAL} - SM_{START} + \Sigma\ PRECIP + \Sigma\ RUNOFF\right) \qquad [9\text{-}9]$$

Taking the partial of yield with respect to average stress,

$$\frac{\partial YIELD}{\partial \overline{STR}} \quad -62.5908 \; . \; \overline{STR} \qquad [9\text{-}10]$$

Combining equations 9-9 and 9-10, it is possible to estimate the impact of certain observation errors directly to yield. For example, the error analysis of the METRUN precipitation estimates showed a persistent overestimation of light precipitation and an underestimation of heavy rainfalls. The verification table generated in Section 6 (Fig. 6-7) was analyzed to estimate the average total observed season precipitation and the average total predicted precipitation amounts per day, and then multiplying by the number of days processed. For this project, these values were

AVERAGE OBSERVED TOTAL	212.72
AVERAGE PREDICTED TOTAL	257.50

Assuming that the start and final soil moisture levels remain the same, and using the nominal values in Section 9.1, the effect of an increase of a 44.78mm precipitation increase is a decrease in average stress of 0.0615. Evaluated at a nominal average stress of 0.5, the net effect on yield is an increase of 1.92 bu/a. An important observation is that as long as total precipitation is constant, it does not matter when or in what amounts rainfall is recorded. Similarly if start soil moisture is over estimated by 25mm, the net impact is an increase in total ET, decrease in stress of -.034, and an increase in yield of slightly more than 1 bu/a.

9.3.2 Average Stress Model Sensitivity

A common question raised about the current EarthSat System yield model centers on the acknowledged fact that the averaged planting to ripe stress value can be derived from several scenarios. This concern is legitimate and must be answered. The answer, however, may rest more in the physiology of wheat than in a sensitivity analysis. The following paragraphs will address the pertinent physiological factors and discuss a brief scenario simulation sensitivity evaluation.

9.3.2.1 Moisture Stress in Relation to Yield and Plant Physiology

Yield Y in wheat is expressed quite clearly by the following simple expression:

$$Y = H_n \cdot K_n \cdot W_k$$

where:

H_n = No. of heads per plant

K_n = No. of kernels per head

W_k = Weight per kernel

Each term in this expression is defined rather uniquely at specific growth stages. The distribution of these specific stages is roughly symmetrical to the flowering of the plant. For example, for a 100 day variety:

- The number of heads is determined at the Tillering stage approximately 20 days after planting.
- The number of kernels per head is defined at flowering approximately 50 days or so after planting.
- The weight per kernel is defined in the filling stages usually by the Soft Dough stage approximately 80 days after planting.

The effect of moisture stress on yield is shown by Figure 8-45 to be approximately symmetrical around flowering. That is, if stress is held constant throughout the crop growth period, yield will vary according to the function described by Figure 8-45. Therefore, averaged planting to ripe stress will have the same influence on yield if it is arrived at from a constant stress, one which is high early in the season and low toward the end or low early and high later on, as long as it is distributed roughly symmetrically to flowering.

In the EarthSat System, use of averaged planting to ripe stress the average is significantly weighted to the flowering period through, (a) the K coefficients and (b) the length of the critical phenological intervals, i.e. approximately 50 days from Jointing to Soft Dough when moisture stress is most significant.

In an excercise to test analytically some of the assertions mode in the previous paragraphs the Monte Carlo simulation routine was used to define a number of probable and improbable weather scenarios. In the analysis, the three primary variables, i.e. temperature, ETP and precipitation were systematically varied through three, offset modes ranging from +1/2σ to -1/2σ, using an historical data set. Each of the three variables were offset and daily values were generated by the Monte Carlo simulation. Rainfall was generated by the Markov state probabilities defined in Section 8.

The Monte Carlo simulation models was then cycled through ten times for each of the 27 probable and improbable scenarios.

The results shown in Table 2 for average stress variations, but neglecting such absurdities as low temperatures and high ETP, high temperatures and low ETP, etc. demonstrate the invariability of the average stress for symmetrically distributed weather scenarios.

The temperature influence on the length of the wheat crop season is clearly shown in Table 3. High early temperatures shorten the season length while low early temperatures lengthen the season. The symmetrical distribution specified however still produces a symmetrical influence as the wheat plant centered on flowering.

TABLE 2

AVERAGE STRESS MEANS

TEMPERATURE MODE			PRECIP. MODE		
			1	2	3
1	E M	1	.54	.67	.65
	T O	2	.55	.64	.67
	P D	3	.48	.64	.65
	E				
			1	2	3
2		1	.53	.58	.67
		2	.54	.69	.68
		3	.54	.67	.67
			1	2	3
3		1	.53	.70	.69
		2	.53	.70	.70
		3	.56	.71	.70

TABLE 3

SEASON LENGTH MEANS

TEMPERATURE MODE			PRECIP. MODE		
			1	2	3
1	E M	1	75.0	73.1	75.2
	T O	2	75.5	75.2	75.3
	P D	3	73.3	75.7	75.5
	E				
			1	2	3
2		1	85.3	86.7	87.4
		2	87.8	86.2	85.1
		3	88.3	86.0	85.3
			1	2	3
3		1	109.2	106.9	110.5
		2	107.0	101.9	108.5
		3	108.3	105.5	102.0

The use of the averaged planting to ripe stress model has been shown in Section 8 to be inferior by about a one bushel standard error of estimate to the daily weighted moisture stress approach. However, there is no doubt that the averaged approach produces acceptable results.

The Monte Carlo simulation was used where the 3 driving variables (temperature, ETP, and precipitation) were systematically offset. That is, using the historically derived climatological data, each variable was systematically offset and the daily values generated randomly about the offset mean. The offset, or bias, is +1/2σ of that variable's observed variation at day 91 and decreases linearly to -1/2σ at day 280. A second mode has values -1/2σ and +1/2σ at days 91 and 270 respectively, while a third, used as a base for comparison has no systematic offsets over time. While temperature and ETP are treated as described, precipitation amount is not varied. Instead, the Markov rain state probabilities are modified, simulation more frequent rain patterns at one end of the season and drought at the other.

With the above modifications, the Monte Carlo simulation model discussed in Section 9.2.1 was cycled ten times for each of the 27 possible combinations of variable modes. The results are summarized in Tables 9-2 through 9-3. Analysis of the tables provides some insights into the model. First, as might be expected from the sensitivity coefficients in Table 1, early season higher temperatures will substantially shorten the growing season. Conversely, a cool start will result in a long season. It must be noted that if ETP is systematically higher throughout the season, then average stress will rise. However, a planting-to-ripe average as a yield indicator does not appear to be sensitive to this type of variation. Third, in Table 2, note that the precipitation mode determines average stress, regardless of season length or ETP mode.

Explanations for these results appears to agree with the analysis in Section 9.3.1. If the total precipitation increases, then average stress will, in average, drop. Similarly, if the average ETP remains approximately constant, then no variation in average stress can be detected, regardless of the time in the growth cycle high ETP is observed. Temperature, despite the variation in season length and accompanying shift in the application of k-coefficients appears to have no discernible impact on stress. Caution must be used in extending the Monte Carlo results too far. They are based only on 10 iterations and, as a result, statistical significance tests were not applied.

10.0 SYSTEM OPERATIONAL EVALUATION

The "System" operated during 1975 over the upper Great Plain hard red spring wheat was obviously a prototype developmental system. The prior development work had brought the system to a state of quasi-readiness; however, the new region brought with it new problems and demands. The fact that these problems were overcome and the demands met is certainly demonstrated by the fact that a system was operating within 30 days of final go-ahead. Yield estimates were developed for the test area at two week intervals/bushels/acre with region aggregated errors approaching zero.

In the following sections we will examine some of the operating problems in the 1975 operating environment and then look forward to a 1976 operating environment and then to a 1980 operating environment.

10.1 1975 Operating Problems

In 1975 ground observations were acquired from Service C teletype rolls that were periodically picked up at the World Weather Building near Hillcrest Heights, Maryland approximately 56 miles from EarthSat's office. SMS satellite data were received by mail in standard hard copy print formats from Kansas City. The majority of the operating problems were associated with these data inputs.

10.1.1 Preparation of Synoptic Station Data for Input to the System

The major steps involved in the preparation of synoptic stations meteorological data are graphically outlined in

Figure 10-1. A detailed discussion of each of these steps is presented in Section 4 of this report.

During the operations minor problems were encountered at several steps of the data preparation. These were: 1) Service C teletype transmission errors and/or erroneous readings of meteorological parameters, 2) missing data, 3) introduction of errors during data extraction and keypunching.

Most of the transmission errors and erroneous readings inherent with any teletype data system could be recognized and corrected by an experienced meteorological technician.

To overcome the problem of missing data we telephoned the synoptic stations periodically. In future operations Service A teletype transmissions could be used as a back-up to overcome this problem.

Obvious errors introduced during data extraction and keypunching were corrected by computer software subroutines which checked the data before these entered the data library. In the future these subroutines could be refined to eliminate more subtle errors.

Notwithstanding these minor problems, the manual process of extraction and preparation of synoptic data for the AGMET system was generally smooth and trouble-free. One major improvement envisioned for the future would be to channel the teletype reports directly into a computer data storage system. This would greatly speed up the operations. Of course, software would be necessary to check data for consistency, transmission errors, and original reporting errors before these could be fed into an AGMET system.

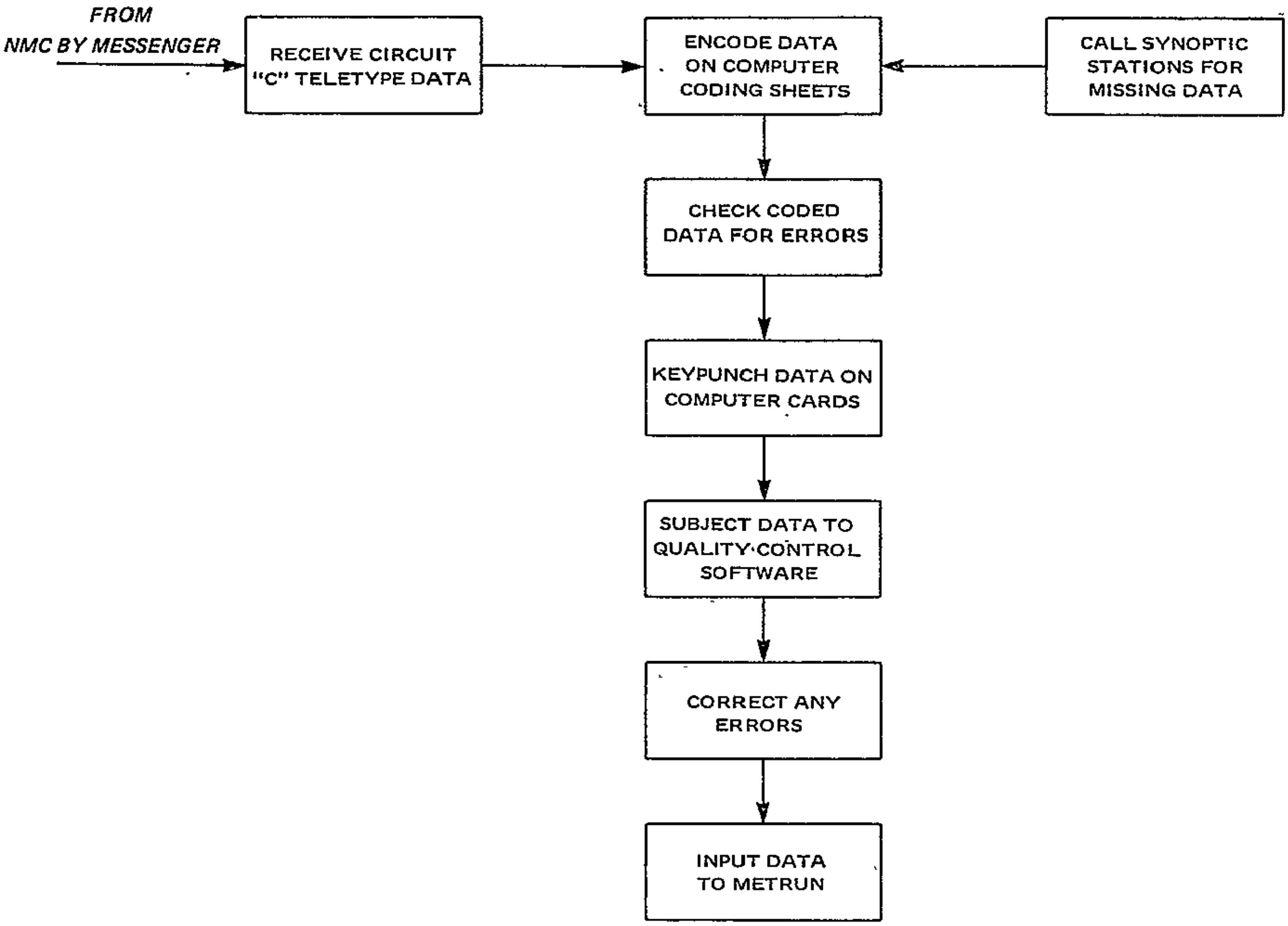


Figure 10-1: Procedure for preparation of meteorological data from synoptic stations.

10.1.2 Preparation of Satellite Data for Input to AGMET

The major steps involved in the extraction of cloud cover information from SMS images are graphically outlined in Figure 10-2.

The utilization of satellite cloud cover for estimation of the net radiation term in the Penman ETP equation and for improving rainfall estimates is a major and unique feature of our AGMET system. Several minor problems were inherent in the manual and visual extraction of cloud information from SMS images:

1. Analysts' subjectivity in cloud cover analysis and location introduce random errors of the order of 30 ly/day in the net radiation estimation.
2. Excessive manpower requirements. Approximately two man-days were required to analyze, encode, punch, and check one day of satellite data (four SMS images).

A major improvement which could eliminate some of the analyst's subjectivity and greatly speed up operations, especially if the system is to be employed over larger areas (the entire U.S., for example), would be a computer-analyst interface system. In such a system, outlined in Figure 10-3, the needed teletype and satellite image data is contained in a computer data base accessible to the analyst via a CRT display. The analyst would use the display to locate cloud types, rainfall areas, etc., verified by teletype data which could be alternatively or simultaneously displayed with the satellite image. The analysts would have available such parameters as cloud brightness and cloud top temperatures and actual rain reports

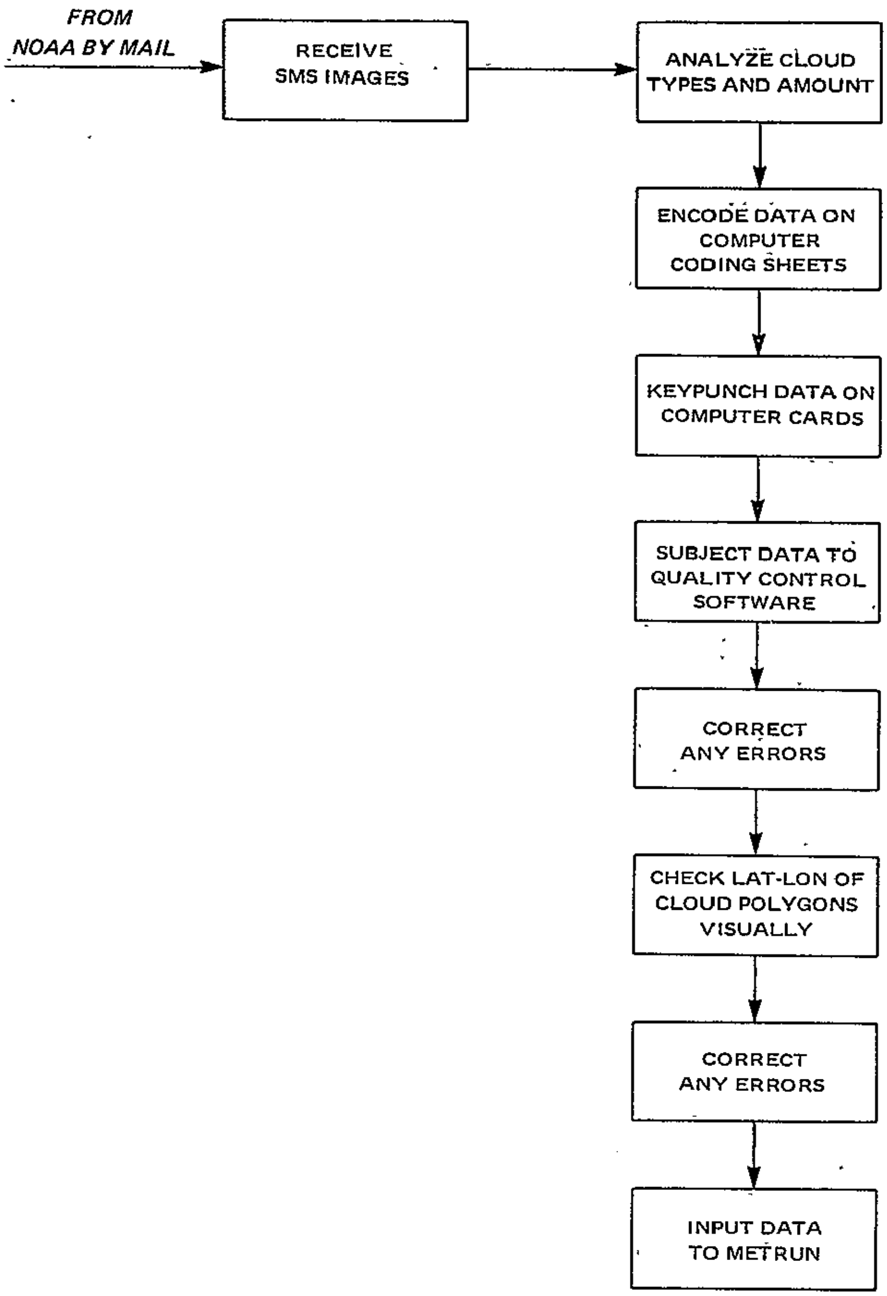


Figure 10-2: Procedure for extraction of cloud cover information from SMS images.

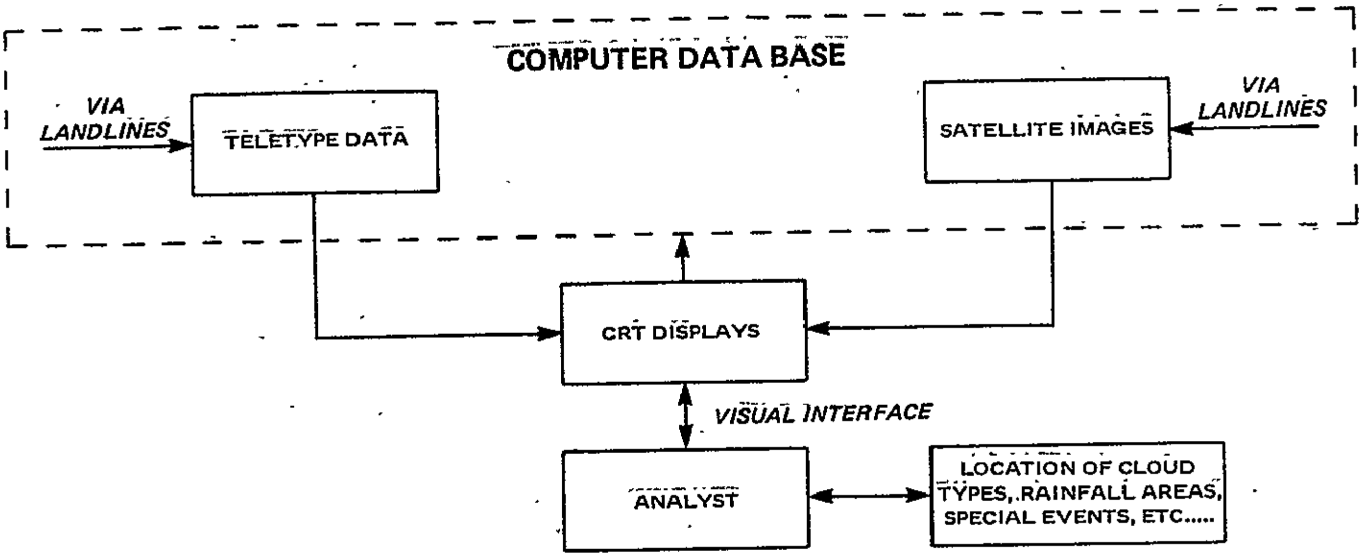


Figure 10-3: Postulated interactive system for processing meteorological inputs.

to delineate rainfall areas and amounts. The analyst would then use a cursor to outline on the CRT cloud types rainfall areas, etc., and would have these introduced into the computer data base. Such a system would permit the analysis of a greater number of images per day which would more accurately depict the spatial cloud (and therefore rainfall) patterns.

Various levels of sophistication are available between the manual-visual system employed last summer and the CRT-analyst interface system outlined above. Nevertheless, the major improvement, and one that we think necessary to speed up cloud cover analysis, is a CRT display of cloud cover images from which areal cloud analyses can automatically be encoded on cards, tapes, or preferably onto disks.

10.1.3 Regional Data Base Preparation

Soils

In the initial preparation phase soils data were derived from 1:2,500,000 soils maps. Because of the relative coarseness of our 12.5 x 12.5 n.m. cells it was assumed that the broad scale delineations would be adequate. Figure 3-3 in Section 3 presents a map of soil classes as assigned.

Subsequent review of yield variance on a county basis suggests a need to improve our description of soils. Initial evalations of LANDSAT images suggest that soil boundaries could best be defined from this source. Actual texture and crop available moisture derivations would come from use of soil association maps.

Active Cells

In the 1975 operations we laid out a grid/cell geobase system over the entire four state test region. All processing activities were accomplished over all cells where a soil assignment had been made. This approach does not consider whether there is actually a crop planted in the cells.

In the future LANDSAT images should be used to delineate agricultural land from non-agricultural lands on a percent of cell basis. This would have the effect of reducing the total number of cells processed. It might have a further effect in improving yield estimate by improvement in the weighting of acreage in our aggregated yields.

10.1.4 Computer Software

The software used in the "System" operations in 1975 operated effectively but probably less efficiently than might be required for global applications. The specific items that might be considered for change to improve efficiency include:

(a) METRUN

(b) AGRUN I-II

(c) PREDRUN

METRUN should be carefully reviewed to assure that all functions operate as separate modules, i.e., I/O, Processing, and Area calculations. The overall philosphy of the software should be carefully reviewed in the framework of a larger area operation.

AGRUN should be reviewed to assure efficient structure in Ag-historic and site files. Some additional thoughts need to be directed to display procedures.

PREDRUN as it is currently configured is very site specific. Operations over larger areas will require some rewrite.

All of the foregoing items refer specifically to problems associated with use of the 1975 system in a larger context. None of the adjustments is very complex or expensive.

10.1.5 Changes and Adjustments for Global Operations

Global operations of the EarthSat System would be best accomplished in the context of the discussions to be presented in Section 10.2. If, however, there is interest in running the 1975 "System" over larger areas of the world the following suggestions are valid.

(a) The global crop (i.e., wheat) population should be grouped into sampling regions which represent "YIELD ECOZONES" and effectively represent a sufficient sample of the production universe. Each sample should be one or two LANDSAT frames in size.

(b) The geobased grid included in each "yield ecozone" can be variable, i.e., some zones with small soils variations could use a 50 n.m. grid while others would use the current 12.5 n.m. grid.

(c) The model should be run on a daily basis over each sample site using the alternative daily stress weighted model.

(d) The total number of sampled ecozones would be allocated on the basis of mean daily rainfall event size for the region. Over the 1975 test regions approximately 85 percent of all specific events were between 152 n.m.^{2} and 10,000 n.m.^{2}.

(e) Weighted aggregations would then be used to prepare yield estimates for areas equal in size to one or two CRD and larger.

(f) LANDSAT historical images would provide a basis for ecozone development and would provide improved soil and soil moisture release curve data.

The foregoing suggestions would permit the operation of a global system which could permit physical explanations for all yield modifying events. The loss of detailed moisture stress descriptions would not influence relatively large area aggregates. Accuracies obtained in this manner should surpass standard regression approaches particularly in highly anomalous years.

In the operational mode discussed in Section 10.2 there would be no need to sample but it obviously could be done if desired. A limited test of a sampling scheme in N. Dakota is discussed in Section 8.

10.1.6 Applications of Weather Forecasts

During the 1975 test two approaches were used to estimate the "future" weather to provide end-of-year yield estimates. The first used with QPRED was not a forecast at all; it simply was a statement that the past stress will be the future. In the averaged stress model this statement became more true as the number of actual days included in the average stress increased. The second approach termed SPRED for simulation Prediction used the distribution of historical weather in a Monte Carlo simulation model. During the 1975 tests SPRED used only historical weather; there were no attempts to test modified historical distributions based on short or long range forecasts.

The SPRED approach is easily adapted to short and long range forecasts which are usually presented as "departures from normal." The adaptations recognize the fact that we will always be operating in a probabilistic world. Forecast "departures from normal" would be used to modify the historical distribution used by the SPRED model. Thus a combination of accurate short range forecast, whereby the distribution would contain only a limited variance, and larger range forecasts, whereby the variance would increase but the mean would be defined by the forecast, could be used to develop reasonably accurate end-of-year estimate with the added benefit of a day by day estimate of probable error due to weather uncertainty.

10.2 Future Operations of the EarthSat System

10.2.1 Background

A routine U.S. effort toward global crop monitoring would logically involve NOAA's National Weather Service (NWS) since it has traditionally provided weather support for agriculture and has served as the prime national interface on other global weather efforts through the World Meteorological Organization. Although the present purpose is to highlight satellite inputs to such an operation, a brief discussion of the NWS National Meteorological Center (NMC), and its facilities for supporting such a mission, will provide useful background for the subsequent satellite interface discussion.

The NMC is the primary NWS mission support element. Using global collections of all types of observational data, its numerical analysis and prediction facilities generate daily some 800 graphic weather pattern depictions and about the same number of alphanumeric message blocks which are disseminated as scheduled facsimile and teletypewriter transmissions (NOAA 1975). NMC was recently relocated in expanded, more modern World Weather Building (WWB) quarters near Suitland, and NWS is diligently pursuing other improvements which will provide a highly automated and more effective weather service for the late seventies.

A Digital Weather Radar Experiment (D/RADEX) has recently advanced to an approved operational project which will provide continuous and complete cloud echo coverage for all 50 states and surrounding coastal zones. The reduction of direct probe (balloon) rawindsonde data is also fast becoming a mini computer supported automatic operation. Data inputs and product dissemination is undergoing a major modernization and upgrading under the Automation of Field Operations and Services (AFOS) project which is currently involved in a $40M procurement of some 275 mini computer-based data communication and processing systems. These interactive systems will be interconnected through a National Digital Circuit (NDC).

A new 8-level global numerical prediction model, now in operational test, will soon support routine global data analyses and predictions, and NOAA's large central computing facility has recently been expanded to provide improved support for such prediction service.

Traditionally, the NMC has cooperated with those seeking to enhance and diversify its product line. Over the years the NWS Techniques Development Lab and others have utilized the NMC observational data base and its numerical analysis and prediction fields to generate wind component forecasts for flight operations, maximum/minimum temperature forecasts, and many other biproduct advisory outputs in support of specialized customer requirements. As such developments are stablized through operational testing, they then become a part of the routine production. Assuming proper resource support, it therefore seems appropriate to consider global crop monitoring as a likely adjunct to NMC operations. The present EARTHSAT Spring Wheat Yield Model study effort provides insight toward such an operation.

The study stresses the vital role of satellite image data - particularly if crop monitoring is to be carried out over sparse weather observation regions on a global basis. Since the National Environmental Satellite Service (NESS) is charged with supplying satellite image information on an operational basis, it is of interest to examine in some detail the various aspects of such support to an NWS global crop monitoring operation.

At first glance, such a cooperative operation has much to recommend it. NWS and NESS are NOAA sister organizations with collocated operations. They share central computer support and other facilities in the Suitland/WWB complex, and interactive cooperative relationships are well established. The following discussions will examine the operating environment in some detail, noting the satellite data sources, the operational satellite data processing and support facilities and the several interfaces through which satellite information would be made available for such a global crop monitoring operating at NMC. Details of the satellite data information extraction operations are projected in the context of related on-going operational activities, and a scenario is presented whereby a late seventies beginning operation could be achieved. A final discussion deals with a more advanced operation which would utilize new satellite source data and improved image data manipulating technology.

10.2.2 The 1976-1980 Operating Environment

By the late seventies a number of satellite programs will be providing data of value for global agricultural monitoring. Some programs will stress operational commitments and so provide data and derived products in near real time while others will collect data in support of off-line experiments and research. All have received impetus from The World Meteorological Organizations' Global Atmospheric Research Project (GARP), and many nations have environmental monitoring space projects which are now committed to the support of the First Global GARP Experiment (FGGE) in 1978.

For the U.S., TIROS-N and the following operational NOAA satellites represents the primary data source for global monitoring on a daily basis (Ludwig 1975). With quasi polar, sun synchronous orbits, two such spacecraft will provide complete global coverage four times each day. Four half mile resolution sensors will provide visual and infrared imagery (a fifth channel will be added on later spacecraft). This Advanced Very High Resolution Radiometer (AVHRR) will provide full resolution digital data locally through a direct High Resolution Picture Transmission (HRPT). About 100 minutes of such data can also be obtained each day from remote areas through spacecraft tape storage. Central processing of more detailed imagery can thereby be achieved for areas of special interest. Complete global coverage is achieved through on-board averaging of stored information. Even though spatial resolution is thus reduced to about 2 miles, the resulting digital samples are retained as 10-bit quantities in order to maximize their quantitative utility.

A compound TIROS Operational Vertical Sounder (TOVS) will provide additional information, not only for generating atmospheric soundings but for surface applications as well. Included are: a basic sounding unit with fourteen sensor channels for tropospheric water vapor and thermal measurements; a three sensor "chopper" unit for stratospheric temperature measurements; and a four sensor microwave unit for surface temperature sensing. Although measuring at various coarser resolutions, these sensors should provide valuable supplemental information for crop monitoring.

The TIROS-N series will also provide a Data Collection System (DCS) whereby unmanned observation stations may be interrogated to provide valuable "ground truth" observations from remote areas. The NWS Hydrologic Service is currently experimenting with some thirty remote platforms and more are to be acquired. Projecting the current trend in international meteorological cooperation, it seems reasonable to expect that rainfall, river stage, snow depth, surface temperature, and other observational data could be made available in near real time from many agricultural regions of the globe by the early 1980's.

Present NOAA plans project the TIROS-N operational series to extend from 1978 into the mid 1980's. During this period it seems likely that developmental efforts will result in the addition of more advanced sensors. Among these efforts it seems reasonable to expect improved capability in sensing surface temperature (improved spatial resolution microwave sensing), atmospheric moisture, and perhaps surface soil moisture. Whatever the improvements realized, they will tend to enhance any beginning crop monitoring operation.

Although not global in coverage, NOAA's new Geostationary Operational Environmental Satellite (GOES) system must also be considered a prime information source for agricultural monitoring within the western hemisphere. NASA's prototype spacecraft, Synchronous Meteorological Satellite, SMS-2, and NOAA's GOES-1 are currently providing image data for practically all vegetated portions of the Americas and equatorial islands. Half mile visual channel image data is available in the daytime and four mile IR day is available both day and night from the Visible and Infrared Spin Scan Radiometer (VISSR). Half hourly coverage is obtained from each satellite on a staggered basis so that overlapped coverage is available over most of the contiguous 48 United States at 15 minute intervals.

GOES also provides a DCS facility (Nelson 1975) which is currently in an operational test status. A new ground support processing system is now being activated toward a fully operational commitment in support of FGGE in 1978 (WMO 1975). Relay capability of each satellite is projected at a mix of some 10,000 observations per day. The current GOES central processing activity has settled into a stable production, but changes will, no doubt, occur as new products and sensor improvements expand this beginning operation. A funded effort is currently under way to modify the VISSR by adding sensor channels for sounder application. Although the VISSR Atmospheric Sounder (VAS) version may not fly until the 1980's, these, or perhaps other sensor improvements, will also tend to enhance agricultural monitoring capabilities.

LANDSAT and Nimbus satellite data must also be considered as important inputs to a future global crop monitoring operation. Despite their development and experimental charters, these NASA projects can provide vital support to such an operation. As in EarthSat's current Wheat Model Study, sensor inputs from such programs can provide the necessary satellite data for intercomparison with ground truth sites and so provide the means for projecting application into regions with sparse ground observations. Applications studies using ultra high resolution imagery, or data from new experimental sensors, also provide the impetus for making such data available on more operationally-oriented satellite programs. Experiments in more advanced on-board processing or improved ground processing techniques can similarly benefit an evolving operation. Close and cooperative association between these programs and a global crop monitoring operation would therefore seem highly desirable as a means for improving its precision and expanding its impact.

Other satellite programs offer potential information sources. Perhaps the most likely are the oncoming European Space Agency's geostationary METEOSAT and the Japanese Geostationary Meteorological Satellite (GMS). METEOSAT is to be stationed near the Greenwich meridian and GMS will be positioned near 140°E. Both are now projected to begin operations in support of FGGE in 1978.

Each program has maintained interface compatibility between their DCS system and that on GOES. One may therefore anticipate the international exchange of greater amounts of satellite data on a near real time basis. Already such international cooperation has begun with France routinely relaying direct readout sounder data from NOAA polar orbiting spacecraft through the geostationary DCS facility into Suitland.

The SEASAT program represents another possible interface. With approved funding, both in NASA's developmental procurement and in NOAA's processing preparations, first launch is projected for 1978. Although projected as a NOAA operation in support of ocean interests (oceanography, fisheries, etc.), there may be overlap in surface sensing over land - particularly from the planned microwave sensors.

Should such information be of value for agricultural monitoring, this new operational polar orbiter system would be able to offer data in near real time on a global basis.

Other space developments could have impact but timing and other details appear less certain. Perhaps the greatest impact could come from further developments in communications satellites and in satellite-to-satellite relay capabilities (such as NASA's TDRS effort). Conceivably, direct relay from a LANDSAT having steerable imaging capability could transform the present program into a near real time operation with selectable global coverage on a daily basis. Short of such ultimate ideas, there appears to be an ample supply of satellite data which would justify an operational global crop monitoring effort by the end of the present decade.

Apart from the availability of source data, the impact of satellites on such a crop monitoring program requires an appropriate data processing and analysis facility. A brief review of the NESS processing facilities, as projected into the late 70's is therefore in order.

A rather complete description of the GOES central data processing and analysis facility is available Bristor (1975), and a companion facility for the TIROS-N operation is presently under contract development. With both satellite systems providing digital source data, great emphasis is being placed on the quantitative extraction of information from all sensor packages. Care is therefore exercised in converting raw bit streams into meaningful engineering units through proper application of accompanying calibration data. Special attention is also being given to the problem of applying proper radiometric corrections for varying attenuations due to atmospheric constituents. And substantial resources are devoted to the optimum earth location and geometric normalization of all sensor data. A diagnostic quality assurance effort assesses noise content and other incoming signal quality factors, and provides an overall monitor service for product adequacy and timeliness. Both satellite systems will be serviced by dedicated preprocessing facilities and specialized product output display and distribution equipment.

A large scale central computer complex is provided as a shared NOAA facility for NWS and NESS operations. Three IBM 360/195's with 64 spindles (6400 M Bytes total capacity) of disk storage comprise the present system. Both NMC and NESS have direct access to the central facility through special high speed selector channels. Thus each may inject masses of preprocessed data and extract formatted outputs for facsimile and teletype transmission and for local display. More importantly, each also has ready access to all data bases and products. Within this operational environment, production which requires a diversity of observational inputs, and special output user interfaces, can be carried out in an optimal fashion.

The NESS operation recognized the need for visual inspection of imagery and human decision making. The present GOES operational facility includes three Man-Machine Interactive Processing Systems (MMIPS) to support such activity, and it appears that the TIROS-N operation will require somewhat similar systems. In a developing image processing operation, experience seems to indicate a step-wise progression into full automation. Products are often tested and evaluated with human decision makers "in the loop." Once the product is accepted, obvious automation steps are usually taken, but certain human decision steps may not have ready automatic equivalents or the changeover may be too costly. Complete automation of one production task is often followed by the initiation of a new test product which then passes through similar stages. A global crop monitoring effort would fit well into this evolutionary production environment.

10.2.3 Quasi-Automated Satellite Inputs to a Day-One Operation

The process of extracting quantitative information from satellite imagery tends to be hierarchical with more sophisticated processing resulting in the generating of more complex output products which represent greater value to the user. Initial processing steps are usually required for nearly all products so that their cost is justified in terms of the entire production. However, as the processing steps become more specialized, the common product cluster often becomes rather small. In order to avoid uncertainties in committing resources on singular costly products, one therefore strives to develop a processing approach which maintaines maximum generality in the more complex processing steps.

In the earlier TIROS Operational Satellite (TOS) system this ideal was pursued in processing vidicon image data. Beyond the preprocessing steps (calibration to remove vignetting; radiative correction for solar zenith angle; earth location and mapping) an attempt was made to transform mapped image clusters into generalized image "descriptors." Rather simple parameters were used to describe average cloud brightness and other characteristics of the individual image sector brightness topographies. Although this approach found some application Miller et al (1971), problems with vidicon responses and calibration discouraged those interested in quantitative applications. Now with multiple channel digital data there is new appeal for this approach. The Air Weather Service has developed a processing system whereby several "state parameters" are extracted from satellite image data and entered into a 4-D computer data base along with other observables. Various analyses and predictions are then made using all available information in each cluster volume for each time period. Efforts persist toward greater objectivity and generality in the generation and use of such state parameters Booth (1973), and it seems desirable to amplify this effort with the larger bulk of multi-channel data to come from TIROS-N.

Many approaches to feature extraction from image data have been suggested in the pattern recognition literature Tou (1975) and Kanal (1974). Current contract study efforts toward the design of the TIROS-N data processing facility will, hopefully, incorporate an economical means whereby a descriptor set with wide ranging product applications may be generated. Whether descriptors are derived from direct image cluster pattern measurements (e.g., a brightness topography laplacian), from measures of cluster Fourier Transforms, or from histographs, one would expect direct applicability of the resulting parameters to the crop monitoring operation. Past studies Barrett (1973), and the current Wheat Model Study all suggests the value of cloud amount and type from visual channel satellite data, and efforts continue toward the extraction of independent information from multi-channel data Follansbee et al (1975). Considering the important requirement for cloud type amount, and vertical distribution in many other customer interface areas, it would be surprising if a beginning crop monitoring operation required extensive independent information extractions beyond those planned for other NESS production.

In order to project a beginning operation, one might postulate a TIROS-N data processing arrangement based upon stated requirements. Once the system design study is complete, one may then modify the plan to more precisely confirm to the operational environment. From present indications one may project the following as situation features in support of a day-one operation:

- Satellite sensor data from TIROS-N will be preprocessed (calibrated, radiometrically corrected and earth located) and available as a randomly accessible data base in near real time on a global coverage basis within the Suitland 360/195 central computer facility.
- Additionally, a derived set of parameters will be available from image data cluster sets with several such parameters aimed directly at the determination of cloud amount, cloud type and vertical distribution.

- Interactive graphic facilities will be available if needed for further separation of data classes or for monitoring of a beginning crop modeling and monitoring operation.
- Global TIROS-N data sets will be available on a four times per day basis, and all such sets will be accessible with adequate 195 computer time for a once-per-day operational computation.
- The situation will be similar to the above for SMS/GOES VISSR data except that information will be available at 3-hourly intervals and only for the Americans.
- Output facilities will be available for suitable local output (graphic and/or alphanumeric hard copy) and for the automatic transmission of similar product messages or graphics.

All of the above is, of course, predicated upon the assumption that the global crop monitoring mission would successfully compete with other missions as a cost effective endeavor within the national interest.

With the above projections, one may visualize a program package based on the present Wheat Model Study and resident in the 360/195 system at Suitland. This portion of the overall NESS applications software library would be subdivided into several components:

1. A TIROS-N input data interface model
2. An SMS/GOES input data interface model
3. A near real time data input interface for in situ weather observations and all other timely inputs

4. An integration and model calculation module
5. A production output module
6. A diagnostic development and test module

The first module would transform preprocessed TIROS-N data and derived intermediate descriptors into a data base synthesized and formatted as measurements of precipitation, sunshine, and other factors required as inputs to the generalized crop monitoring model. Software supporting this task would function largely as an automated activity, but some inputs may not be adequately separated into proper classes as required by the generalized crop model. A case in point might involve frontal zones where baroclinic accelerations tend to produce a complexity of multi-level clouds with different motions and overlapping pattern features. In such cases the use of an interactive graphic facility may provide justifiable payoff since resolution of such cases would be important in terms of model outputs. Human resourcefulness could select alternate sensor displays and result in decisions beyond the discriminating ability within the automated software. The overall result of this first stage activity would be to accrue current inputs to the model data base, and such activity would presumably take place periodically as an appropriate volume of input data had accumulated. With four global coverages per day from the two operational spacecraft, this work would likely be done in 6-hourly batches.

In general, such activity could be gracefully combined with other operations since the only time-critical deadline would involve injection of the final batch of input data and the scheduled production run.

The second item represents a parallel task related to the first, but VISSR data processing will involve different software. And the interactive work would likely utilize the MMIPS interface. Data additions could occur at 3 hour intervals, but, again, the final deadline is the only critical scheduling consideration. Although the VISSR data input activity is similar to that for TIROS-N, the particular descriptors generated will likely differ. This results from the fact that image data sequences are available on a more frequent basis, and product goals for the two data sources are different. However, with different transformation software, the tasks involved in adding to the crop monitor model data base would function much as in the TIROS-N case.

The third activity accumulates all direct probe meteorological measurements as currently obtained through NWS channels over their global telecommunication links. The advent of AFOS will improve the timeliness of such data collections for domestic regions, but the data will be sorted, reformatted and stored by NMC in the 360/195 much as it is today.

A significant increase in this data base may be expected at the DCS systems on both TIROS-N and SMS/GOES expand into full load operations. This augmentation is to be a shared responsibility with NESS forwarding only partially processed bit streams into the 195 and NMC doing the final transformation, sorting and formatting into standard observational collectives. Aside from increased bulk, however, the software module which transforms these inputs into an appropriate crop monitor data base will accomplish much the same tasks as the now involved with the Wheat Yield model. This software would likely function as a completely automated activity, perhaps operating uhder NMC supervision as an appendage to their operational software which digests incoming data into their data base.

The fourth component is the core of the activity providing the transformation of input information through the generalized model into output indicator fields. There would likely be a variety of computer output files expressing results not only as simple yield figures but in various interpretive forms.

The production output module would contain a variety of selectable routines which would create formatted messages, graphic displays, printouts and other options. A vital output form would transfer daily production into a multi-tagged archive file which could then be utilized in generating a variety of periodic off-line surveys and other summary reports.

The sixth module provides the important means by which faults are diagnosed and improvements made. Again, human interaction would be important, and considerable software support is required so that the diagnostician may explore symptoms with graphics or hard copy printouts.

As model improvements are developed, this module also provides the means for evaluation and test. Specialized data bases (from LANDSAT, Nimbus, aircraft, micro surface station networks, or other sources) would undergo special interpretation to generate new regression coefficients or otherwise make model revisions. Once the revised model was ready for test, this test version would interact with the routine model production software in an operational simulation mode. Because of the variability in developmental activities much of this diagnostic software would function best as separate modules operating under some common protocol and interface formatting arrangement.

The above scenario describes some of the main features of a generalized crop monitoring operation. Although details of the TIROS-N data processing arrangement must await the outcome of current contract studies, the broad picture, as stated above, can be inferred from stated requirements. More detail can be added as NOAA/NESS formulates their final hardware/software design early in 1976. Once decisions are made, the procurement, installation, and testing of the facility will step ahead on a tight schedule in preparation for the planned launch of TIROS-N in 1978.

10.2.4 An Evolving Future System for 1980-85

By 1985 the SMS/GOES and TIROS-N operations will have stabilized into rather routine activities but by then several changes appear likely:

- Larger and faster large scale computers will be available and the pressures from advances in numerical weather prediction and an expanding satellite activity will result in a move to replace the 360/195 complex. It will likely be economically advantageous to replace existing equipment with mainframes having at least 5-fold throughput improvements; random access rotating storage with 5-fold capacity improvement; very much larger high speed memories.

- The VAS sensor package will have replaced the VISSR in the SMS/GOES operation to present the opportunity for indirect atmospheric soundings at 2 or 3-hour intervals over an area some 170° in longitude by about 100° of latitude. Even if soundings were produced at 2° spacing each 4 hours the calculations for these 255,000 soundings would have a major resource impact.
- The TIROS-N operational series will be reaching the end of its projected 8-year lifetime and a new system of polar orbiters with more advanced sensors will likely amplify the global data set, perhaps by a factor of two.
- Advances in telecommunications capabilities and competition between carriers will make practical the exchange of much larger basic data sets.
- Improvements in microelectronic and/or optical digital data handling techniques will generate faster and improved methods for the practical extraction of quantitative information parameters from image data.

All of the above ingredients suggest a substantial jump in environmental satellite activities for the latter 1980's. In order to justify such a jump there must be strong arguments for economic payoff in terms of operational product improvements. In the case of global agricultural activities one can visualize desirable advancements beyond a simple monitoring function. The principal need for advancement would appear to involve the ability to predict deviations from normal yield with sufficient precision and over realistic time spans so that alternative actions might be taken to avoid famine. While some work has been done in using satellite data for very short range predictions, any longer range capability must depend upon the development of better longer range weather prediction even with eventual linkage to climate and climatic trends, McQuigg (1975). While work in this area might now seem premature, EarthSat is interested in considering such future possibilities as a part of its interest in the overall crop yield and monitoring effort. Once current efforts have evolved into a meaningful operational service there will likely be interest in addressing such a program as an international cooperative effort.

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11.0 SUMMARY

The 1975 test of the EarthSat Spring Wheat Yield "System" has provided a comprehensive review of the strengths and weaknesses of the "System". Particular strengths seem to be apparent in the geobased data management system and the systematic plant weather environment diagnostic elements. Some small weakness is found in the moisture budgeting functional elements and in the yield model. None of the weaknesses are totally significant to the system. Alternative approaches have been examined and partially tested to overcome all of the weakness. Some specific findings of the system test include:

(a) Precipitation estimates were accurate to within 3mm 72 percent of the time and 7mm 90 percent of the time.

(b) Potential evapotranspiration (ETP) estimates were within 2mm of Class A pan evaporation measurements 68 percent of the time.

(c) The phenology or growth stage (BMT) "clock" error averages + 3.4 days for the jointing (BMT = 2), Heading (BMT = 3) and Soft Dough (BMT = 4) stages.

(d) Evapotranspiration estimates (ET) at 7 day intervals seem to show the correct sign but the magnitude averaged -25mm in error. A suggested change in the moisture release function improves the absolute error to -8mm.

(e) Yield forecasts prepared early in the test at two week intervals using a N. Dakota (developed over 3 counties) model and N. Dakota trend show errors of -0.5 percent in N. Dakota, -13 percent in Montana, +30 percent in S. Dakota, and -7 percent in Minnesota.

(f) Yield forecasts prepared after reevaluation of the trends for each Crop Reporting District (CRD) and the introduction of a high temperature factor produced errors at the state level of -0.5 percent for Montana, and +10 percent in N. Dakota, S. Dakota and Minnesota. The residual errors may be due, in part to the inability to accurately define recent year trends with existing analytical techniques.

(g) Coefficients for weather stress appear to be constant for all four states.

(h) CRD correlation coefficients for Montana, N. Dakota and Minnesota are approximately .75. County level correlation coefficients in Montana and N. Dakota are approximately .45 and .55 respectively.

(i) Tests of a weighted daily stress yield model suggest improved sensitivity over the averaged planting to ripe stress model.

(j) The "System" seems to describe spatial variances in yields at 2 to 3 country aggregate levels.

(k) The "System" can be directly applied to other areas of the world for spring wheat using a sampling technique if aggregate yields at CRD or state level only is the objective.

(l) The "System" can be operated on a global scale assuming large total samples of wheat growing regions for the dollar equivalent of an hour of IBM 360/50 per real time weak. This estimate assumes that all meteorological data entry is automated, and does not include personnel costs, or display costs.

(m) The output from the system for stress, BMT rainfall, soil moisture yield, etc., is at a scale that can be used interactively with LANDSAT.

(n) LANDSAT image data can provide a direct input to the suggested weighted daily stress yield model.

(o) Future plans in NOAA's TIROS-N program imply a good possibility that automated entry of satellite data will be operational.

(p) The "System" can be used to run physiological plant models, i.e., dry matter accumulation models over large areas. This potential will allow marked further "System" growth and adaptation to other crops and new variations. Such "growth" is not possible with most other approaches.

The 1975 test has shown that the "System" is strong in its diagnostic elements but somewhat weaker in its yield predictive elements. Recommendations for improvements to both elements have been developed and there is therefore no basic limitation to future regional and/or global applications. Complete "System" software documentation has been developed and adjustments for other areas and/or computers are minimal.

12.0 RECOMMENDATIONS

EarthSat is optimistic about the outcome of evaluations of its 1975 "System" test and as such it is appropriate to present some recommendations for future applications, testing and research needs.

12.1 Further Applications

The basic diagnostic elements of the system together with the geobased data management scheme are applicable to any region of the world therefore the following direct applications are recommended:

(a) The 1975 "System" as documented should be applied to corn, soy bean and winter wheat regions of the United State either as a sampled basis, i.e., as suggested for global operations or over all producing areas. Existing physiological models should be tested with the basic data derived. Examples of existing physiology models include:

- SYMAIZ by Duncan, U. of Kentucky
- CORNMOD by C. Baker and B. Curry, Ohio State
- SOYMOD by C. Baker and B. Curry, Ohio State
- SIMCOT by D. Baker USDA Mississippi State
- A Winter Wheat Model by Ricketts, Oregon Stai

(b) The 1975 "System" run should be tested further on its ability to describe the variance in dry matter accumulation rates for use by the USDA in their energing within-year yield forecasting models.

(c) The 1975 "System" should be tested as an adjunct to the NOAA regression yield models in several foreign countries selected as candidates for LACIE future emphasis. The system would probably be most readily operated over a series of LANDSAT sample ecozone units representative of the production distribution of the areas under study.

(d) The basic diagnostic model parts of the "System" should be tested at first order weather stations and the diagnosed data on a daily basis could then be aggregated for CRD size areas on a weekly basis. This simplified approach should yield results that surpass standard regression approach and they would further offer the opportunity to apply new physiology models.

(e) The basic "System" should be applied to hydrological as well as agricultural problems.

12.2 Further Research Studies

The current model is, in general, fairly well developed; there are, however a number of areas that could be studied in much more depth. These include:

(a) The overestimation of light precipitation amounts is a critical item. Work should be directed toward means to correct this tendency. Possible approaches may include statistical studies to allow insertion of an offset into the rain/no rain determination or further applications of direct satellite derived data.

(b) The "System" appears to describe variations in plant condition for "good" or "bad" conditions quite well. LANDSAT imaged data seems to clearly substantiate this assertion. Further studies of historical and current LANDSAT data will further define the range of definable conditions.

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(c) LANDSAT data should be tested to provide soil characteristics to be included in the model. For example soil dry down rates are needed by the model. These dry down rates are poorly defined by existing models.

(d) Additional "middle" model approaches, i.e., non dry matter, should be examined using the "System" output.

12.3 Remote Sensing Application Studies

The application of remote sensing from satellites to the "System" is really in its infancy. The following items cover recommendations for further research into the further applications of remote sensing in the system.

(a) Explore the availability of operational polar satellite data inputs for global crop monitoring. Extrapolating to the 1980 time frame, this would amount to a cooperative investigation with NOAA into the interrelationships between information extraction activities in support of their presently projected product line and the related input needs for crop monitoring. A number of current developmental efforts will likely influence TIROS-N production, and the blending of such activities with a crop monitoring usage may well require outside investigative assistance.

One present effort considers the determination of percent cloud cover over small sectors using brightness thresholding of visual channel imagery in an automated procedure related to that utilized in the present EarthSat Wheat Model study. With cloud cover thus supplied, the coincident IR sample array then undergoes analysis in histogram form with resulting extractions of surface layer air temperature and moisture estimates. Considering the additional image data channels on TIROS-N, this approach may well evolve into a generalized parameter extraction operation.

Another area of activity involves the exploiting of multi channel atmospheric sounder data in several related meteorological applications. One treatment generates mapped topographies showing response differences between a lower tropospheric response channel and a channel with response near the tropopause. Preliminary examination suggests application as a stability indicator for the lower atmosphere. If successful, such a tool would provide evidence for potential convective rainfall development. Other mappings of single channel sounder data indicate the vertical extent of convective clouds already developed thereby suggesting a direct indicator of convective rainfall severity. Construction of mapped mosaics using response from a stratospheric channel suggest a direct simulation of stratospheric thickness. By proper contouring and thermal wind interpretation, such analyses may provide measures of accelerational intensity in precipitation producing frontal zones. A sequence of such charts is now produced on a daily scheduled basis for routine evaluation and experimental operational use With TOVS, such specialized data manipulations should substantially supplement the information to be derived from the vertical profiles of temperature and moisture.

Still other efforts within NOAA are concerned with the modeling of precipitation mechanisms. One developmental effort has used radar data to help establish a lifetime estimate for convective shower cloud cells.

In all of these areas there appears to be many challenges for the development of operational applications. If quantitative extractions are to be utilized in a global crop monitoring effort, meaningful resources must be dedicated to this singular goal.

(b) Examine the separate potential contribution of operational geostationary meteorological satellites in agricultural modeling. Although there are many direct counterparts to polar oribiter data interpretation, the geostationary satellites provide the unique opportunity for generating additional short term trend information. Convective cell life cycles and other trends in cloudiness, usually expressed as best estimate model parameters in the case of infrequent data inputs, may be measured more directly using the frequent imaging cycles of geostationary satellites. Current developmental efforts are attempting to exploit such added inputs for mid latitude rainfall estimation. At present such new developments may find application only over western hemisphere land areas, but, with international cooperation, such application may well extend to all agricultural regions using the network of geostationary meteorological satellites projected for the late seventies.

As the VAS replaces the present VISSR on SMS/GOES, similar trend information will be available for the atmosphere as a whole. (Although decisions have yet to be made, there is the possibility that this change could occur with GOES-C with launch in 1978.) Changes in moisture flux and in atmospheric stability will represent new measurements of direct value in deriving rainfall estimates.

By 1980 the opportunity will exist for the amalgamation of polar orbiter and geostationary satellite data. With dual TIROS-N-type satellites providing inputs four times per day and the system of geostationary satellites supplying supplementary trend data, there appears to be great potential for definitive global crop monitoring, but again, specific resource commitments will be required for such preparation.

(c) Assess the potential contribution of other satellite systems. Further assessment of the impact of the previously mentioned LANDSAT, Nimbus, and SEASAT programs on agricultural modeling certainly appears desirable. Perhaps the continuing strong LANDSAT applications development activities supported by NASA, Interior and Agriculture provide only restricted opportunity for new exploitive investigations, but some new effort may be desirable, particularly in maximizing the interplay of such data in the development of generalized global agricultural models.

SEASAT, now scheduled for first launch in May, 1978, would seem to offer new opportunity for applications development. Although primary service for retrospective users will be the responsibility of the Jet Propulsion Laboratory (18), certain data will be available operationally under an agreement now being negotiated between the U.S. Navy Weather Service, NOAA and NASA. Of particular interest is the data to come from the Scanning Microwave Radiometer (SMR), which will be relayed from Alaska to Monerey, California where the raw bit stream will undergo transformation into engineering units with proper earth location information appended. Data will then be available for all operational applications through normal weather data distribution channels. Apart from marine applications, the SMR data is also under consideration as a new source for measurement of precipitation and soil moisture. Since soil moisture relates more directly to crop yield than rainfall, the latter measurement potential is of particular interest. The five channel instrument will provide measurements in a variety of spatial resolutions with the highest frequency channel (37 GHz) providing 10 Km resolution.

Global coverage of SMR data from SEASAT requires 36 hours since successive passes do not provide contiguous viewing at all latitudes. However SMR will also be carried on Nimbus G with launch schedule within the same time frame thus providing the potential for supplemental overlap. Despite the comparative time sparsity of SMR data, these independent inputs should certainly prove valuable for crop monitoring application. Intercomparisons between SMR and TOVS/MSU data may also provide added opportunity for reinforcement of the indications of each. Such efforts in support of the specific crop monitoring mission will comprise an added investigative task requiring separate resources.

(d) Examine the interplay between direct probe observational inputs and indirect measurements from satellites. Clearly, satellite data must contribute as a substitute where no direct probe information is available. Many areas lack adequate local ground-based observation, and in other instances, information is obtained only on a post analysis basis.

The present meteorological synoptic reporting network mainly reflects the status of global economic development. Many areas of potential agricultural importance are, at best, marginally represented in terms of local meteorological observations. In such circumstances, the existing reports with spatial or temporal sparcity or with deficiency in content provide only partial needs for an agricultural model. Once a generalized crop monitoring model has been developed, one valuable use will involve diagnosing the adequacy of existing weather reporting networks and recommending locations and time intervals for new observations. With significant growth potential in the remote station data relay load in the SMS/GOES DCS, such an analysis could provide valuable guidance toward a western hemisphere crop monitoring operation. And with guidance available for establishing DCS traffic for TIROS-N, the similar needs for a global network could be more economically developed.

(e) Investigate the impact of crop monitoring as an adjunct activity within the projected NOAA operation circa 1980. Within NESS the SMS/GOES data handling and computer processing facility commenced operations in 1974 with the launch of SMS-1, but operational improvements continue. Direct linkage between dedicated equipment and the shared 360/195 central processing facility has only recently been activated. Raw ingest data may now be transferred to the central facility and properly formatted output products returned with minimal operator intervension.

The new Data Processing Support System (DPSS) for TIROS-N is now in the final design phase. It will provide similar 360/195 interfacing capability and will include an archival mass storage system.

Although the combined NESS processing support facilities would seem to offer ample capacity for inclusion of a crop monitoring operation, there are many practical details to be addressed. Provision for properly formatted input data, the attachment of model calculations to other related production, and the operational output monitoring, reporting and archiving, all represent new planning and implementation tasks. This effort would represent a substantial negotiation involving a project team with proper resources.

(f) Investigate the impact of a crop monitoring operation on projected NMC processing activities. As mentioned at the outset, a NOAA crop monitoring effort would likely be assigned as a National Weather Service mission, and, since it would be a computerized activity using direct probe observations, it would, no doubt, be assigned as an NMC production task. Apart from satellite and direct probe data inputs, the model might also use the three-dimensional weather analyses and predicted fields which comprise the numerical weather prediction activity. There is thus need at this interface for interactive planning -- both in crop model development and in later operational activities.

(g) Work with NASA and NOAA to develop and refine a generalized global crop monitoring model for routine operations. Following the approach used in the present EarthSat Wheat Yield Model, one must generalize those parameter features which have been made specific to wheat, and model those secondary parameters of most significance with greater generality. The mating of observational representations with the model parameters then becomes an iterative process in which developmental data samples are utilized to develop maximum correspondence. Additional tests on independent data samples may suggest further refinement before provisional operations begin.

(h) Design and develop a product monitoring capability which not only generates reports and assessment analyses for output users but evaluates model deficiencies and conducts a continuing improvement effort. This can best be done as a post task by the development team involved in the preceding task. New processing techniques, new data sources and the activation of different model parameters must all be considered in the continuing production improvement. Any alterations or revisions must undergo test evaluations in competition with the operational model. Only after concensus agreement would operational changes be made. Even then, means must be devised for relating past production to new model outputs in order to maintain long term continuity for eventual climatic comparisons.

As mentioned above, substantial resource commitments are involved in the enumerated tasks. Should national policy dictate the activation of such a global effort, then resources would presumably be available. If governmental manpower restriction preclude assignment of in-house resources, EarthSat welcomes the opportunity to provide assistance. A first task might well involve establishing a more detailed set of tasks such as those enumerated above. Such a survey could provide quantitative estimates of resource requirements so as to establish cost figures. A companion study could project the likely skill of the monitoring effort so as to provide a cost versus yield analysis.

Presuming a favorable output based upon national goals and considering the cost/benefit analysis, the next phase would involve specific planning, first for the developmental aspects of the mission, and, finally, preparations for routine operations.

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APPENDIX I

LISTING OF GEOBASE FILE STRUCTURE
(Includes Soil Categories)

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
206	335	2	48.92N	113.22W	MONTANA	NORTH CENTRAL	GLACIER	1	1
206	336	1	48.69N	112.63W	MONTANA	NORTH CENTRAL	GLACIER	1	2
206	336	2	48.58N	112.89W	MONTANA	NORTH CENTRAL	GLACIER	1	3
206	336	3	48.75N	113.06W	MONTANA	NORTH CENTRAL	GLACIER	1	4
206	336	4	48.86N	112.80W	MONTANA	NORTH CENTRAL	GLACIER	1	5
206	337	1	48.35N	112.31W	MONTANA	NORTH CENTRAL	PONDERA	1	6
206	337	2	48.24N	112.56W	MONTANA	NORTH CENTRAL	PONDERA	1	7
206	337	3	48.41N	112.73W	MONTANA	NORTH CENTRAL	GLACIER	1	8
206	337	4	48.52N	112.47W	MONTANA	NORTH CENTRAL	GLACIER	1	9
206	338	1	48.01N	111.99W	MONTANA	NORTH CENTRAL	TETON	1	10
206	338	2	47.91N	112.24W	MONTANA	NORTH CENTRAL	TETON	1	11
206	338	3	48.07N	112.40W	MONTANA	NORTH CENTRAL	TETON	1	12
206	338	4	48.18N	112.15W	MONTANA	NORTH CENTRAL	PONDERA	1	13
206	339	1	47.67N	111.68W	MONTANA	NORTH CENTRAL	TETON	1	14
206	339	2	47.57N	111.93W	MONTANA	NORTH CENTRAL	TETON	1	15
206	339	3	47.74N	112.08W	MONTANA	NORTH CENTRAL	TETON	1	16
206	339	4	47.84N	111.83W	MONTANA	NORTH CENTRAL	TETON	1	17
206	340	1	47.33N	111.37W	MONTANA	CENTRAL	CASCADE	1	18
206	340	2	47.23N	111.62W	MONTANA	CENTRAL	CASCADE	1	19
206	340	3	47.40N	111.77W	MONTANA	CENTRAL	CASCADE	1	20
206	340	4	47.50N	111.52W	MONTANA	CENTRAL	CASCADE	1	21
206	341	1	46.99N	111.06W	MONTANA	CENTRAL	MEAGHER	1	22
206	341	2	46.89N	111.31W	MONTANA	CENTRAL	MEAGHER	1	23
206	341	3	47.06N	111.46W	MONTANA	CENTRAL	CASCADE	1	24
206	341	4	47.16N	111.21W	MONTANA	CENTRAL	CASCADE	1	25
206	342	1	46.65N	110.77W	MONTANA	CENTRAL	MEAGHER	1	26
206	342	2	46.55N	111.01W	MONTANA	CENTRAL	MEAGHER	1	27
206	342	3	46.72N	111.16W	MONTANA	CENTRAL	MEAGHER	1	28
206	342	4	46.82N	110.91W	MONTANA	CENTRAL	MEAGHER	1	29
206	343	1	46.31N	110.47W	MONTANA	CENTRAL	MEAGHER	1	30
206	343	2	46.21N	110.72W	MONTANA	CENTRAL	MEAGHER	1	31
206	343	3	46.38N	110.87W	MONTANA	CENTRAL	MEAGHER	1	32
206	343	4	46.48N	110.62W	MONTANA	CENTRAL	MEAGHER	1	33
206	344	1	45.97N	110.18W	MONTANA	SOUTH CENTRAL	SWEET GRASS	1	34
206	344	2	45.87N	110.43W	MONTANA	SOUTH CENTRAL	PARK	1	35
206	344	3	46.04N	110.57W	MONTANA	SOUTH CENTRAL	PARK	1	36
206	344	4	46.14N	110.33W	MONTANA	SOUTH CENTRAL	PARK	1	37
206	345	1	45.63N	109.90W	MONTANA	SOUTH CENTRAL	SWEET GRASS	1	38
206	345	2	45.53N	110.15W	MONTANA	SOUTH CENTRAL	SWEET GRASS	1	39
206	345	3	45.70N	110.29W	MONTANA	SOUTH CENTRAL	PARK	1	40
206	345	4	45.80N	110.04W	MONTANA	SOUTH CENTRAL	SWEET GRASS	1	41
206	346	1	45.29N	109.62W	MONTANA	SOUTH CENTRAL	STILLWATER	1	42
206	346	3	45.36N	110.01W	MONTANA	SOUTH CENTRAL	SWEET GRASS	1	43
206	346	4	45.46N	109.76W	MONTANA	SOUTH CENTRAL	STILLWATER	1	44
207	336	1	48.90N	112.12W	MONTANA	NORTH CENTRAL	TOOLE	1	45
207	336	2	48.80N	112.38W	MONTANA	NORTH CENTRAL	GLACIER	1	46
207	336	3	48.97N	112.54W	MONTANA	NORTH CENTRAL	GLACIER	1	47
207	337	1	48.56N	111.80W	MONTANA	NORTH CENTRAL	TOOLE	1	48
207	337	2	48.46N	112.05W	MONTANA	NORTH CENTRAL	TOOLE	1	49
207	337	3	48.63N	112.21W	MONTANA	NORTH CENTRAL	GLACIER	1	50

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I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
207	337	4	48.73N	111.96W	MONTANA	NORTH CENTRAL	TOOLE	1	51
207	338	1	48.22N	111.48W	MONTANA	NORTH CENTRAL	TOOLE	1	52
207	338	2	48.12N	111.74W	MONTANA	NORTH CENTRAL	PONDERA	1	53
207	338	3	48.29N	111.89W	MONTANA	NORTH CENTRAL	PONDERA	1	54
207	338	4	48.39N	111.64W	MONTANA	NORTH CENTRAL	TOOLE	1	55
207	339	1	47.88N	111.17W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	56
207	339	2	47.78N	111.42W	MONTANA	NORTH CENTRAL	TETON	1	57
207	339	3	47.95N	111.58W	MONTANA	NORTH CENTRAL	TETON	1	58
207	339	4	48.05N	111.32W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	59
207	340	1	47.54N	110.86W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	60
207	340	2	47.44N	111.12W	MONTANA	CENTRAL	CASCADE	1	61
207	340	3	47.61N	111.27W	MONTANA	CENTRAL	CASCADE	1	62
207	340	4	47.71N	111.01W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	63
207	341	1	47.20N	110.56W	MONTANA	CENTRAL	JUDITH BASIN	1	64
207	341	2	47.09N	110.81W	MONTANA	CENTRAL	CASCADE	1	65
207	341	3	47.26N	110.96W	MONTANA	CENTRAL	CASCADE	1	66
207	341	4	47.37N	110.71W	MONTANA	CENTRAL	CASCADE	1	67
207	342	1	46.85N	110.27W	MONTANA	CENTRAL	JUDITH BASIN	1	68
207	342	2	46.75N	110.52W	MONTANA	CENTRAL	MEAGHER	1	69
207	342	3	46.92N	110.66W	MONTANA	CENTRAL	CASCADE	1	70
207	342	4	47.02N	110.41W	MONTANA	CENTRAL	JUDITH BASIN	1	71
207	343	1	46.51N	109.98W	MONTANA	CENTRAL	WHEATLAND	4	72
207	343	2	46.41N	110.23W	MONTANA	CENTRAL	WHEATLAND	1	73
207	343	3	46.58N	110.37W	MONTANA	CENTRAL	MEAGHER	1	74
207	343	4	46.68N	110.12W	MONTANA	CENTRAL	WHEATLAND	1	75
207	344	1	46.17N	109.69W	MONTANA	SOUTH CENTRAL	SWEET GRASS	4	76
207	344	2	46.07N	109.94W	MONTANA	SOUTH CENTRAL	SWEET GRASS	1	77
207	344	3	46.24N	110.08W	MONTANA	CENTRAL	WHEATLAND	1	78
207	344	4	46.34N	109.83W	MONTANA	CENTRAL	WHEATLAND	1	79
207	345	1	45.82N	109.41W	MONTANA	SOUTH CENTRAL	STILLWATER	4	80
207	345	2	45.73N	109.66W	MONTANA	SOUTH CENTRAL	SWEET GRASS	1	81
207	345	3	45.90N	109.80W	MONTANA	SOUTH CENTRAL	SWEET GRASS	1	82
207	345	4	45.99N	109.55W	MONTANA	SOUTH CENTRAL	SWEET GRASS	4	83
207	346	1	45.48N	109.14W	MONTANA	SOUTH CENTRAL	CARBON	4	84
207	346	2	45.38N	109.38W	MONTANA	SOUTH CENTRAL	CARBON	1	85
207	346	3	45.56N	109.52W	MONTANA	SOUTH CENTRAL	STILLWATER	1	86
207	346	4	45.65N	109.27W	MONTANA	SOUTH CENTRAL	STILLWATER	1	87
207	347	1	45.14N	108.87W	MONTANA	SOUTH CENTRAL	CARBON	1	88
207	347	2	45.04N	109.11W	MONTANA	SOUTH CENTRAL	CARBON	1	89
207	347	3	45.21N	109.24W	MONTANA	SOUTH CENTRAL	CARBON	1	90
207	347	4	45.31N	109.00W	MONTANA	SOUTH CENTRAL	CARBON	1	91
208	337	1	48.77N	111.28W	MONTANA	NORTH CENTRAL	TOOLE	1	92
208	337	2	48.67N	111.54W	MONTANA	NORTH CENTRAL	TOOLE	1	93
208	337	3	48.84N	111.70W	MONTANA	NORTH CENTRAL	TOOLE	1	94
208	337	4	48.95N	111.44W	MONTANA	NORTH CENTRAL	TOOLE	1	95
208	338	1	48.43N	110.96W	MONTANA	NORTH CENTRAL	LIBERTY	1	96
208	338	2	48.33N	111.22W	MONTANA	NORTH CENTRAL	LIBERTY	1	97
208	338	3	48.50N	111.38W	MONTANA	NORTH CENTRAL	TOOLE	1	98
208	338	4	48.60N	111.12W	MONTANA	NORTH CENTRAL	LIBERTY	1	99
208	339	1	48.09N	110.66W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	100

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
208	339	2	47.98N	110.91W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	101
208	339	3	48.15N	111.07W	MONTANA	NORTH CENTRAL	LIBERTY	1	102
208	339	4	48.26N	110.81W	MONTANA	NORTH CENTRAL	LIBERTY	1	103
208	340	1	47.74N	110.35W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	104
208	340	2	47.64N	110.61W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	105
208	340	3	47.81N	110.76W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	106
208	340	4	47.91N	110.50W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	107
208	341	1	47.40N	110.06W	MONTANA	CENTRAL	FERGUS	4	108
208	341	2	47.30N	110.31W	MONTANA	CENTRAL	JUDITH BASIN	1	109
208	341	3	47.47N	110.46W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	110
208	341	4	47.57N	110.20W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	111
208	342	1	47.05N	109.76W	MONTANA	CENTRAL	FERGUS	1	112
208	342	2	46.95N	110.02W	MONTANA	CENTRAL	JUDITH BASIN	1	113
208	342	3	47.12N	110.16W	MONTANA	CENTRAL	JUDITH BASIN	1	114
208	342	4	47.22N	109.91W	MONTANA	CENTRAL	JUDITH BASIN	1	115
208	343	1	46.71N	109.48W	MONTANA	CENTRAL	FERGUS	1	116
208	343	2	46.61N	109.73W	MONTANA	CENTRAL	WHEATLAND	1	117
208	343	3	46.78N	109.87W	MONTANA	CENTRAL	JUDITH BASIN	1	118
208	343	4	46.88N	109.62W	MONTANA	CENTRAL	FERGUS	1	119
208	344	1	46.36N	109.19W	MONTANA	CENTRAL	GOLDEN VALLEY	4	120
208	344	2	46.25N	109.44W	MONTANA	CENTRAL	GOLDEN VALLEY	4	121
208	344	3	46.44N	109.58W	MONTANA	CENTRAL	WHEATLAND	4	122
208	344	4	46.53N	109.33W	MONTANA	CENTRAL	GOLDEN VALLEY	4	123
208	345	1	46.02N	108.92W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	124
208	345	2	45.92N	109.16W	MONTANA	SOUTH CENTRAL	STILLWATER	4	125
208	345	3	46.09N	109.30W	MONTANA	SOUTH CENTRAL	STILLWATER	4	126
208	345	4	46.19N	109.05W	MONTANA	CENTRAL	GOLDEN VALLEY	4	127
208	346	1	45.67N	108.64W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	1	128
208	346	2	45.58N	108.89W	MONTANA	SOUTH CENTRAL	CARBON	1	129
208	346	3	45.75N	109.03W	MONTANA	SOUTH CENTRAL	STILLWATER	4	130
208	346	4	45.84N	108.78W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	131
208	347	1	45.32N	108.38W	MONTANA	SOUTH CENTRAL	BIG HORN	1	132
208	347	2	45.23N	108.62W	MONTANA	SOUTH CENTRAL	BIG HORN	1	133
208	347	3	45.40N	108.76W	MONTANA	SOUTH CENTRAL	CARBON	1	134
208	347	4	45.50N	108.51W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	1	135
208	348	3	45.06N	108.49W	MONTANA	SOUTH CENTRAL	CARBON	1	136
208	348	4	45.15N	108.24W	MONTANA	SOUTH CENTRAL	CARBON	1	137
209	337	1	48.98N	110.75W	MONTANA	NORTH CENTRAL	HILL	1	138
209	337	2	48.88N	111.02W	MONTANA	NORTH CENTRAL	LIBERTY	1	139
209	338	1	48.63N	110.44W	MONTANA	NORTH CENTRAL	HILL	1	140
209	338	2	48.53N	110.70W	MONTANA	NORTH CENTRAL	HILL	1	141
209	338	3	48.71N	110.86W	MONTANA	NORTH CENTRAL	LIBERTY	1	142
209	338	4	48.81N	110.60W	MONTANA	NORTH CENTRAL	HILL	1	143
209	339	1	48.29N	110.14W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	144
209	339	2	48.19N	110.40W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	145
209	339	3	48.36N	110.55W	MONTANA	NORTH CENTRAL	HILL	1	146
209	339	4	48.46N	110.29W	MONTANA	NORTH CENTRAL	HILL	1	147
209	340	1	47.94N	109.84W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	148
209	340	2	47.84N	110.10W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	149
209	340	3	48.01N	110.25W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	150

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
209	340	4	48.11N	109.99W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	151
209	341	1	47.59N	109.54W	MONTANA	CENTRAL	FERGUS	4	152
209	341	2	47.50N	109.80W	MONTANA	CENTRAL	FERGUS	4	153
209	341	3	47.67N	109.95W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	154
209	341	4	47.77N	109.69W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	155
209	342	1	47.25N	109.25W	MONTANA	CENTRAL	FERGUS	1	156
209	342	2	47.15N	109.51W	MONTANA	CENTRAL	FERGUS	1	157
209	342	3	47.32N	109.65W	MONTANA	CENTRAL	FERGUS	1	158
209	342	4	47.42N	109.40W	MONTANA	CENTRAL	FERGUS	1	159
209	343	1	46.93N	108.97W	MONTANA	CENTRAL	FERGUS	1	160
209	343	2	46.80N	109.22W	MONTANA	CENTRAL	FERGUS	1	161
209	343	3	46.98N	109.37W	MONTANA	CENTRAL	FERGUS	1	162
209	343	4	47.07N	109.11W	MONTANA	CENTRAL	FERGUS	1	163
209	344	1	46.55N	108.69W	MONTANA	CENTRAL	MUSSELSHELL	4	164
209	344	2	46.46N	108.94W	MONTANA	CENTRAL	GOLDEN VALLEY	4	165
209	344	3	46.63N	109.08W	MONTANA	CENTRAL	GOLDEN VALLEY	1	166
209	344	4	46.73N	108.83W	MONTANA	CENTRAL	MUSSELSHELL	1	167
209	345	1	46.20N	108.42W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	168
209	345	2	46.11N	108.67W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	169
209	345	3	46.28N	108.80W	MONTANA	CENTRAL	MUSSELSHELL	4	170
209	345	4	46.38N	108.55W	MONTANA	CENTRAL	MUSSELSHELL	4	171
209	346	1	45.86N	108.15W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	172
209	346	2	45.76N	108.40W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	1	173
209	346	3	45.94N	108.53W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	174
209	346	4	46.03N	108.28W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	175
209	347	1	45.51N	107.88W	MONTANA	SOUTH CENTRAL	BIG HORN	4	176
209	347	2	45.42N	108.13W	MONTANA	SOUTH CENTRAL	BIG HORN	1	177
209	347	3	45.59N	108.26W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	1	178
209	347	4	45.69N	108.01W	MONTANA	SOUTH CENTRAL	BIG HORN	4	179
209	348	1	45.16N	107.62W	MONTANA	SOUTH CENTRAL	BIG HORN	1	180
209	348	2	45.07N	107.87W	MONTANA	SOUTH CENTRAL	BIG HORN	1	181
209	348	3	45.24N	108.00W	MONTANA	SOUTH CENTRAL	BIG HORN	1	182
209	348	4	45.34N	107.75W	MONTANA	SOUTH CENTRAL	BIG HORN	1	183
210	338	1	48.84N	109.92W	MONTANA	NORTH CENTRAL	HILL	1	184
210	338	2	48.74N	110.18W	MONTANA	NORTH CENTRAL	HILL	1	185
210	338	3	48.91N	110.33W	MONTANA	NORTH CENTRAL	HILL	1	186
210	338	4	49.01N	110.07W	MONTANA	NORTH CENTRAL	HILL	1	187
210	339	1	48.49N	109.61W	MONTANA	NORTH CENTRAL	HILL	1	188
210	339	2	48.39N	109.88W	MONTANA	NORTH CENTRAL	HILL	1	189
210	339	3	48.56N	110.03W	MONTANA	NORTH CENTRAL	HILL	1	190
210	339	4	48.66N	109.76W	MONTANA	NORTH CENTRAL	HILL	1	191
210	340	1	48.14N	109.32W	MONTANA	NORTH CENTRAL	BLAINE	1	192
210	340	2	48.04N	109.58W	MONTANA	NORTH CENTRAL	CHOUTEAU	1	193
210	340	3	48.21N	109.73W	MONTANA	NORTH CENTRAL	HILL	1	194
210	340	4	48.31N	109.46W	MONTANA	NORTH CENTRAL	BLAINE	1	195
210	341	1	47.79N	109.03W	MONTANA	CENTRAL	FERGUS	4	196
210	341	2	47.69N	109.29W	MONTANA	CENTRAL	FERGUS	4	197
210	341	3	47.87N	109.43W	MONTANA	NORTH CENTRAL	BLAINE	1	198
210	341	4	47.96N	109.17W	MONTANA	NORTH CENTRAL	BLAINE	1	199
210	342	1	47.44N	108.74W	MONTANA	CENTRAL	FERGUS	4	200

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
210	342	2	47.34N	109.00W	MONTANA	CENTRAL	FERGUS	1	201
210	342	3	47.52N	109.14W	MONTANA	CENTRAL	FERGUS	4	202
210	342	4	47.62N	108.88W	MONTANA	CENTRAL	FERGUS	4	203
210	343	1	47.09N	108.46W	MONTANA	CENTRAL	PETROLEUM	4	204
210	343	2	47.00N	108.72W	MONTANA	CENTRAL	FERGUS	1	205
210	343	3	47.17N	108.86W	MONTANA	CENTRAL	FERGUS	1	206
210	343	4	47.27N	108.60W	MONTANA	CENTRAL	PETROLEUM	4	207
210	344	1	46.74N	108.18W	MONTANA	CENTRAL	MUSSELSHELL	4	208
210	344	2	46.65N	108.44W	MONTANA	CENTRAL	MUSSELSHELL	4	209
210	344	3	46.82N	108.58W	MONTANA	CENTRAL	PETROLEUM	1	210
210	344	4	46.92N	108.32W	MONTANA	CENTRAL	PETROLEUM	4	211
210	345	1	46.39N	107.91W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	212
210	345	2	46.30N	108.17W	MONTANA	CENTRAL	MUSSELSHELL	4	213
210	345	3	46.47N	108.30W	MONTANA	CENTRAL	MUSSELSHELL	4	214
210	345	4	46.57N	108.05W	MONTANA	CENTRAL	MUSSELSHELL	4	215
210	346	1	46.04N	107.65W	MONTANA	SOUTH CENTRAL	BIG HORN	1	216
210	346	2	45.95N	107.90W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	217
210	346	3	46.12N	108.03W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	218
210	346	4	46.22N	107.78W	MONTANA	SOUTH CENTRAL	YELLOWSTONE	4	219
210	347	1	45.69N	107.38W	MONTANA	SOUTH CENTRAL	BIG HORN	4	220
210	347	2	45.60N	107.63W	MONTANA	SOUTH CENTRAL	BIG HORN	1	221
210	347	3	45.78N	107.77W	MONTANA	SOUTH CENTRAL	BIG HORN	1	222
210	347	4	45.87N	107.51W	MONTANA	SOUTH CENTRAL	BIG HORN	1	223
210	348	1	45.34N	107.13W	MONTANA	SOUTH CENTRAL	BIG HORN	1	224
210	348	2	45.25N	107.38W	MONTANA	SOUTH CENTRAL	BIG HORN	1	225
210	348	3	45.43N	107.50W	MONTANA	SOUTH CENTRAL	BIG HORN	1	226
210	348	4	45.52N	107.26W	MONTANA	SOUTH CENTRAL	BIG HORN	4	227
210	349	1	44.99N	106.87W	MONTANA	SOUTH CENTRAL	BIG HORN	4	228
210	349	3	45.08N	107.25W	MONTANA	SOUTH CENTRAL	BIG HORN	1	229
210	349	4	45.17N	107.00W	MONTANA	SOUTH CENTRAL	BIG HORN	1	230
211	338	2	48.94N	109.65W	MONTANA	NORTH CENTRAL	HILL	1	231
211	339	1	48.69N	109.08W	MONTANA	NORTH CENTRAL	BLAINE	1	232
211	339	2	48.59N	109.35W	MONTANA	NORTH CENTRAL	BLAINE	1	233
211	339	3	48.76N	109.50W	MONTANA	NORTH CENTRAL	BLAINE	1	234
211	339	4	48.86N	109.23W	MONTANA	NORTH CENTRAL	BLAINE	1	235
211	340	1	48.33N	108.79W	MONTANA	NORTH CENTRAL	BLAINE	1	236
211	340	2	48.24N	109.05W	MONTANA	NORTH CENTRAL	BLAINE	1	237
211	340	3	48.41N	109.20W	MONTANA	NORTH CENTRAL	BLAINE	1	238
211	340	4	48.51N	106.94W	MONTANA	NORTH CENTRAL	BLAINE	1	239
211	341	1	47.98N	108.50W	MONTANA	NORTH CENTRAL	PHILLIPS	1	240
211	341	2	47.89N	108.77W	MONTANA	NORTH CENTRAL	PHILLIPS	4	241
211	341	3	48.06N	108.91W	MONTANA	NORTH CENTRAL	BLAINE	1	242
211	341	4	48.16N	108.65W	MONTANA	NORTH CENTRAL	BLAINE	1	243
211	342	1	47.63N	108.22W	MONTANA	NORTH CENTRAL	PHILLIPS	4	244
211	342	2	47.54N	108.48W	MONTANA	CENTRAL	FERGUS	4	245
211	342	3	47.71N	108.62W	MONTANA	NORTH CENTRAL	PHILLIPS	4	246
211	342	4	47.81N	108.36W	MONTANA	NORTH CENTRAL	PHILLIPS	1	247
211	343	1	47.28N	107.94W	MONTANA	CENTRAL	PETROLEUM	4	248
211	343	2	47.19N	108.20W	MONTANA	CENTRAL	PETROLEUM	4	249
211	343	3	47.36N	108.34W	MONTANA	CENTRAL	PETROLEUM	4	250

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
211	343	4	47.45N	108.08W	MONTANA	CENTRAL	PETROLEUM	4	251
211	344	1	46.93N	107.67W	MONTANA	NORTHEAST	GARFIELD	4	252
211	344	2	46.83N	107.93W	MONTANA	CENTRAL	PETROLEUM	4	253
211	344	3	47.01N	108.06W	MONTANA	CENTRAL	PETROLEUM	4	254
211	344	4	47.10N	107.81W	MONTANA	NORTHEAST	GARFIELD	4	255
211	345	1	46.58N	107.40W	MONTANA	SOUTHEAST	ROSEBUD	4	256
211	345	2	46.48N	107.66W	MONTANA	SOUTH CENTRAL	TREASURE	4	257
211	345	3	46.66N	107.79W	MONTANA	SOUTHEAST	ROSEBUD	4	258
211	345	4	46.75N	107.54W	MONTANA	SOUTHEAST	ROSEBUD	4	259
211	346	1	46.22N	107.14W	MONTANA	SOUTH CENTRAL	TREASURE	1	260
211	346	2	46.13N	107.39W	MONTANA	SOUTH CENTRAL	TREASURE	1	261
211	346	3	46.31N	107.53W	MONTANA	SOUTH CENTRAL	TREASURE	4	262
211	346	4	46.40N	107.27W	MONTANA	SOUTH CENTRAL	TREASURE	4	263
211	347	1	45.87N	106.88W	MONTANA	SOUTHEAST	ROSEBUD	4	264
211	347	2	45.78N	107.13W	MONTANA	SOUTH CENTRAL	BIG HORN	4	265
211	347	3	45.96N	107.26W	MONTANA	SOUTH CENTRAL	BIG HORN	4	266
211	347	4	46.05N	107.01W	MONTANA	SOUTH CENTRAL	TREASURE	4	267
211	348	1	45.52N	106.63W	MONTANA	SOUTHEAST	ROSEBUD	4	268
211	348	2	45.43N	106.88W	MONTANA	SOUTH CENTRAL	BIG HORN	4	269
211	348	3	45.61N	107.01W	MONTANA	SOUTH CENTRAL	BIG HORN	4	270
211	348	4	45.70N	106.75W	MONTANA	SOUTHEAST	ROSEBUD	4	271
211	349	1	45.17N	106.38W	MONTANA	SOUTH CENTRAL	BIG HORN	4	272
211	349	2	45.08N	106.63W	MONTANA	SOUTH CENTRAL	BIG HORN	4	273
211	349	3	45.26N	106.75W	MONTANA	SOUTHEAST	ROSEBUD	4	274
211	349	4	45.34N	106.50W	MONTANA	SOUTHEAST	ROSEBUD	4	275
211	350	4	44.99N	106.26W	MONTANA	SOUTHEAST	POWDER RIVER	4	276
212	339	1	48.88N	108.55W	MONTANA	NORTH CENTRAL	BLAINE	1	277
212	339	2	48.78N	108.82W	MONTANA	NORTH CENTRAL	BLAINE	1	278
212	339	3	48.96N	108.97W	MONTANA	NORTH CENTRAL	BLAINE	1	279
212	340	1	48.53N	108.26W	MONTANA	NORTH CENTRAL	PHILLIPS	1	280
212	340	2	48.43N	108.53W	MONTANA	NORTH CENTRAL	BLAINE	1	281
212	340	3	48.61N	108.67W	MONTANA	NORTH CENTRAL	BLAINE	1	282
212	340	4	48.70N	108.40W	MONTANA	NORTH CENTRAL	BLAINE	1	283
212	341	1	48.17N	107.98W	MONTANA	NORTH CENTRAL	PHILLIPS	1	284
212	341	2	48.08N	108.24W	MONTANA	NORTH CENTRAL	PHILLIPS	1	285
212	341	3	48.25N	108.38W	MONTANA	NORTH CENTRAL	PHILLIPS	1	286
212	341	4	48.35N	108.12W	MONTANA	NORTH CENTRAL	PHILLIPS	1	287
212	342	1	47.82N	107.70W	MONTANA	NORTH CENTRAL	PHILLIPS	1	288
212	342	2	47.72N	107.96W	MONTANA	NORTH CENTRAL	PHILLIPS	1	289
212	342	3	47.90N	108.10W	MONTANA	NORTH CENTRAL	PHILLIPS	1	290
212	342	4	47.99N	107.84W	MONTANA	NORTH CENTRAL	PHILLIPS	1	291
212	343	1	47.46N	107.42W	MONTANA	NORTHEAST	GARFIELD	4	292
212	343	2	47.37N	107.68W	MONTANA	NORTHEAST	GARFIELD	4	293
212	343	3	47.55N	107.82W	MONTANA	NORTHEAST	GARFIELD	4	294
212	343	4	47.64N	107.56W	MONTANA	NORTHEAST	GARFIELD	4	295
212	344	1	47.11N	107.15W	MONTANA	NORTHEAST	GARFIELD	4	296
212	344	2	47.02N	107.41W	MONTANA	NORTHEAST	GARFIELD	4	297
212	344	3	47.20N	107.55W	MONTANA	NORTHEAST	GARFIELD	4	298
212	344	4	47.29N	107.29W	MONTANA	NORTHEAST	GARFIELD	4	299
212	345	1	46.76N	106.89W	MONTANA	SOUTHEAST	ROSEBUD	4	300

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
212	345	2	46.67N	107.15W	MONTANA	SOUTHEAST	ROSEBUD	4	301
212	345	3	46.84N	107.28W	MONTANA	SOUTHEAST	ROSEBUD	4	302
212	345	4	46.93N	107.02W	MONTANA	NORTHEAST	GARFIELD	4	303
212	346	1	46.40N	106.63W	MONTANA	SOUTHEAST	ROSEBUD	4	304
212	346	2	46.31N	106.89W	MONTANA	SOUTHEAST	ROSEBUD	1	305
212	346	3	46.49N	107.02W	MONTANA	SOUTHEAST	ROSEBUD	4	306
212	346	4	46.58N	106.76W	MONTANA	SOUTHEAST	ROSEBUD	4	307
212	347	1	46.05N	106.37W	MONTANA	SOUTHEAST	ROSEBUD	4	308
212	347	2	45.96N	106.63W	MONTANA	SOUTHEAST	ROSEBUD	4	309
212	347	3	46.14N	106.76W	MONTANA	SOUTHEAST	ROSEBUD	4	310
212	347	4	46.23N	106.50W	MONTANA	SOUTHEAST	ROSEBUD	1	311
212	348	1	45.70N	106.12W	MONTANA	SOUTHEAST	POWDER RIVER	4	312
212	348	2	45.61N	106.38W	MONTANA	SOUTHEAST	ROSEBUD	4	313
212	348	3	45.78N	106.50W	MONTANA	SOUTHEAST	ROSEBUD	4	314
212	348	4	45.87N	106.25W	MONTANA	SOUTHEAST	ROSEBUD	4	315
212	349	1	45.34N	105.88W	MONTANA	SOUTHEAST	POWDER RIVER	4	316
212	349	2	45.26N	106.13W	MONTANA	SOUTHEAST	POWDER RIVER	4	317
212	349	3	45.43N	106.25W	MONTANA	SOUTHEAST	POWDER RIVER	4	318
212	349	4	45.52N	106.00W	MONTANA	SOUTHEAST	POWDER RIVER	4	319
212	350	3	45.08N	106.01W	MONTANA	SOUTHEAST	POWDER RIVER	4	320
212	350	4	45.17N	105.76W	MONTANA	SOUTHEAST	POWDER RIVER	4	321
213	339	2	48.97N	108.28W	MONTANA	NORTH CENTRAL	BLAINE	1	322
213	340	1	48.71N	107.72W	MONTANA	NORTH CENTRAL	PHILLIPS	1	323
213	340	2	48.62N	107.99W	MONTANA	NORTH CENTRAL	PHILLIPS	1	324
213	340	3	48.80N	108.14W	MONTANA	NORTH CENTRAL	PHILLIPS	1	325
213	340	4	48.89N	107.87W	MONTANA	NORTH CENTRAL	PHILLIPS	1	326
213	341	1	48.36N	107.44W	MONTANA	NORTH CENTRAL	PHILLIPS	1	327
213	341	2	48.27N	107.71W	MONTANA	NORTH CENTRAL	PHILLIPS	1	328
213	341	3	48.44N	107.85W	MONTANA	NORTH CENTRAL	PHILLIPS	1	329
213	341	4	48.54N	107.58W	MONTANA	NORTH CENTRAL	PHILLIPS	1	330
213	342	1	48.00N	107.17W	MONTANA	NORTHEAST	VALLEY	4	331
213	342	2	47.91N	107.43W	MONTANA	NORTH CENTRAL	PHILLIPS	1	332
213	342	3	48.04N	107.57W	MONTANA	NORTH CENTRAL	PHILLIPS	1	333
213	342	4	48.18N	107.30W	MONTANA	NORTHEAST	VALLEY	1	334
213	343	1	47.65N	106.90W	MONTANA	NORTHEAST	GARFIELD	4	335
213	343	2	47.56N	107.16W	MONTANA	NORTHEAST	GARFIELD	4	336
213	343	3	47.73N	107.30W	MONTANA	NORTHEAST	VALLEY	4	337
213	343	4	47.82N	107.03W	MONTANA	NORTHEAST	VALLEY	4	338
213	344	1	47.29N	106.63W	MONTANA	NORTHEAST	GARFIELD	4	339
213	344	2	47.20N	106.89W	MONTANA	NORTHEAST	GARFIELD	4	340
213	344	3	47.38N	107.03W	MONTANA	NORTHEAST	GARFIELD	4	341
213	344	4	47.47N	106.76W	MONTANA	NORTHEAST	GARFIELD	4	342
213	345	1	46.93N	106.37W	MONTANA	NORTHEAST	GARFIELD	4	343
213	345	2	46.85N	106.63W	MONTANA	SOUTHEAST	ROSEBUD	4	344
213	345	3	47.02N	106.76W	MONTANA	NORTHEAST	GARFIELD	4	345
213	345	4	47.11N	106.50W	MONTANA	NORTHEAST	GARFIELD	4	346
213	346	1	46.58N	106.11W	MONTANA	SOUTHEAST	CUSTER	4	347
213	346	2	46.49N	106.37W	MONTANA	SOUTHEAST	ROSEBUD	4	348
213	346	3	46.67N	106.50W	MONTANA	SOUTHEAST	ROSEBUD	4	349
213	346	4	46.76N	106.24W	MONTANA	SOUTHEAST	ROSEBUD	4	350

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
213	347	1	46.22N	106.86W	MONTANA	SOUTHEAST	CUSTER	4	351
213	347	2	46.14N	106.12W	MONTANA	SOUTHEAST	CUSTER	4	352
213	347	3	46.31N	106.25W	MONTANA	SOUTHEAST	ROSEBUD	1	353
213	347	4	46.40N	105.99W	MONTANA	SOUTHEAST	CUSTER	1	354
213	348	1	45.87N	105.62W	MONTANA	SOUTHEAST	CUSTER	4	355
213	348	2	45.78N	105.87W	MONTANA	SOUTHEAST	POWDER RIVER	4	356
213	348	3	45.96N	105.99W	MONTANA	SOUTHEAST	CUSTER	4	357
213	348	4	46.04N	105.74W	MONTANA	SOUTHEAST	CUSTER	4	358
213	349	1	45.51N	105.37W	MONTANA	SOUTHEAST	POWDER RIVER	4	359
213	349	2	45.43N	105.63W	MONTANA	SOUTHEAST	POWDER RIVER	4	360
213	349	3	45.60N	105.73W	MONTANA	SOUTHEAST	POWDER RIVER	4	361
213	349	4	45.69N	105.40W	MONTANA	SOUTHEAST	POWDER RIVER	4	362
213	350	1	45.16N	105.13W	MONTANA	SOUTHEAST	CARTER	4	363
213	350	2	45.07N	105.39W	MONTANA	SOUTHEAST	POWDER RIVER	4	364
213	350	3	45.25N	105.51W	MONTANA	SOUTHEAST	POWDER RIVER	4	365
213	350	4	45.33N	105.25W	MONTANA	SOUTHEAST	POWDER RIVER	4	366
213	355	1	43.38N	104.00W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	1	367
213	356	1	43.03N	103.79W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	1	368
213	356	4	43.21N	103.90W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	1	369
214	340	1	48.90N	107.18W	MONTANA	NORTHEAST	VALLEY	1	370
214	340	2	48.81N	107.45W	MONTANA	NORTH CENTRAL	PHILLIPS	1	371
214	340	3	48.99N	107.59W	MONTANA	NORTH CENTRAL	PHILLIPS	1	372
214	341	1	48.54N	106.90W	MONTANA	NORTHEAST	VALLEY	1	373
214	341	2	48.45N	107.17W	MONTANA	NORTHEAST	VALLEY	1	374
214	341	3	48.63N	107.31W	MONTANA	NORTH CENTRAL	PHILLIPS	1	375
214	341	4	48.72N	107.04W	MONTANA	NORTHEAST	VALLEY	1	376
214	342	1	48.18N	106.63W	MONTANA	NORTHEAST	VALLEY	1	377
214	342	2	48.09N	106.90W	MONTANA	NORTHEAST	VALLEY	1	378
214	342	3	48.27N	107.04W	MONTANA	NORTHEAST	VALLEY	1	379
214	342	4	48.36N	106.77W	MONTANA	NORTHEAST	VALLEY	1	380
214	343	1	47.83N	106.37W	MONTANA	NORTHEAST	GARFIELD	4	381
214	343	2	47.74N	106.63W	MONTANA	NORTHEAST	GARFIELD	4	382
214	343	3	47.91N	106.77W	MONTANA	NORTHEAST	VALLEY	4	383
214	343	4	48.00N	106.50W	MONTANA	NORTHEAST	VALLEY	1	384
214	344	1	47.47N	106.10W	MONTANA	NORTHEAST	MC CONE	4	385
214	344	2	47.38N	106.37W	MONTANA	NORTHEAST	GARFIELD	4	386
214	344	3	47.56N	106.50W	MONTANA	NORTHEAST	GARFIELD	4	387
214	344	4	47.65N	106.23W	MONTANA	NORTHEAST	MC CONE	4	388
214	345	1	47.11N	105.85W	MONTANA	SOUTHEAST	PRAIRIE	4	389
214	345	2	47.02N	106.11W	MONTANA	SOUTHEAST	PRAIRIE	4	390
214	345	3	47.20N	106.24W	MONTANA	NORTHEAST	GARFIELD	4	391
214	345	4	47.29N	105.97W	MONTANA	NORTHEAST	MC CONE	4	392
214	346	1	46.75N	105.59W	MONTANA	SOUTHEAST	PRAIRIE	4	393
214	346	2	46.67N	105.85W	MONTANA	SOUTHEAST	CUSTER	4	394
214	346	3	46.84N	105.98W	MONTANA	SOUTHEAST	CUSTER	4	395
214	346	4	46.93N	105.72W	MONTANA	SOUTHEAST	PRAIRIE	4	396
214	347	1	46.39N	105.35W	MONTANA	SOUTHEAST	CUSTER	4	397
214	347	2	46.31N	105.60W	MONTANA	SOUTHEAST	CUSTER	4	398
214	347	3	46.49N	105.73W	MONTANA	SOUTHEAST	CUSTER	1	399
214	347	4	46.57N	105.47W	MONTANA	SOUTHEAST	CUSTER	1	400

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
214	348	1	46.04N	105.10W	MONTANA	SOUTHEAST	CUSTER	4	401
214	348	2	45.95N	105.36W	MONTANA	SOUTHEAST	CUSTER	4	402
214	348	3	46.13N	105.48W	MONTANA	SOUTHEAST	CUSTER	4	403
214	348	4	46.21N	105.22W	MONTANA	SOUTHEAST	CUSTER	4	404
214	349	1	45.68N	104.86W	MONTANA	SOUTHEAST	CARTER	4	405
214	349	2	45.60N	105.12W	MONTANA	SOUTHEAST	POWDER RIVER	4	406
214	349	3	45.77N	105.24W	MONTANA	SOUTHEAST	POWDER RIVER	4	407
214	349	4	45.86N	104.98W	MONTANA	SOUTHEAST	CARTER	4	408
214	350	1	45.32N	104.63W	MONTANA	SOUTHEAST	CARTER	4	409
214	350	2	45.24N	104.88W	MONTANA	SOUTHEAST	CARTER	4	410
214	350	3	45.42N	105.00W	MONTANA	SOUTHEAST	CARTER	4	411
214	350	4	45.50N	104.75W	MONTANA	SOUTHEAST	CARTER	4	412
214	351	3	45.06N	104.77W	MONTANA	SOUTHEAST	CARTER	4	413
214	351	4	45.14N	104.51W	MONTANA	SOUTHEAST	CARTER	4	414
214	353	1	44.25N	103.95W	SOUTH DAKOTA	WEST CENTRAL	LAWRENCE	4	415
214	354	1	43.90N	103.73W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	4	416
214	354	2	43.82N	103.98W	SOUTH DAKOTA	SOUTHWEST	CUSTER	4	417
214	354	4	44.07N	103.84W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	4	418
214	355	1	43.54N	103.51W	SOUTH DAKOTA	SOUTHWEST	CUSTER	4	419
214	355	2	43.46N	103.76W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	4	420
214	355	3	43.64N	103.87W	SOUTH DAKOTA	SOUTHWEST	CUSTER	4	421
214	355	4	43.72N	103.62W	SOUTH DAKOTA	SOUTHWEST	CUSTER	4	422
214	356	1	43.19N	103.30W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	1	423
214	356	2	43.11N	103.55W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	1	424
214	356	3	43.29N	103.65W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	1	425
214	356	4	43.36N	103.41W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	1	426
215	340	2	48.99N	106.91W	MONTANA	NORTHEAST	VALLEY	1	427
215	341	1	48.72N	106.36W	MONTANA	NORTHEAST	VALLEY	1	428
215	341	2	48.63N	106.63W	MONTANA	NORTHEAST	VALLEY	1	429
215	341	3	48.81N	106.77W	MONTANA	NORTHEAST	VALLEY	1	430
215	341	4	48.90N	106.50W	MONTANA	NORTHEAST	VALLEY	1	431
215	342	1	48.36N	106.09W	MONTANA	NORTHEAST	VALLEY	1	432
215	342	2	48.27N	106.36	MONTANA	NORTHEAST	VALLEY	1	433
215	342	3	48.45N	106.50W	MONTANA	NORTHEAST	VALLEY	1	434
215	342	4	48.54N	106.23	MONTANA	NORTHEAST	VALLEY	1	435
215	343	1	48.00N	105.83W	MONTANA	NORTHEAST	MC CONE	1	436
215	343	2	47.91N	106.10W	MONTANA	NORTHEAST	MC CONE	1	437
215	343	3	48.09N	106.23W	MONTANA	NORTHEAST	VALLEY	1	438
215	343	4	48.18N	105.96W	MONTANA	NORTHEAST	VALLEY	1	439
215	344	1	47.64N	105.57W	MONTANA	NORTHEAST	MC CONE	1	440
215	344	2	47.55N	105.84W	MONTANA	NORTHEAST	MC CONE	4	441
215	344	3	47.73N	105.97W	MONTANA	NORTHEAST	MC CONE	4	442
215	344	4	47.82N	105.70W	MONTANA	NORTHEAST	MC CONE	4	443
215	345	1	47.28N	105.32W	MONTANA	NORTHEAST	DAWSON	4	444
215	345	2	47.20N	105.58W	MONTANA	NORTHEAST	MC CONE	4	445
215	345	3	47.37N	105.71	MONTANA	NORTHEAST	MC CONE	4	446
215	345	4	47.46N	105.44W	MONTANA	NORTHEAST	MC CONE	1	447
215	346	1	46.92N	105.07W	MONTANA	NORTHEAST	DAWSON	4	448
215	346	2	46.84N	105.33W	MONTANA	SOUTHEAST	PRAIRIE	4	449
215	346	3	47.02N	105.46W	MONTANA	SOUTHEAST	PRAIRIE	4	450

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
215	346	4	47.10N	105.19	MONTANA	NORTHEAST	DAWSON	4	451
215	347	1	46.56N	104.83W	MONTANA	SOUTHEAST	CUSTER	4	452
215	347	2	46.48N	105.09W	MONTANA	SOUTHEAST	CUSTER	4	453
215	347	3	46.66N	105.21W	MONTANA	SOUTHEAST	PRAIRIE	1	454
215	347	4	46.74N	104.95W	MONTANA	SOUTHEAST	PRAIRIE	1	455
215	348	1	46.20N	104.59W	MONTANA	SOUTHEAST	FALLON	4	456
215	348	2	46.12N	104.84W	MONTANA	SOUTHEAST	CARTER	4	457
215	348	3	46.30N	104.97	MONTANA	SOUTHEAST	CUSTER	4	458
215	348	4	46.38N	104.71	MONTANA	SOUTHEAST	FALLON	4	459
215	349	1	45.84N	104.35W	MONTANA	SOUTHEAST	CARTER	3	460
215	349	2	45.76N	104.61W	MONTANA	SOUTHEAST	CARTER	3	461
215	349	3	45.94N	104.73W	MONTANA	SOUTHEAST	CARTER	3	462
215	349	4	46.02N	104.47W	MONTANA	SOUTHEAST	CARTER	3	463
215	350	1	45.48N	104.12W	MONTANA	SOUTHEAST	CARTER	3	464
215	350	2	45.40N	104.37W	MONTANA	SOUTHEAST	CARTER	3	465
215	350	3	45.58N	104.49W	MONTANA	SOUTHEAST	CARTER	3	466
215	350	4	45.66N	104.23W	MONTANA	SOUTHEAST	CARTER	3	467
215	351	1	45.13N	103.89W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	468
215	351	2	45.05N	104.15W	MONTANA	SOUTHEAST	CARTER	4	469
215	351	3	45.22N	104.26W	MONTANA	SOUTHEAST	CARTER	4	470
215	351	4	45.30N	104.01W	SOUTH DAKOTA	NORTHWEST	HARDING	3	471
215	352	1	44.77N	103.67W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	472
215	352	2	44.69N	103.92W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	473
215	352	3	44.87N	104.03W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	474
215	352	4	44.95N	103.78W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	475
215	353	1	44.41N	103.45W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	476
215	353	2	44.33N	103.70W	SOUTH DAKOTA	WEST CENTRAL	LAWRENCE	4	477
215	353	3	44.51N	103.81W	SOUTH DAKOTA	WEST CENTRAL	LAWRENCE	1	478
215	353	4	44.59N	103.56W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	479
215	354	1	44.05N	103.23W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	480
215	354	2	43.97N	103.48W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	4	481
215	354	3	44.15N	103.59W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	4	482
215	354	4	44.23N	103.34W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	483
215	355	1	43.69N	103.02W	SOUTH DAKOTA	SOUTHWEST	CUSTER	1	484
215	355	2	43.62N	103.27W	SOUTH DAKOTA	SOUTHWEST	CUSTER	1	485
215	355	3	43.80N	103.38W	SOUTH DAKOTA	SOUTHWEST	CUSTER	4	486
215	355	4	43.87N	103.13W	SOUTH DAKOTA	SOUTHWEST	CUSTER	1	487
215	356	1	43.34N	102.81W	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	488
215	356	2	43.26N	103.06W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	1	489
215	356	3	43.44N	103.16W	SOUTH DAKOTA	SOUTHWEST	FALL RIVER	1	490
215	356	4	43.51N	102.92W	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	491
215	357	3	43.08N	102.94W	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	492
215	357	4	43.16N	102.71W	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	493
216	341	1	48.90N	105.81W	MONTANA	NORTHEAST	DANIELS	1	494
216	341	2	48.81N	106.09W	MONTANA	NORTHEAST	DANIELS	1	495
216	341	3	48.99N	106.22W	MONTANA	NORTHEAST	VALLEY	1	496
216	342	1	48.54N	105.55W	MONTANA	NORTHEAST	ROOSEVELT	1	497
216	342	2	48.45N	105.82W	MONTANA	NORTHEAST	ROOSEVELT	1	498
216	342	3	48.63N	105.95W	MONTANA	NORTHEAST	DANIELS	1	499
216	342	4	48.72N	105.68W	MONTANA	NORTHEAST	DANIELS	1	500

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
216	343	1	48.17N	105.29W	MONTANA	NORTHEAST	ROOSEVELT	1	501
216	343	2	48.09N	105.56W	MONTANA	NORTHEAST	MC CONE	1	502
216	343	3	48.27N	105.69W	MONTANA	NORTHEAST	ROOSEVELT	1	503
216	343	4	48.35N	105.42W	MONTANA	NORTHEAST	ROOSEVELT	1	504
216	344	1	47.81N	105.03W	MONTANA	NORTHEAST	RICHLAND	1	505
216	344	2	47.73N	105.30W	MONTANA	NORTHEAST	DAWSON	1	506
216	344	3	47.91N	105.43W	MONTANA	NORTHEAST	MC CONE	1	507
216	344	4	47.99N	105.16W	MONTANA	NORTHEAST	RICHLAND	1	508
216	345	1	47.45N	104.79W	MONTANA	NORTHEAST	DAWSON	1	509
216	345	2	47.37N	105.05W	MONTANA	NORTHEAST	DAWSON	4	510
216	345	3	47.55N	105.18W	MONTANA	NORTHEAST	DAWSON	1	511
216	345	4	47.63N	104.91W	MONTANA	NORTHEAST	DAWSON	1	512
216	346	1	47.09N	104.54W	MONTANA	NORTHEAST	DAWSON	1	513
216	346	2	47.00N	104.81W	MONTANA	NORTHEAST	DAWSON	1	514
216	346	3	47.19N	104.93W	MONTANA	NORTHEAST	DAWSON	4	515
216	346	4	47.27N	104.66W	MONTANA	NORTHEAST	DAWSON	4	516
216	347	1	46.73N	104.30W	MONTANA	SOUTHEAST	WIBAUX	4	517
216	347	2	46.64N	104.56W	MONTANA	SOUTHEAST	FALLON	4	518
216	347	3	46.82N	104.68W	MONTANA	SOUTHEAST	PRAIRIE	4	519
216	347	4	46.91N	104.42W	MONTANA	SOUTHEAST	WIBAUX	4	520
216	348	1	46.36N	104.06W	NORTH DAKOTA	SOUTHWEST	SLOPE	3	521
216	348	2	46.28N	104.33W	MONTANA	SOUTHEAST	FALLON	4	522
216	348	3	46.46N	104.44W	MONTANA	SOUTHEAST	FALLON	4	523
216	348	4	46.55N	104.18W	MONTANA	SOUTHEAST	FALLON	4	524
216	349	1	46.00N	103.83W	NORTH DAKOTA	SOUTHWEST	BOWMAN	4	525
216	349	2	45.92N	104.09W	MONTANA	SOUTHEAST	FALLON	4	526
216	349	3	46.10N	104.21W	MONTANA	SOUTHEAST	FALLON	4	527
216	349	4	46.18N	103.95W	NORTH DAKOTA	SOUTHWEST	BOWMAN	3	528
216	350	1	45.64N	103.61W	SOUTH DAKOTA	NORTHWEST	HARDING	1	529
216	350	2	45.56N	103.86W	SOUTH DAKOTA	NORTHWEST	HARDING	1	530
216	350	3	45.74N	103.98W	SOUTH DAKOTA	NORTHWEST	HARDING	1	531
216	350	4	45.82N	103.72W	SOUTH DAKOTA	NORTHWEST	HARDING	1	532
216	351	1	45.28N	103.38W	SOUTH DAKOTA	NORTHWEST	HARDING	3	533
216	351	2	45.20N	103.64W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	534
216	351	3	45.38N	103.75W	SOUTH DAKOTA	NORTHWEST	HARDING	3	535
216	351	4	45.46N	103.49W	SOUTH DAKOTA	NORTHWEST	HARDING	3	536
216	352	1	44.92N	103.16W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	537
216	352	2	44.84N	103.42W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	538
216	352	3	45.02N	103.53W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	539
216	352	4	45.10N	103.27W	SOUTH DAKOTA	NORTHWEST	BUTTE	3	540
216	353	1	44.56N	102.95W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	541
216	353	2	44.49N	103.20W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	542
216	353	3	44.67N	103.31W	SOUTH DAKOTA	NORTHWEST	BUTTE	1	543
216	353	4	44.74N	103.05	SOUTH DAKOTA	NORTHWEST	BUTTE	1	544
216	354	1	44.20N	102.73W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	545
216	354	2	44.13N	102.99W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	546
216	354	3	44.31N	103.09W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	547
216	354	4	44.38N	102.84	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	548
216	355	1	43.84N	102.53W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	549
216	355	2	43.77N	102.78W	SOUTH DAKOTA	SOUTHWEST	CUSTER	1	550

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
216	355	3	43.95N	102.6	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	551
216	355	4	44.02N	102.63	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	552
216	356	1	43.49N	102.35	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	553
216	356	2	43.41N	102.57	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	554
216	356	3	43.59N	102.5	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	555
216	356	4	43.66N	102.42	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	556
216	357	1	43.13N	102.1	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	557
216	357	2	43.05N	102.37	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	558
216	357	3	43.23N	102.47	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	559
216	357	4	43.31N	102.22	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	560
217	341	2	48.99N	105.54	MONTANA	NORTHEAST	DANIELS	1	561
217	342	1	48.71N	105.00	MONTANA	NORTHEAST	SHERIDAN	1	562
217	342	2	48.62N	105.27	MONTANA	NORTHEAST	DANIELS	1	563
217	342	3	48.80N	105.40	MONTANA	NORTHEAST	DANIELS	1	564
217	342	4	48.89N	105.13	MONTANA	NORTHEAST	DANIELS	1	565
217	343	1	48.34N	104.74	MONTANA	NORTHEAST	ROOSEVELT	1	566
217	343	2	48.26N	105.02	MONTANA	NORTHEAST	ROOSEVELT	1	567
217	343	3	48.44N	105.14	MONTANA	NORTHEAST	ROOSEVELT	1	568
217	343	4	48.53N	104.87	MONTANA	NORTHEAST	ROOSEVELT	1	569
217	344	1	47.98N	104.4	MONTANA	NORTHEAST	RICHLAND	1	570
217	344	2	47.99N	104.7	MONTANA	NORTHEAST	RICHLAND	1	571
217	344	3	48.08N	104.69	MONTANA	NORTHEAST	RICHLAND	1	572
217	344	4	48.15N	104.62	MONTANA	NORTHEAST	ROOSEVELT	1	573
217	345	1	47.62N	104.25	MONTANA	NORTHEAST	RICHLAND	1	574
217	345	2	47.53N	104.52	MONTANA	NORTHEAST	RICHLAND	1	575
217	345	3	47.71N	104.54	MONTANA	NORTHEAST	RICHLAND	1	576
217	345	4	47.80N	104.37	MONTANA	NORTHEAST	RICHLAND	1	577
217	346	1	47.25N	104.01	NORTH DAKOTA	SOUTHWEST	GOLDEN VALLEY	3	578
217	346	2	47.17N	104.27	MONTANA	SOUTHEAST	WIBAUX	4	579
217	346	3	47.35N	104.40	MONTANA	NORTHEAST	RICHLAND	1	580
217	346	4	47.43N	104.13	MONTANA	NORTHEAST	RICHLAND	1	581
217	347	1	46.89N	103.77	NORTH DAKOTA	SOUTHWEST	GOLDEN VALLEY	3	582
217	347	2	46.81N	104.04	NORTH DAKOTA	SOUTHWEST	GOLDEN VALLEY	1	583
217	347	3	46.99N	104.15	MONTANA	SOUTHEAST	WIBAUX	4	584
217	347	4	47.07N	103.89	NORTH DAKOTA	SOUTHWEST	GOLDEN VALLEY	1	585
217	348	1	46.52N	103.54	NORTH DAKOTA	SOUTHWEST	SLOPE	3	586
217	348	2	46.45N	103.80	NORTH DAKOTA	SOUTHWEST	SLOPE	3	587
217	348	3	46.63N	103.92	NORTH DAKOTA	SOUTHWEST	GOLDEN VALLEY	1	588
217	348	4	46.71N	103.65	NORTH DAKOTA	SOUTHWEST	GOLDEN VALLEY	3	589
217	349	1	46.16N	103.31	NORTH DAKOTA	SOUTHWEST	BOWMAN	1	590
217	349	2	46.08N	103.57	NORTH DAKOTA	SOUTHWEST	BOWMAN	3	591
217	349	3	46.26N	103.69	NORTH DAKOTA	SOUTHWEST	BOWMAN	1	592
217	349	4	46.34N	103.42	NORTH DAKOTA	SOUTHWEST	SLOPE	1	593
217	350	1	45.80N	103.04	SOUTH DAKOTA	NORTHWEST	HARDING	1	594
217	350	2	45.72N	103.35	SOUTH DAKOTA	NORTHWEST	HARDING	1	595
217	350	3	45.90N	103.46	SOUTH DAKOTA	NORTHWEST	HARDING	1	596
217	350	4	45.98N	103.29	NORTH DAKOTA	SOUTHWEST	BOWMAN	1	597
217	351	1	45.44N	102.87	SOUTH DAKOTA	NORTHWEST	PERKINS	1	598
217	351	2	45.36N	103.13	SOUTH DAKOTA	NORTHWEST	HARDING	1	599
217	351	3	45.54N	103.24	SOUTH DAKOTA	NORTHWEST	HARDING	1	600

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
217	351	4	45.62N	102.98W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	601
217	352	1	45.07N	102.65W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	602
217	352	2	45.00N	102.91W	SOUTH DAKOTA	WEST CENTRAL	MEADE	3	603
217	352	3	45.18N	103.02W	SOUTH DAKOTA	NORTHWEST	BUTTE	3	604
217	352	4	45.26N	102.76W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	605
217	353	1	44.71N	102.44W	SOUTH DAKOTA	WEST CENTRAL	MEADE	3	606
217	353	2	44.64N	102.69W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	607
217	353	3	44.82N	102.80W	SOUTH DAKOTA	WEST CENTRAL	MEADE	3	608
217	353	4	44.89N	102.55W	SOUTH DAKOTA	WEST CENTRAL	MEADE	3	609
217	354	1	44.35N	102.23W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	610
217	354	2	44.28N	102.48W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	611
217	354	3	44.46N	102.59W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	612
217	354	4	44.53N	102.34W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	613
217	355	1	43.99N	102.03W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	614
217	355	2	43.92N	102.28W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	615
217	355	3	44.10N	102.38W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	616
217	355	4	44.17N	102.13W	SOUTH DAKOTA	WEST CENTRAL	PENNINGTON	1	617
217	356	1	43.63N	101.83W	SOUTH DAKOTA	SOUTHWEST	WASHABAUGH	1	618
217	356	2	43.56N	102.07W	SOUTH DAKOTA	SOUTHWEST	WASHABAUGH	1	619
217	356	3	43.74N	102.18W	SOUTH DAKOTA	SOUTHWEST	SHANNON	1	620
217	356	4	43.81N	101.93W	SOUTH DAKOTA	WEST CENTRAL	JACKSON	1	621
217	357	1	43.27N	101.63W	SOUTH DAKOTA	SOUTHWEST	BENNETT	1	622
217	357	2	43.20N	101.88W	SOUTH DAKOTA	SOUTHWEST	BENNETT	1	623
217	357	3	43.38N	101.97W	SOUTH DAKOTA	SOUTHWEST	BENNETT	1	624
217	357	4	43.45N	101.73W	SOUTH DAKOTA	SOUTHWEST	WASHABAUGH	1	625
217	358	4	43.09N	101.53W	SOUTH DAKOTA	SOUTHWEST	BENNETT	3	626
218	342	1	48.88N	104.44W	MONTANA	NORTHEAST	SHERIDAN	1	627
218	342	2	48.79N	104.72W	MONTANA	NORTHEAST	SHERIDAN	1	628
218	342	3	48.97N	104.85W	MONTANA	NORTHEAST	SHERIDAN	1	629
218	343	1	48.51N	104.19W	MONTANA	NORTHEAST	SHERIDAN	1	630
218	343	2	48.43N	104.47W	MONTANA	NORTHEAST	SHERIDAN	1	631
218	343	3	48.61N	104.59W	MONTANA	NORTHEAST	SHERIDAN	1	632
218	343	4	48.69N	104.32W	MONTANA	NORTHEAST	SHERIDAN	1	633
218	344	1	48.14N	103:95W	NORTH DAKOTA	NORTHWEST	WILLIAMS	1	634
218	344	2	48.06N	104.22W	MONTANA	NORTHEAST	ROOSEVELT	1	635
218	344	3	48.24N	104.34W	MONTANA	NORTHEAST	ROOSEVELT	1	636
218	344	4	48.33N	104.07W	MONTANA	NORTHEAST	ROOSEVELT	1	637
218	345	1	47.78N	103.71W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	1	638
218	345	2	47.70N	103.98W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	3	639
218	345	3	47.88N	104.10W	MONTANA	NORTHEAST	RICHLAND	1	640
218	345	4	47.96N	103.83W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	1	641
218	346	1	47.41N	103.47W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	3	642
218	346	2	47.33N	103.74W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	3	643
218	346	3	47.51N	103.86W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	3	644
218	346	4	47.59N	103.59W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	3	645
218	347	1	47.05N	103.24W	NORTH DAKOTA	SOUTHWEST	BILLINGS	4	646
218	347	2	46.97N	103.50W	NORTH DAKOTA	SOUTHWEST	BILLINGS	3	647
218	347	3	47.15N	103.62W	NORTH DAKOTA	SOUTHWEST	BILLINGS	3	648
218	347	4	47.23N	103.35W	NORTH DAKOTA	SOUTHWEST	BILLINGS	3	649
218	348	1	46.68N	103.01W	NORTH DAKOTA	SOUTHWEST	STARK	1	650

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
218	348	2	46.60N	103.27W	NORTH DAKOTA	SOUTHWEST	SLOPE	3	651
218	348	3	46.79N	103.39W	NORTH DAKOTA	SOUTHWEST	BILLINGS	3	652
218	348	4	46.86N	103.12W	NORTH DAKOTA	SOUTHWEST	STARK	4	653
218	349	1	46.32N	102.79W	NORTH DAKOTA	SOUTHWEST	ADAMS	1	654
218	349	2	46.24N	103.05W	NORTH DAKOTA	SOUTHWEST	BOWMAN	1	655
218	349	3	46.42N	103.16W	NORTH DAKOTA	SOUTHWEST	SLOPE	1	656
218	349	4	46.50N	102.90W	NORTH DAKOTA	SOUTHWEST	HETTINGER	1	657
218	350	1	45.95N	102.57W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	658
218	350	2	45.88N	102.83W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	659
218	350	3	46.06N	102.94W	NORTH DAKOTA	SOUTHWEST	ADAMS	1	660
218	350	4	46.13N	102.67W	NORTH DAKOTA	SOUTHWEST	ADAMS	1	661
218	351	1	45.59N	102.35W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	662
218	351	2	45.51N	102.61W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	663
218	351	3	45.69N	102.72W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	664
218	351	4	45.77N	102.46W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	665
218	352	1	45.22N	102.14W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	666
218	352	2	45.15N	102.40W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	667
218	352	3	45.33N	102.50W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	668
218	352	4	45.41N	102.24W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	669
218	353	1	44.86N	101.93W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	1	670
218	353	2	44.79N	102.19W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	671
218	353	3	44.97N	102.29W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	672
218	353	4	45.04N	102.03W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	3	673
218	354	1	44.50N	101.73W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	674
218	354	2	44.43N	101.98W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	675
218	354	3	44.61N	102.08W	SOUTH DAKOTA	WEST CENTRAL	MEADE	1	676
218	354	4	44.68N	101.83W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	1	677
218	355	1	44.14N	101.52W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	678
218	355	2	44.06N	101.78W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	679
218	355	3	44.24N	101.88W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	680
218	355	4	44.32N	101.62W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	681
218	356	1	43.77N	101.33W	SOUTH DAKOTA	SOUTHWEST	WASHABAUGH	4	682
218	356	2	43.70N	101.58W	SOUTH DAKOTA	SOUTHWEST	WASHABAUGH	4	683
218	356	3	43.86N	101.68W	SOUTH DAKOTA	WEST CENTRAL	JACKSON	1	684
218	356	4	43.95N	101.43W	SOUTH DAKOTA	WEST CENTRAL	JACKSON	1	685
218	357	1	43.41N	101.13W	SOUTH DAKOTA	SOUTH CENTRAL	TODD	1	686
218	357	2	43.34N	101.38W	SOUTH DAKOTA	SOUTHWEST	BENNETT	1	687
218	357	3	43.52N	101.48W	SOUTH DAKOTA	SOUTHWEST	WASHABAUGH	1	688
218	357	4	43.59N	101.23W	SOUTH DAKOTA	SOUTHWEST	WASHABAUGH	1	689
218	358	1	43.05N	100.94W	SOUTH DAKOTA	SOUTH CENTRAL	TODD	3	690
218	358	3	43.16N	101.28W	SOUTH DAKOTA	SOUTHWEST	BENNETT	3	691
218	358	4	43.23N	101.04W	SOUTH DAKOTA	SOUTH CENTRAL	TODD	3	692
219	342	2	48.96N	104.14W	MONTANA	NORTHEAST	SHERIDAN	1	693
219	343	1	48.67N	103.64W	NORTH DAKOTA	NORTHWEST	DIVIDE	1	694
219	343	2	48.59N	103.92W	NORTH DAKOTA	NORTHWEST	WILLIAMS	1	695
219	343	3	48.77N	104.04W	NORTH DAKOTA	NORTHWEST	DIVIDE	1	696
219	343	4	48.86N	103.76W	NORTH DAKOTA	NORTHWEST	DIVIDE	1	697
219	344	1	48.30N	103.48W	NORTH DAKOTA	NORTHWEST	WILLIAMS	1	698
219	344	2	48.22N	103.67W	NORTH DAKOTA	NORTHWEST	WILLIAMS	1	699
219	344	3	48.41N	103.79W	NORTH DAKOTA	NORTHWEST	WILLIAMS	1	700

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
219	344	4	48.49N	103.52W	NORTH DAKOTA	NORTHWEST	WILLIAMS	1	701
219	345	1	47.94N	103.16W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	1	702
219	345	2	47.86N	103.43W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	1	703
219	345	3	48.04N	103.55W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	3	704
219	345	4	48.12N	103.29W	NORTH DAKOTA	NORTHWEST	WILLIAMS	3	705
219	346	1	47.57N	102.93W	NORTH DAKOTA	WEST CENTRAL	DUNN	3	706
219	346	2	47.49N	103.20W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	3	707
219	346	3	47.67N	103.32W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	3	708
219	346	4	47.75N	103.04W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	3	709
219	347	1	47.20N	102.70W	NORTH DAKOTA	WEST CENTRAL	DUNN	3	710
219	347	2	47.12N	102.97W	NORTH DAKOTA	WEST CENTRAL	DUNN	3	711
219	347	3	47.31N	103.08W	NORTH DAKOTA	SOUTHWEST	BILLINGS	4	712
219	347	4	47.39N	102.84W	NORTH DAKOTA	WEST CENTRAL	DUNN	3	713
219	348	1	46.83N	102.47W	NORTH DAKOTA	SOUTHWEST	STARK	1	714
219	348	2	46.76N	102.74W	NORTH DAKOTA	SOUTHWEST	STARK	1	715
219	348	3	46.94N	102.85W	NORTH DAKOTA	SOUTHWEST	STARK	3	716
219	348	4	47.02N	102.59W	NORTH DAKOTA	SOUTHWEST	STARK	1	717
219	349	1	46.47N	102.26W	NORTH DAKOTA	SOUTHWEST	HETTINGER	1	718
219	349	2	46.39N	102.52W	NORTH DAKOTA	SOUTHWEST	HETTINGER	1	719
219	349	3	46.58N	102.63W	NORTH DAKOTA	SOUTHWEST	HETTINGER	3	720
219	349	4	46.65N	102.36W	NORTH DAKOTA	SOUTHWEST	HETTINGER	1	721
219	350	1	46.10N	102.04W	NORTH DAKOTA	SOUTHWEST	ADAMS	1	722
219	350	2	46.03N	102.30W	NORTH DAKOTA	SOUTHWEST	ADAMS	3	723
219	350	3	46.21N	102.41W	NORTH DAKOTA	SOUTHWEST	ADAMS	3	724
219	350	4	46.28N	102.15W	NORTH DAKOTA	SOUTHWEST	HETTINGER	1	725
219	351	1	45.74N	101.83W	SOUTH DAKOTA	NORTHWEST	CORSON	3	726
219	351	2	45.66N	102.09W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	727
219	351	3	45.84N	102.20W	SOUTH DAKOTA	NORTHWEST	PERKINS	1	728
219	351	4	45.92N	101.93W	SOUTH DAKOTA	NORTHWEST	CORSON	1	729
219	352	1	45.37N	101.62W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	1	730
219	352	2	45.30N	101.88W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	1	731
219	352	3	45.48N	101.99W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	1	732
219	352	4	45.55N	101.72W	SOUTH DAKOTA	NORTHWEST	CORSON	3	733
219	353	1	45.01N	101.42W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	1	734
219	353	2	44.93N	101.67W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	1	735
219	353	3	45.12N	101.79W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	3	736
219	353	4	45.19N	101.52W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	737
219	354	1	44.64N	101.22W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	738
219	354	2	44.57N	101.47W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	739
219	354	3	44.75N	101.57W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	1	740
219	354	4	44.82N	101.31W	SOUTH DAKOTA	NORTHWEST	ZIEBACH	1	741
219	355	1	44.28N	101.02W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	742
219	355	2	44.21N	101.27W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	743
219	355	3	44.39N	101.37W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	744
219	355	4	44.46N	101.12W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	745
219	356	1	43.91N	100.82W	SOUTH DAKOTA	SOUTH CENTRAL	JONES	1	746
219	356	2	43.84N	101.08W	SOUTH DAKOTA	SOUTH CENTRAL	MELLETTE	1	747
219	356	3	44.03N	101.17W	SOUTH DAKOTA	WEST CENTRAL	HAAKON	1	748
219	356	4	44.10N	100.92W	SOUTH DAKOTA	SOUTH CENTRAL	JONES	1	749
219	357	1	43.55N	100.63W	SOUTH DAKOTA	SOUTH CENTRAL	MELLETTE	1	750

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
219	357	2	43.48N	100.88W	SOUTH DAKOTA	SOUTH CENTRAL	MELLETTE	1	751
219	357	3	43.66N	100.98W	SOUTH DAKOTA	SOUTH CENTRAL	MELLETTE	1	752
219	357	4	43.73N	100.73W	SOUTH DAKOTA	SOUTH CENTRAL	MELLETTE	1	753
219	358	1	43.19N	100.45W	SOUTH DAKOTA	SOUTH CENTRAL	TODD	3	754
219	358	2	43.12N	100.70W	SOUTH DAKOTA	SOUTH CENTRAL	TODD	3	755
219	358	3	43.30N	100.79W	SOUTH DAKOTA	SOUTH CENTRAL	TODD	3	756
219	358	4	43.37N	100.54W	SOUTH DAKOTA	SOUTH CENTRAL	TODD	3	757
220	343	1	48.83N	103.08W	NORTH DAKOTA	NORTHWEST	DIVIDE	1	758
220	343	2	48.75N	103.36W	NORTH DAKOTA	NORTHWEST	DIVIDE	1	759
220	343	3	48.94N	103.48W	NORTH DAKOTA	NORTHWEST	DIVIDE	1	760
220	344	1	48.46N	102.84W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	3	761
220	344	2	48.38N	103.12W	NORTH DAKOTA	NORTHWEST	WILLIAMS	1	762
220	344	3	48.57N	103.24W	NORTH DAKOTA	NORTHWEST	WILLIAMS	1	763
220	344	4	46.65N	102.96W	NORTH DAKOTA	NORTHWEST	DIVIDE	1	764
220	345	1	49.09N	102.61W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	3	765
220	345	2	48.01N	102.88W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	1	766
220	345	3	48.20N	103.00W	NORTH DAKOTA	NORTHWEST	WILLIAMS	3	767
220	345	4	48.28N	102.72W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	3	768
220	346	1	47.72N	102.38W	NORTH DAKOTA	WEST CENTRAL	DUNN	4	769
220	346	2	47.65N	102.65W	NORTH DAKOTA	WEST CENTRAL	DUNN	3	770
220	346	3	47.83N	102.77W	NORTH DAKOTA	WEST CENTRAL	MC KENZIE	4	771
220	346	4	47.91N	102.49W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	1	772
220	347	1	47.35N	102.16W	NORTH DAKOTA	WEST CENTRAL	MERCER	1	773
220	347	2	47.28N	102.43W	NORTH DAKOTA	WEST CENTRAL	DUNN	3	774
220	347	3	47.46N	102.54W	NORTH DAKOTA	WEST CENTRAL	DUNN	3	775
220	347	4	47.54N	102.27W	NORTH DAKOTA	WEST CENTRAL	DUNN	3	776
220	348	1	46.98N	101.94W	NORTH DAKOTA	SOUTH CENTRAL	MORTON	3	777
220	348	2	46.91N	102.21W	NORTH DAKOTA	SOUTHWEST	STARK	1	778
220	348	3	47.09N	102.32W	NORTH DAKOTA	WEST CENTRAL	DUNN	1	779
220	348	4	47.17N	102.05	NORTH DAKOTA	WEST CENTRAL	MERCER	3	780
220	349	1	46.62N	101.72W	NORTH DAKOTA	SOUTH CENTRAL	GRANT	3	781
220	349	2	46.54N	101.99W	NORTH DAKOTA	SOUTH CENTRAL	GRANT	1	782
220	349	3	46.73N	102.10W	NORTH DAKOTA	SOUTHWEST	STARK	1	783
220	349	4	46.80N	101.83W	NORTH DAKOTA	SOUTH CENTRAL	MORTON	1	784
220	350	1	46.25N	101.51W	NORTH DAKOTA	SOUTH CENTRAL	GRANT	3	785
220	350	2	46.18N	101.78W	NORTH DAKOTA	SOUTH CENTRAL	GRANT	1	786
220	350	3	46.36N	101.68W	NORTH DAKOTA	SOUTH CENTRAL	GRANT	3	787
220	350	4	46.43N	101.41W	NORTH DAKOTA	SOUTH CENTRAL	GRANT	3	788
220	351	1	45.88N	101.30W	SOUTH DAKOTA	NORTHWEST	CORSON	1	789
220	351	2	45.81N	101.57W	SOUTH DAKOTA	NORTHWEST	CORSON	3	790
220	351	3	45.99N	101.67W	NORTH DAKOTA	SOUTH CENTRAL	SIOUX	3	791
220	351	4	46.06N	101.41W	NORTH DAKOTA	SOUTH CENTRAL	SIOUX	3	792
220	352	1	45.51N	101.19W	SOUTH DAKOTA	NORTHWEST	CORSON	3	793
220	352	2	45.44N	101.35W	SOUTH DAKOTA	NORTHWEST	DEWEY	3	794
220	352	3	45.63N	101.46W	SOUTH DAKOTA	NORTHWEST	CORSON	3	795
220	352	4	45.70N	101.20W	SOUTH DAKOTA	NORTHWEST	CORSON	3	796
220	353	1	45.15N	100.90W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	797
220	353	2	45.09N	101.16W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	798
220	353	3	45.26N	101.26W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	799
220	353	4	45.33N	101.60W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	800

I	J	K	LAT.	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
220	354	1	44.78N	100.70W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	801
220	354	2	44.71N	100.96W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	802.
220	354	3	44.89N	101.06W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	803
220	354	4.	44.96N	100.80W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	804
220	355	1	44.42N	100.51W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	805
220	355	2	44.35N	100.76W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	806
220	355	3	44.53N	100.86W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	807
220	355	4	44.60N	100.60W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	808
220	356	1	44.05N	100.32W	SOUTH DAKOTA	SOUTH CENTRAL	LYMAN	1	809
220	356	2	43.98N	100.57W	SOUTH DAKOTA	SOUTH CENTRAL	JONES	1	810
220	356	3	44.16N	100.67W	SOUTH DAKOTA	SOUTH CENTRAL	JONES	1	811
220	356	4	44.23N	100.41W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	812
220	357	1	43.69N	100.13W	SOUTH DAKOTA	SOUTH CENTRAL	TRIPP	1	813
220	357	2	43.62N	100.38W	SOUTH DAKOTA	SOUTH CENTRAL	MELLETTE	1	814
220	357	3	43.80N	100.48W	SOUTH DAKOTA	SOUTH CENTRAL	JONES	1	815
220	357	4	43.87N	100.22W	SOUTH DAKOTA	SOUTH CENTRAL	LYMAN	1	816
220	358	1	43.32N	99.96W	SOUTH DAKOTA	SOUTH CENTRAL	TRIPP	3	817
220	358	2	43.25N	100.20W	SOUTH DAKOTA	SOUTH CENTRAL	TRIPP	3	818
220	358	3	43.44N	100.29W	SOUTH DAKOTA	SOUTH CENTRAL	MELLETTE	1	819
220	358	4	43.50N	100.04W	SOUTH DAKOTA	SOUTH CENTRAL	TRIPP	1	820
220	359	3	43.07N	100.11W	SOUTH DAKOTA	SOUTH CENTRAL	TRIPP	3	821
220	359	4	43.14N	99.86W	SOUTH DAKOTA	SOUTH CENTRAL	TRIPP	3	822
221	343	1	48.99N	102.51W	NORTH DAKOTA	NORTHWEST	BURKE	1	823
221	343	2	48.91N	102.80W	NORTH DAKOTA	NORTHWEST	BURKE	1	824
221	344	1	48.62N	102.28W	NORTH DAKOTA	NORTHWEST	BURKE	3	825
221	344	2	48.54N	102.56W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	1	826
221	344	3	48.72N	102.68W	NORTH DAKOTA	NORTHWEST	BURKE	3	827
221	344	4	48.80N	102.40W	NORTH DAKOTA	NORTHWEST	BURKE	1	828
221	345	1	48.24N	102.05W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	1	829
221	345	2	48.17N	102.33W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	1	830
221	345	3	48.35N	102.45W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	1	831
221	345	4	48.43N	102.17W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	3	832
221	346	1	47.87N	101.83W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	833
221	346	2	47.80N	102.11W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	834
221	346	3	47.98N	102.22W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	1	835
221	346	4	48.06N	101.94W	NORTH DAKOTA	NORTHWEST	MOUNTRAIL	1	836
221	347	1	47.50N	101.61W	NORTH DAKOTA	WEST CENTRAL	MERCER	1	837
221	347	2	47.43N	101.88W	NORTH DAKOTA	WEST CENTRAL	MERCER	1	838
221	347	3	47.61N	101.99W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	839
221	347	4	47.69N	101.72W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	840
221	348	1	47.13N	101.39	NORTH DAKOTA	WEST CENTRAL	OLIVER	3	841
221	348	2	47.06N	101.67	NORTH DAKOTA	WEST CENTRAL	OLIVER	1	842
221	348	3	47.24N	101.77W	NORTH DAKOTA	WEST CENTRAL	MERCER	1	843
221	348	4	47.32N	101.50W	NORTH DAKOTA	WEST CENTRAL	MERCER	3	844
221	349	1	46.76N	101.18W	NORTH DAKOTA	SOUTH CENTRAL	MORTON	3	845
221	349	2	46.69N	101.45W	NORTH DAKOTA	SOUTH CENTRAL	MORTON	3	846
221	349	3	46.87N	101.56W	NORTH DAKOTA	SOUTH CENTRAL	MORTON	1	847
221	349	4	46.95N	101.29W	NORTH DAKOTA	SOUTH CENTRAL	MORTON	1	848
221	350	1	46.39N	100.98W	NORTH DAKOTA	SOUTH CENTRAL	SIOUX	4	849
221	350	2	46.32N	101.24W	NORTH DAKOTA	SOUTH CENTRAL	GRANT	3	850

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
221	350	3	46.50N	101.35W	NORTH DAKOTA	SOUTH CENTRAL	GRANT	4	851
221	350	4	46.58N	101.08W	NORTH DAKOTA	SOUTH CENTRAL	MORTON	1	852
221	351	1	46.02N	100.77W	NORTH DAKOTA	SOUTH CENTRAL	SIOUX	3	853
221	351	2	45.95N	101.04W	SOUTH DAKOTA	NORTHWEST	CORSON	1	854
221	351	3	46.14N	101.14W	NORTH DAKOTA	SOUTH CENTRAL	SIOUX	3	855
221	351	4	46.21N	100.87W	NORTH DAKOTA	SOUTH CENTRAL	SIOUX	3	856
221	352	1	45.65N	100.57W	SOUTH DAKOTA	NORTHWEST	CORSON	1	857
221	352	2	45.58N	100.84W	SOUTH DAKOTA	NORTHWEST	CORSON	3	858
221	352	3	45.77N	100.94W	SOUTH DAKOTA	NORTHWEST	CORSON	3	859
221	352	4	45.84N	100.67W	SOUTH DAKOTA	NORTHWEST	CORSON	1	860
221	353	1	45.29N	100.38W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	861
221	353	2	45.22N	100.64W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	862
221	353	3	45.40N	100.74W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	863
221	353	4	45.47N	100.47W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	864
221	354	1	44.92N	100.18W	SOUTH DAKOTA	CENTRAL	SULLY	1	865
221	354	2	44.85N	100.44W	SOUTH DAKOTA	CENTRAL	SULLY	1	866
221	354	3	45.03N	100.54W	SOUTH DAKOTA	NORTHWEST	DEWEY	1	867
221	354	4	45.10N	100.28W	SOUTH DAKOTA	NORTH CENTRAL	POTTER	1	868
221	355	1	44.55N	99.99W	SOUTH DAKOTA	CENTRAL	HUGHES	1	869
221	355	2	44.48N	100.25W	SOUTH DAKOTA	CENTRAL	HUGHES	1	870
221	355	3	44.67N	100.35W	SOUTH DAKOTA	CENTRAL	SULLY	1	871
221	355	4	44.73N	100.09W	SOUTH DAKOTA	CENTRAL	SULLY	1	872
221	356	1	44.18N	99.81W	SOUTH DAKOTA	CENTRAL	HUGHES	1	873
221	356	2	44.12N	100.06W	SOUTH DAKOTA	SOUTH CENTRAL	LYMAN	1	874
221	356	3	44.30N	100.16W	SOUTH DAKOTA	WEST CENTRAL	STANLEY	1	875
221	356	4	44.37N	99.90W	SOUTH DAKOTA	CENTRAL	HUGHES	1	876
221	357	1	43.82N	99.63W	SOUTH DAKOTA	SOUTH CENTRAL	LYMAN	1	877
221	357	2	43.75N	99.88W	SOUTH DAKOTA	SOUTH CENTRAL	LYMAN	1	878
221	357	3	43.93N	99.97W	SOUTH DAKOTA	SOUTH CENTRAL	LYMAN	1	879
221	357	4	44.00N	99.72W	SOUTH DAKOTA	SOUTH CENTRAL	LYMAN	1	880
221	358	1	43.45N	99.45W	SOUTH DAKOTA	SOUTH CENTRAL	GREGORY	1	881
221	358	2	43.39N	99.70W	SOUTH DAKOTA	SOUTH CENTRAL	TRIPP	1	882
221	358	3	43.57N	99.79W	SOUTH DAKOTA	SOUTH CENTRAL	TRIPP	1	883
221	358	4	43.63N	99.54W	SOUTH DAKOTA	SOUTH CENTRAL	LYMAN	1	884
221	359	1	43.09N	99.27W	SOUTH DAKOTA	SOUTH CENTRAL	GREGORY	3	885
221	359	3	43.20N	99.61W	SOUTH DAKOTA	SOUTH CENTRAL	TRIPP	3	886
221	359	4	43.27N	99.36W	SOUTH DAKOTA	SOUTH CENTRAL	GREGORY	1	887
222	344	1	48.77N	101.72W	NORTH DAKOTA	NORTHWEST	RENVILLE	1	888
222	344	2	48.69N	102.00W	NORTH DAKOTA	NORTHWEST	WARD	1	889
222	344	3	48.88N	102.11W	NORTH DAKOTA	NORTHWEST	BURKE	1	890
222	344	4	48.95N	101.83W	NORTH DAKOTA	NORTHWEST	RENVILLE	1	891
222	345	1	48.39N	101.49W	NORTH DAKOTA	NORTHWEST	WARD	1	892
222	345	2	48.32N	101.77W	NORTH DAKOTA	NORTHWEST	WARD	1	893
222	345	3	48.51N	101.89W	NORTH DAKOTA	NORTHWEST	WARD	1	894
222	345	4	48.58N	101.60W	NORTH DAKOTA	NORTHWEST	RENVILLE	1	895
222	346	1	48.02N	101.27W	NORTH DAKOTA	NORTHWEST	WARD	1	896
222	346	2	47.95N	101.55W	NORTH DAKOTA	NORTHWEST	WARD	3	897
222	346	3	48.13N	101.66W	NORTH DAKOTA	NORTHWEST	WARD	3	898
222	346	4	48.21N	101.38W	NORTH DAKOTA	NORTHWEST	WARD	1	899
222	347	1	47.65N	101.06W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	900

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
222	347	2	47.57N	101.33W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	901
222	347	3	47.76N	101.44W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	902
222	347	4	47.83N	101.17W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	903
222	348	1	47.27N	100.85W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	904
222	348	2	47.20N	101.12W	NORTH DAKOTA	WEST CENTRAL	OLIVER	3	905
222	348	3	47.39N	101.23W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	906
222	348	4	47.46N	100.95W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	907
222	349	1	46.90N	100.64W	NORTH DAKOTA	SOUTH CENTRAL	BURLEIGH	1	908
222	349	2	46.83N	100.91W	NORTH DAKOTA	SOUTH CENTRAL	MORTON	3	909
222	349	3	47.02N	101.02W	NORTH DAKOTA	WEST CENTRAL	OLIVER	3	910
222	349	4	47.09N	100.74W	NORTH DAKOTA	SOUTH CENTRAL	BURLEIGH	3	911
222	350	1	46.53N	100.44W	NORTH DAKOTA	SOUTH CENTRAL	EMMONS	3	912
222	350	2	46.46N	100.71W	NORTH DAKOTA	SOUTH CENTRAL	SIOUX	4	913
222	350	3	46.65N	100.81W	NORTH DAKOTA	SOUTH CENTRAL	MORTON	3	914
222	350	4	46.72N	100.54W	NORTH DAKOTA	SOUTH CENTRAL	BURLEIGH	3	915
222	351	1	46.16N	100.24W	NORTH DAKOTA	SOUTH CENTRAL	EMMONS	1	916
222	351	2	46.09N	100.51W	NORTH DAKOTA	SOUTH CENTRAL	EMMONS	3	917
222	351	3	46.28N	100.61W	NORTH DAKOTA	SOUTH CENTRAL	EMMONS	3	918
222	351	4	46.35N	100.34W	NORTH DAKOTA	SOUTH CENTRAL	EMMONS	3	919
222	352	1	45.79N	100.04W	SOUTH DAKOTA	NORTH CENTRAL	CAMPBELL	1	920
222	352	2	45.72N	100.31W	SOUTH DAKOTA	NORTH CENTRAL	CAMPBELL	1	921
222	352	3	45.91N	100.41W	SOUTH DAKOTA	NORTH CENTRAL	CAMPBELL	1	922
222	352	4	45.98N	100.14W	SOUTH DAKOTA	NORTH CENTRAL	CAMPBELL	1	923
222	353	1	45.42N	99.65W	SOUTH DAKOTA	NORTH CENTRAL	WALWORTH	1	924
222	353	2	45.35N	100.11W	SOUTH DAKOTA	NORTH CENTRAL	WALWORTH	1	925
222	353	3	45.54N	100.21W	SOUTH DAKOTA	NORTH CENTRAL	WALWORTH	1	926
222	353	4	45.61N	99.95W	SOUTH DAKOTA	NORTH CENTRAL	WALWORTH	1	927
222	354	1	45.05N	99.66W	SOUTH DAKOTA	NORTH CENTRAL	POTTER	1	928
222	354	2	44.98N	99.92W	SOUTH DAKOTA	NORTH CENTRAL	POTTER	1	929
222	354	3	45.17N	100.02W	SOUTH DAKOTA	NORTH CENTRAL	POTTER	1	930
222	354	4	45.24N	99.76W	SOUTH DAKOTA	NORTH CENTRAL	POTTER	1	931
222	355	1	44.68N	99.48W	SOUTH DAKOTA	CENTRAL	HYDE	1	932
222	355	2	44.62N	99.74W	SOUTH DAKOTA	CENTRAL	SULLY	1	933
222	355	3	44.80N	99.83W	SOUTH DAKOTA	CENTRAL	SULLY	1	934
222	355	4	44.87N	99.57W	SOUTH DAKOTA	CENTRAL	HYDE	1	935
222	356	1	44.31N	99.30	SOUTH DAKOTA	CENTRAL	HAND	1	936
222	356	2	44.25N	99.55	SOUTH DAKOTA	CENTRAL	HYDE	1	937
222	356	3	44.43N	99.64W	SOUTH DAKOTA	CENTRAL	HYDE	1	938
222	356	4	44.50N	99.39W	SOUTH DAKOTA	CENTRAL	HYDE	1	939
222	357	1	43.95N	99.12W	SOUTH DAKOTA	CENTRAL	BRULE	1	940
222	357	2	43.88N	99.37	SOUTH DAKOTA	SOUTH CENTRAL	LYMAN	1	941
222	357	3	44.07N	99.46	SOUTH DAKOTA	CENTRAL	BUFFALO	1	942
222	357	4	44.13N	99.21	SOUTH DAKOTA	CENTRAL	BUFFALO	1	943
222	358	1	43.58N	99.44	SOUTH DAKOTA	CENTRAL	BRULE	1	944
222	358	2	43.52N	99.20	SOUTH DAKOTA	CENTRAL	BRULE	1	945
222	358	3	43.70N	99.28W	SOUTH DAKOTA	CENTRAL	BRULE	1	946
222	358	4	43.76N	99.03W	SOUTH DAKOTA	CENTRAL	BRULE	1	947
222	359	1	43.21N	98.77W	SOUTH DAKOTA	SOUTHEAST	CHARLES MIX	1	948
222	359	2	43.15N	99.02W	SOUTH DAKOTA	SOUTH CENTRAL	GREGORY	1	949
222	359	3	43.33N	99.11W	SOUTH DAKOTA	SOUTH CENTRAL	GREGORY	1	950

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
222	359	4	43.40N	98.86W	SOUTH DAKOTA	SOUTHEAST	CHARLES MIX	1	951
223	344	1	48.91N	101.15W	NORTH DAKOTA	NORTH CENTRAL	BOTTINEAU	1	952
223	344	2	48.84N	101.43W	NORTH DAKOTA	NORTH CENTRAL	BOTTINEAU	1	953
223	345	1	48.54N	100.93W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	3	954
223	345	2	48.47N	101.21W	NORTH DAKOTA	NORTHWEST	RENVILLE	1	955
223	345	3	48.65N	101.32W	NORTH DAKOTA	NORTH CENTRAL	BOTTINEAU	1	956
223	345	4	48.73N	101.04W	NORTH DAKOTA	NORTH CENTRAL	BOTTINEAU	3	957
223	346	1	48.16N	100.71W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	1	958
223	346	2	48.09N	100.99W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	1	959
223	346	3	48.28N	101.19W	NORTH DAKOTA	NORTHWEST	WARD	1	960
223	346	4	48.35N	100.82W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	3	961
223	347	1	47.79N	100.50W	NORTH DAKOTA	CENTRAL	SHERIDAN	1	962
223	347	2	47.72N	100.78W	NORTH DAKOTA	WEST CENTRAL	MC LEAN	1	963
223	347	3	47.91N	100.89W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	1	964
223	347	4	47.98N	100.61W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	1	965
223	348	1	47.41N	100.30W	NORTH DAKOTA	CENTRAL	SHERIDAN	3	966
223	348	2	47.35N	100.57W	NORTH DAKOTA	SOUTH CENTRAL	BURLEIGH	1	967
223	348	3	47.53N	100.68W	NORTH DAKOTA	CENTRAL	SHERIDAN	3	968
223	348	4	47.60N	100.40W	NORTH DAKOTA	CENTRAL	SHERIDAN	1	969
223	349	1	47.04N	100.10W	NORTH DAKOTA	SOUTH CENTRAL	BURLEIGH	1	970
223	349	2	46.97N	100.37W	NORTH DAKOTA	SOUTH CENTRAL	BURLEIGH	1	971
223	349	3	47.16N	100.47W	NORTH DAKOTA	SOUTH CENTRAL	BURLEIGH	1	972
223	349	4	47.23N	100.20W	NORTH DAKOTA	SOUTH CENTRAL	BURLEIGH	1	973
223	350	1	46.67N	99.90W	NORTH DAKOTA	SOUTHEAST	LOGAN	1	974
223	350	2	46.60N	100.17W	NORTH DAKOTA	SOUTH CENTRAL	EMMONS	1	975
223	350	3	46.79N	100.27W	NORTH DAKOTA	SOUTH CENTRAL	BURLEIGH	1	976
223	350	4	46.85N	100.00W	NORTH DAKOTA	CENTRAL	KIDDER	1	977
223	351	1	46.30N	99.70W	NORTH DAKOTA	SOUTHEAST	MC INTOSH	1	978
223	351	2	46.23N	99.97W	NORTH DAKOTA	SOUTH CENTRAL	EMMONS	1	979
223	351	3	46.41N	100.07W	NORTH DAKOTA	SOUTH CENTRAL	EMMONS	1	980
223	351	4	46.48N	99.80W	NORTH DAKOTA	SOUTHEAST	LOGAN	3	981
223	352	1	45.92N	99.51W	SOUTH DAKOTA	NORTH CENTRAL	MC PHERSON	1	982
223	352	2	45.86N	99.78W	SOUTH DAKOTA	NORTH CENTRAL	CAMPBELL	1	983
223	352	3	46.04N	99.87W	NORTH DAKOTA	SOUTHEAST	MC INTOSH	1	984
223	352	4	46.11N	99.61W	NORTH DAKOTA	SOUTHEAST	MC INTOSH	1	985
223	353	1	45.55N	99.32W	SOUTH DAKOTA	NORTH CENTRAL	EDMUNDS	1	986
223	353	2	45.49N	99.59W	SOUTH DAKOTA	NORTH CENTRAL	EDMUNDS	1	987
223	353	3	45.67N	99.68W	SOUTH DAKOTA	NORTH CENTRAL	MC PHERSON	1	988
223	353	4	45.74N	99.42W	SOUTH DAKOTA	NORTH CENTRAL	MC PHERSON	1	989
223	354	1	45.13N	99.14W	SOUTH DAKOTA	NORTH CENTRAL	FAULK	1	990
223	354	2	45.12N	99.40W	SOUTH DAKOTA	NORTH CENTRAL	FAULK	1	991
223	354	3	45.30N	99.49W	SOUTH DAKOTA	NORTH CENTRAL	EDMUNDS	1	992
223	354	4	45.37N	99.23W	SOUTH DAKOTA	NORTH CENTRAL	EDMUNDS	1	993
223	355	1	44.81N	98.96W	SOUTH DAKOTA	CENTRAL	HAND	1	994
223	355	2	44.75N	99.22W	SOUTH DAKOTA	CENTRAL	HAND	1	995
223	355	3	44.93N	99.31W	SOUTH DAKOTA	NORTH CENTRAL	FAULK	1	996
223	355	4	45.00N	99.05W	SOUTH DAKOTA	NORTH CENTRAL	FAULK	1	997
223	356	1	44.44N	98.78W	SOUTH DAKOTA	CENTRAL	HAND	1	998
223	356	2	44.38N	99.04W	SOUTH DAKOTA	CENTRAL	HAND	1	999
223	356	3	44.56N	99.13W	SOUTH DAKOTA	CENTRAL	HAND	1	1000

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
223	356	4	44.63N	98.87W	SOUTH DAKOTA	CENTRAL	HAND	1	1001
223	357	1	44.07N	98.61W	SOUTH DAKOTA	CENTRAL	JERAULD	1	1002
223	357	2	44.01N	98.86W	SOUTH DAKOTA	CENTRAL	JERAULD	1	1003
223	357	3	44.19N	98.95W	SOUTH DAKOTA	CENTRAL	BUFFALO	1	1004
223	357	4	44.26N	98.69W	SOUTH DAKOTA	CENTRAL	BEADLE	1	1005
223	358	1	43.70N	98.43W	SOUTH DAKOTA	CENTRAL	AURORA	1	1006
223	358	2	43.64N	98.69W	SOUTH DAKOTA	CENTRAL	AURORA	1	1007
223	358	3	43.83N	98.78W	SOUTH DAKOTA	CENTRAL	AURORA	1	1008
223	358	4	43.89N	98.52W	SOUTH DAKOTA	CENTRAL	AURORA	1	1009
223	359	1	43.34N	98.27W	SOUTH DAKOTA	SOUTHEAST	DOUGLAS	1	1010
223	359	2	43.27N	98.52W	SOUTH DAKOTA	SOUTHEAST	CHARLES MIX	1	1011
223	359	3	43.46N	98.60W	SOUTH DAKOTA	SOUTHEAST	DOUGLAS	1	1012
223	359	4	43.52N	98.35W	SOUTH DAKOTA	SOUTHEAST	DOUGLAS	1	1013
223	360	1	42.97N	98.10W	SOUTH DAKOTA	SOUTHEAST	BONHOMME	1	1014
223	360	3	43.09N	98.43W	SOUTH DAKOTA	SOUTHEAST	CHARLES MIX	1	1015
223	360	4	43.15N	98.18W	SOUTH DAKOTA	SOUTHEAST	CHARLES MIX.	1	1016
224	344	2	48.99N	100.86W	NORTH DAKOTA	NORTH CENTRAL	BOTTINEAU	1	1017
224	345	1	48.68N	100.36W	NORTH DAKOTA	NORTH CENTRAL	BOTTINEAU	1	1018
224	345	2	48.61N	100.64W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	3	1019
224	345	3	48.80N	100.75W	NORTH DAKOTA	NORTH CENTRAL	BOTTINEAU	1	1020
224	345	4	48.87N	100.47W	NORTH DAKOTA	NORTH CENTRAL	BOTTINEAU	1	1021
224	346	1	48.30N	100.15W	NORTH DAKOTA	NORTH CENTRAL	PIERCE	3	1022
224	346	2	48.23N	100.43W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	3	1023
224	346	3	48.42N	100.54W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	3	1024
224	346	4	48.49N	100.25W	NORTH DAKOTA	NORTH CENTRAL	PIERCE	3	1025
224	347	1	47.93N	99.94W	NORTH DAKOTA	NORTH CENTRAL	PIERCE	1	1026
224	347	2	47.86N	100.22W	NORTH DAKOTA	CENTRAL	SHERIDAN	1	1027
224	347	3	48.05N	100.33W	NORTH DAKOTA	NORTH CENTRAL	MC HENRY	3	1028
224	347	4	48.11N	100.05W	NORTH DAKOTA	NORTH CENTRAL	PIERCE	3	1029
224	348	1	47.55N	99.74W	NORTH DAKOTA	CENTRAL	WELLS	1	1030
224	348	2	47.48N	100.02W	NORTH DAKOTA	CENTRAL	WELLS	3	1031
224	348	3	47.67N	100.12W	NORTH DAKOTA	CENTRAL	SHERIDAN	1	1032
224	348	4	47.74N	99.84W	NORTH DAKOTA	CENTRAL	WELLS	1	1033
224	349	1	47.18N	99.55W	NORTH DAKOTA	CENTRAL	KIDDER	3	1034
224	349	2	47.11N	99.82W	NORTH DAKOTA	CENTRAL	KIDDER	3	1035
224	349	3	47.30N	99.92W	NORTH DAKOTA	CENTRAL	KIDDER	3	1036
224	349	4	47.36N	99.64	NORTH DAKOTA	CENTRAL	KIDDER	3	1037
224	350	1	46.90N	99.35W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1038
224	350	2	46.74N	99.62W	NORTH DAKOTA	CENTRAL	KIDDER	1	1039
224	350	3	46.92N	99.72W	NORTH DAKOTA	CENTRAL	KIDDER	3	1040
224	350	4	46.99N	99.45	NORTH DAKOTA	CENTRAL	STUTSMAN	3	1041
224	351	1	46.43N	99.16W	NORTH DAKOTA	SOUTHEAST	LOGAN	3	1042
224	351	2	46.36N	99.43W	NORTH DAKOTA	SOUTHEAST	LOGAN	3	1043
224	351	3	46.55N	99.53W	NORTH DAKOTA	SOUTHEAST	LOGAN	3	1044
224	351	4	46.61N	99.26W	NORTH DAKOTA	SOUTHEAST	LOGAN	3	1045
224	352	1	46.05N	98.97W	NORTH DAKOTA	SOUTHEAST	DICKEY	3	1046
224	352	2	45.99N	99.24W	SOUTH DAKOTA	NORTH CENTRAL	MC PHERSON	1	1047
224	352	3	46.18N	99.34W	NORTH DAKOTA	SOUTHEAST	MC INTOSH	3	1048
224	352	4	46.24N	99.07W	NORTH DAKOTA	SOUTHEAST	MC INTOSH	1	1049
224	353	1	45.68N	98.74W	SOUTH DAKOTA	NORTH CENTRAL	MC PHERSON	1	1050

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	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
224	353	2	45.62N	99.06W	SOUTH DAKOTA	NORTH CENTRAL	EDMUNDS	1	1051
224	353	3	45.86N	99.15W	SOUTH DAKOTA	NORTH CENTRAL	MC PHERSON	1	1052
224	353	4	45.87N	98.98W	SOUTH DAKOTA	NORTH CENTRAL	MC PHERSON	1	1053
224	354	1	45.31N	98.61W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	1	1054
224	354	2	45.25N	98.88W	SOUTH DAKOTA	NORTH CENTRAL	FAULK	1	1055
224	354	3	45.43N	98.97W	SOUTH DAKOTA	NORTH CENTRAL	EDMUNDS	1	1056
224	354	4	45.49N	98.70W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	1	1057
224	355	1	44.94N	98.43W	SOUTH DAKOTA	NORTH CENTRAL	SPINK	1	1058
224	355	2	44.87N	98.70W	SOUTH DAKOTA	NORTH CENTRAL	SPINK	1	1059
224	355	3	45.06N	98.79W	SOUTH DAKOTA	NORTH CENTRAL	FAULK	1	1060
224	355	4	45.12N	98.52W	SOUTH DAKOTA	NORTH CENTRAL	SPINK	1	1061
224	356	1	44.57N	98.26W	SOUTH DAKOTA	CENTRAL	BEADLE	1	1062
224	356	2	44.50N	98.52W	SOUTH DAKOTA	CENTRAL	BEADLE	1	1063
224	356	3	44.69N	98.61W	SOUTH DAKOTA	NORTH CENTRAL	SPINK	3	1064
224	356	4	44.75N	98.35W	SOUTH DAKOTA	NORTH CENTRAL	SPINK	1	1065
224	357	1	44.19N	98.09W	SOUTH DAKOTA	EAST CENTRAL	SANBORN	1	1066
224	357	2	44.13N	98.35W	SOUTH DAKOTA	CENTRAL	JERAULD	1	1067
224	357	3	44.32N	98.43W	SOUTH DAKOTA	CENTRAL	BEADLE	1	1068
224	357	4	44.38N	98.18W	SOUTH DAKOTA	CENTRAL	BEADLE	3	1069
224	358	1	43.82N	97.92W	SOUTH DAKOTA	EAST CENTRAL	HANSON	1	1070
224	358	2	43.76N	98.18W	SOUTH DAKOTA	EAST CENTRAL	DAVISON	1	1071
224	358	3	43.95N	98.26W	SOUTH DAKOTA	EAST CENTRAL	SANBORN	1	1072
224	358	4	44.01N	98.01W	SOUTH DAKOTA	EAST CENTRAL	SANBORN	1	1073
224	359	1	43.46N	97.76W	SOUTH DAKOTA	SOUTHEAST	HUTCHINSON	1	1074
224	359	2	43.40N	98.01W	SOUTH DAKOTA	SOUTHEAST	HUTCHINSON	1	1075
224	359	3	43.58N	98.10W	SOUTH DAKOTA	EAST CENTRAL	DAVISON	1	1076
224	359	4	43.64N	97.84W	SOUTH DAKOTA	EAST CENTRAL	HANSON	1	1077
224	360	1	43.09N	97.60W	SOUTH DAKOTA	SOUTHEAST	YANKTON	1	1078
224	360	2	43.03N	97.85W	SOUTH DAKOTA	SOUTHEAST	BONHOMME	1	1079
224	360	3	43.21N	97.93W	SOUTH DAKOTA	SOUTHEAST	HUTCHINSON	1	1080
224	360	4	43.27N	97.68W	SOUTH DAKOTA	SOUTHEAST	HUTCHINSON	1	1081
224	361	4	42.90N	97.52W	SOUTH DAKOTA	SOUTHEAST	YANKTON	1	1082
225	345	1	48.82N	99.79W	NORTH DAKOTA	NORTH CENTRAL	ROLETTE	1	1083
225	345	2	48.75N	100.07W	NORTH DAKOTA	NORTH CENTRAL	ROLETTE	3	1084
225	345	3	48.94N	100.19W	NORTH DAKOTA	NORTH CENTRAL	ROLETTE	1	1085
225	345	4	49.01N	99.89W	NORTH DAKOTA	NORTH CENTRAL	ROLETTE	1	1086
225	346	1	48.44N	99.58W	NORTH DAKOTA	NORTH CENTRAL	PIERCE	1	1087
225	346	2	48.37N	99.87W	NORTH DAKOTA	NORTH CENTRAL	PIERCE	3	1088
225	346	3	48.56N	99.97W	NORTH DAKOTA	NORTH CENTRAL	PIERCE	3	1089
225	346	4	48.63N	99.68W	NORTH DAKOTA	NORTH CENTRAL	ROLETTE	1	1090
225	347	1	48.06N	99.38W	NORTH DAKOTA	NORTH CENTRAL	BENSON	1	1091
225	347	2	47.99N	99.66W	NORTH DAKOTA	NORTH CENTRAL	BENSON	1	1092
225	347	3	48.18N	99.77W	NORTH DAKOTA	NORTH CENTRAL	BENSON	1	1093
225	347	4	48.25N	99.48W	NORTH DAKOTA	NORTH CENTRAL	BENSON	1	1094
225	348	1	47.68N	99.19W	NORTH DAKOTA	CENTRAL	EDDY	1	1095
225	348	2	47.62N	99.46W	NORTH DAKOTA	CENTRAL	WELLS	1	1096
225	348	3	47.81N	99.56W	NORTH DAKOTA	CENTRAL	WELLS	1	1097
225	348	4	47.87N	99.28W	NORTH DAKOTA	NORTH CENTRAL	BENSON	1	1098
225	349	1	47.31N	98.99W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1099
225	349	2	47.24N	99.27W	NORTH DAKOTA	CENTRAL	STUTSMAN	3	1100

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
225	349	3	47.43N	99.37W	NORTH DAKOTA	CENTRAL	WELLS	1	1101
225	349	4	47.50N	99.09W	NORTH DAKOTA	CENTRAL	FOSTER	1	1102
225	350	1	46.93N	98.80W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1103
225	350	2	46.87N	99.08W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1104
225	350	3	47.05N	99.17W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1105
225	350	4	47.12N	98.90W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1106
225	351	1	46.56N	98.62W	NORTH DAKOTA	SOUTHEAST	LA MOURE	1	1107
225	351	2	46.49N	98.89W	NORTH DAKOTA	SOUTHEAST	LA MOURE	1	1108
225	351	3	46.68N	98.98W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1109
225	351	4	46.74N	98.71W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1110
225	352	1	46.18N	98.43W	NORTH DAKOTA	SOUTHEAST	DICKEY	1	1111
225	352	2	46.12N	98.71W	NORTH DAKOTA	SOUTHEAST	DICKEY	1	1112
225	352	3	46.30N	98.80W	NORTH DAKOTA	SOUTHEAST	DICKEY	1	1113
225	352	4	46.37N	98.53W	NORTH DAKOTA	SOUTHEAST	LA MOURE	1	1114
225	353	1	45.81N	98.26W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	3	1115
225	353	2	45.74N	98.52W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	1	1116
225	353	3	45.93N	98.61W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	1	1117
225	353	4	45.99N	98.35W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	1	1118
225	354	1	45.43N	98.08W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	1	1119
225	354	2	45.37N	98.35W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	1	1120
225	354	3	45.56N	98.43W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	1	1121
225	354	4	45.62N	98.17W	SOUTH DAKOTA	NORTH CENTRAL	BROWN	1	1122
225	355	1	45.06N	97.91W	SOUTH DAKOTA	NORTHEAST	CLARK	1	1123
225	355	2	45.00N	98.17W	SOUTH DAKOTA	NORTH CENTRAL	SPINK	1	1124
225	355	3	45.18N	98.26W	SOUTH DAKOTA	NORTH CENTRAL	SPINK	1	1125
225	355	4	45.25N	97.99W	SOUTH DAKOTA	NORTHEAST	DAY	1	1126
225	356	1	44.69N	97.74W	SOUTH DAKOTA	NORTHEAST	CLARK	1	1127
225	356	2	44.63N	98.00W	SOUTH DAKOTA	CENTRAL	BEADLE	1	1128
225	356	3	44.81N	98.09W	SOUTH DAKOTA	NORTH CENTRAL	SPINK	1	1129
225	356	4	44.87N	97.82W	SOUTH DAKOTA	NORTHEAST	CLARK	1	1130
225	357	1	44.31N	97.57W	SOUTH DAKOTA	EAST CENTRAL	KINGSBURY	1	1131
225	357	2	44.25N	97.83W	SOUTH DAKOTA	EAST CENTRAL	KINGSBURY	1	1132
225	357	3	44.44N	97.92W	SOUTH DAKOTA	CENTRAL	BEADLE	1	1133
225	357	4	44.50N	97.66W	SOUTH DAKOTA	EAST CENTRAL	KINGSBURY	1	1134
225	358	1	43.94N	97.41W	SOUTH DAKOTA	EAST CENTRAL	MINER	1	1135
225	358	2	43.88N	97.67W	SOUTH DAKOTA	EAST CENTRAL	MINER	1	1136
225	358	3	44.07N	97.75W	SOUTH DAKOTA	EAST CENTRAL	MINER	1	1137
225	358	4	44.13N	97.49W	SOUTH DAKOTA	EAST CENTRAL	MINER	1	1138
225	359	1	43.57N	97.25W	SOUTH DAKOTA	EAST CENTRAL	MC COOK	1	1139
225	359	2	43.51N	97.51W	SOUTH DAKOTA	EAST CENTRAL	MC COOK	1	1140
225	359	3	43.70N	97.59W	SOUTH DAKOTA	EAST CENTRAL	MC COOK	1	1141
225	359	4	43.76N	97.33W	SOUTH DAKOTA	EAST CENTRAL	MC COOK	1	1142
225	360	1	43.20N	97.09W	SOUTH DAKOTA	SOUTHEAST	TURNER	1	1143
225	360	2	43.14N	97.35W	SOUTH DAKOTA	SOUTHEAST	YANKTON	1	1144
225	360	3	43.33N	97.43W	SOUTH DAKOTA	SOUTHEAST	TURNER	1	1145
225	360	4	43.39N	97.17W	SOUTH DAKOTA	SOUTHEAST	TURNER	1	1146
225	361	1	42.83N	96.94W	SOUTH DAKOTA	SOUTHEAST	CLAY	1	1147
225	361	3	42.96N	97.27W	SOUTH DAKOTA	SOUTHEAST	YANKTON	1	1148
225	361	4	43.02N	97.02W	SOUTH DAKOTA	SOUTHEAST	CLAY	1	1149
226	345	1	48.95N	99.21W	NORTH DAKOTA	NORTHEAST	TOWNER	3	1150

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
226	345	2	48.89N	99.50W	NORTH DAKOTA	NORTHEAST	TOWNER	1	1151
226	346	1	48.57N	99.01W	NORTH DAKOTA	NORTHEAST	TOWNER	3	1152
226	346	2	48.51N	99.30W	NORTH DAKOTA	NORTHEAST	TOWNER	3	1153
226	346	3	48.70N	99.40W	NORTH DAKOTA	NORTHEAST	TOWNER	1	1154
226	346	4	48.76N	99.11W	NORTH DAKOTA	NORTHEAST	TOWNER	3	1155
226	347	1	48.19N	98.82W	NORTH DAKOTA	NORTHEAST	RAMSEY	1	1156
226	347	2	48.13N	99.10W	NORTH DAKOTA	NORTHEAST	RAMSEY	1	1157
226	347	3	48.32N	99.20W	NORTH DAKOTA	NORTHEAST	RAMSEY	1	1158
226	347	4	48.38N	98.91W	NORTH DAKOTA	NORTHEAST	RAMSEY	1	1159
226	348	1	47.81N	98.62W	NORTH DAKOTA	CENTRAL	EDDY	1	1160
226	348	2	47.75N	98.90W	NORTH DAKOTA	CENTRAL	EDDY	3	1161
226	348	3	47.94N	99.00W	NORTH DAKOTA	NORTH CENTRAL	BENSON	1	1162
226	348	4	48.00N	98.72W	NORTH DAKOTA	NORTH CENTRAL	BENSON	1	1163
226	349	1	47.44N	98.43W	NORTH DAKOTA	EAST CENTRAL	GRIGGS	3	1164
226	349	2	47.37N	98.71W	NORTH DAKOTA	CENTRAL	FOSTER	1	1165
226	349	3	47.56N	98.81W	NORTH DAKOTA	CENTRAL	FOSTER	1	1166
226	349	4	47.62N	98.53W	NORTH DAKOTA	EAST CENTRAL	GRIGGS	1	1167
226	350	1	47.06N	98.25W	NORTH DAKOTA	EAST CENTRAL	BARNES	3	1168
226	350	2	46.99N	98.53W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1169
226	350	3	47.18N	98.62W	NORTH DAKOTA	CENTRAL	STUTSMAN	1	1170
226	350	4	47.25N	98.34W	NORTH DAKOTA	EAST CENTRAL	BARNES	3	1171
226	351	1	46.68N	98.07W	NORTH DAKOTA	SOUTHEAST	LA MOURE	1	1172
226	351	2	46.62N	98.34W	NORTH DAKOTA	SOUTHEAST	LA MOURE	1	1173
226	351	3	46.81N	98.43W	NORTH DAKOTA	EAST CENTRAL	BARNES	1	1174
226	351	4	46.87N	98.16W	NORTH DAKOTA	EAST CENTRAL	BARNES	1	1175
226	352	1	46.30N	97.89W	NORTH DAKOTA	SOUTHEAST	SARGENT	1	1176
226	352	2	46.24N	98.16W	NORTH DAKOTA	SOUTHEAST	DICKEY	1	1177
226	352	3	46.43N	98.25W	NORTH DAKOTA	SOUTHEAST	LA MOURE	1	1178
226	352	4	46.49N	97.98W	NORTH DAKOTA	SOUTHEAST	RANSOM	1	1179
226	353	1	45.93N	97.72W	SOUTH DAKOTA	NORTHEAST	MARSHALL	1	1180
226	353	2	45.87N	97.99W	SOUTH DAKOTA	NORTHEAST	MARSHALL	3	1181
226	353	3	46.05N	98.08W	NORTH DAKOTA	SOUTHEAST	DICKEY	3	1182
226	353	4	46.12N	97.80W	NORTH DAKOTA	SOUTHEAST	SARGENT	3	1183
226	354	1	45.55N	97.55W	SOUTH DAKOTA	NORTHEAST	DAY	1	1184
226	354	2	45.49N	97.81W	SOUTH DAKOTA	NORTHEAST	DAY	1	1185
226	354	3	45.68N	97.90W	SOUTH DAKOTA	NORTHEAST	MARSHALL	1	1186
226	354	4	45.74N	97.63W	SOUTH DAKOTA	NORTHEAST	MARSHALL	1	1187
226	355	1	45.18N	97.38W	SOUTH DAKOTA	NORTHEAST	CODINGTON	1	1188
226	355	2	45.12N	97.64W	SOUTH DAKOTA	NORTHEAST	CLARK	1	1189
226	355	3	45.31N	97.73W	SOUTH DAKOTA	NORTHEAST	DAY	1	1190
226	355	4	45.36N	97.46W	SOUTH DAKOTA	NORTHEAST	DAY	1	1191
226	356	1	44.80N	97.21W	SOUTH DAKOTA	NORTHEAST	HAMLIN	1	1192
226	356	2	44.75N	97.48W	SOUTH DAKOTA	NORTHEAST	HAMLIN	1	1193
226	356	3	44.93N	97.56W	SOUTH DAKOTA	NORTHEAST	CLARK	1	1194
226	356	4	44.99N	97.30W	SOUTH DAKOTA	NORTHEAST	CODINGTON	1	1195
226	357	1	44.43N	97.05W	SOUTH DAKOTA	EAST CENTRAL	BROOKINGS	1	1196
226	357	2	44.37N	97.31W	SOUTH DAKOTA	EAST CENTRAL	KINGSBURY	1	1197
226	357	3	44.56N	97.39W	SOUTH DAKOTA	EAST CENTRAL	KINGSBURY	1	1198
226	357	4	44.62N	97.13W	SOUTH DAKOTA	NORTHEAST	HAMLIN	1	1199
226	358	1	44.06N	96.89W	SOUTH DAKOTA	EAST CENTRAL	MOODY	1	1200

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
226	358	2	44.00N	97.15W	SOUTH DAKOTA	EAST CENTRAL	LAKE	1	1201
226	358	3	44.19N	97.23W	SOUTH DAKOTA	EAST CENTRAL	LAKE	1	1202
226	358	4	44.24N	96.97W	SOUTH DAKOTA	EAST CENTRAL	BROOKINGS	1	1203
226	359	1	43.69N	96.74W	SOUTH DAKOTA	EAST CENTRAL	MINNEHAHA	1	1204
226	359	2	43.63N	96.99W	SOUTH DAKOTA	EAST CENTRAL	MINNEHAHA	1	1205
226	359	3	43.81N	97.07W	SOUTH DAKOTA	EAST CENTRAL	LAKE	1	1206
226	359	4	43.87N	96.82W	SOUTH DAKOTA	EAST CENTRAL	MOODY	1	1207
226	360	1	43.31N	96.58W	SOUTH DAKOTA	SOUTHEAST	LINCOLN	1	1208
226	360	2	43.26N	96.84W	SOUTH DAKOTA	SOUTHEAST	LINCOLN	1	1209
226	360	3	43.44N	96.92W	SOUTH DAKOTA	SOUTHEAST	LINCOLN	1	1210
226	360	4	43.50N	96.66W	SOUTH DAKOTA	EAST CENTRAL	MINNEHAHA	1	1211
226	361	2	42.89N	96.69W	SOUTH DAKOTA	SOUTHEAST	UNION	1	1212
226	361	3	43.07N	96.76W	SOUTH DAKOTA	SOUTHEAST	LINCOLN	1	1213
226	361	4	43.13N	96.51W	SOUTH DAKOTA	SOUTHEAST	LINCOLN	1	1214
226	362	2	42.52N	96.54W	SOUTH DAKOTA	SOUTHEAST	UNION	1	1215
226	362	3	42.70N	96.61W	SOUTH DAKOTA	SOUTHEAST	UNION	1	1216
227	346	1	48.70N	98.43W	NORTH DAKOTA	NORTHEAST	CAVALIER	3	1217
227	346	2	48.64N	98.72W	NORTH DAKOTA	NORTHEAST	CAVALIER	3	1218
227	346	3	48.83N	98.82W	NORTH DAKOTA	NORTHEAST	CAVALIER	3	1219
227	346	4	48.89N	98.53W	NORTH DAKOTA	NORTHEAST	CAVALIER	3	1220
227	347	1	48.32N	98.24W	NORTH DAKOTA	NORTHEAST	WALSH	1	1221
227	347	2	48.26N	98.53W	NORTH DAKOTA	NORTHEAST	RAMSEY	3	1222
227	347	3	48.45N	98.63W	NORTH DAKOTA	NORTHEAST	RAMSEY	3	1223
227	347	4	48.51N	98.34W	NORTH DAKOTA	NORTHEAST	RAMSEY	3	1224
227	348	1	47.94N	98.06W	NORTH DAKOTA	NORTHEAST	NELSON	3	1225
227	348	2	47.88N	98.34W	NORTH DAKOTA	NORTHEAST	NELSON	1	1226
227	348	3	48.07N	98.43W	NORTH DAKOTA	NORTHEAST	NELSON	3	1227
227	348	4	48.13N	98.15W	NORTH DAKOTA	NORTHEAST	NELSON	1	1228
227	349	1	47.56N	97.87W	NORTH DAKOTA	EAST CENTRAL	STEELE	1	1229
227	349	2	47.50N	98.16W	NORTH DAKOTA	EAST CENTRAL	GRIGGS	3	1230
227	349	3	47.69N	98.25W	NORTH DAKOTA	EAST CENTRAL	GRIGGS	1	1231
227	349	4	47.75N	97.97W	NORTH DAKOTA	NORTHEAST	NELSON	3	1232
227	350	1	47.18N	97.69W	NORTH DAKOTA	EAST CENTRAL	CASS	3	1233
227	350	2	47.12N	97.97W	NORTH DAKOTA	EAST CENTRAL	BARNES	1	1234
227	350	3	47.31N	98.06W	NORTH DAKOTA	EAST CENTRAL	GRIGGS	3	1235
227	350	4	47.37N	97.78W	NORTH DAKOTA	EAST CENTRAL	STEELE	1	1236
227	351	1	46.89N	97.52W	NORTH DAKOTA	EAST CENTRAL	CASS	1	1237
227	351	2	46.74N	97.79W	NORTH DAKOTA	EAST CENTRAL	BARNES	1	1238
227	351	3	46.93N	97.88W	NORTH DAKOTA	EAST CENTRAL	BARNES	1	1239
227	351	4	46.99N	97.61W	NORTH DAKOTA	EAST CENTRAL	CASS	1	1240
227	352	1	46.42N	97.35W	NORTH DAKOTA	SOUTHEAST	RANSOM	3	1241
227	352	2	46.36N	97.62W	NORTH DAKOTA	SOUTHEAST	RANSOM	1	1242
227	352	3	46.55N	97.71W	NORTH DAKOTA	SOUTHEAST	RANSOM	1	1243
227	352	4	46.61N	97.43W	NORTH DAKOTA	SOUTHEAST	RANSOM	3	1244
227	353	1	46.05N	97.18W	NORTH DAKOTA	SOUTHEAST	RICHLAND	1	1245
227	353	2	45.99N	97.45W	SOUTH DAKOTA	NORTHEAST	MARSHALL	1	1246
227	353	3	46.18N	97.53W	NORTH DAKOTA	SOUTHEAST	SARGENT	1	1247
227	353	4	46.23N	97.26W	NORTH DAKOTA	SOUTHEAST	RICHLAND	1	1248
227	354	1	45.67N	97.01W	SOUTH DAKOTA	NORTHEAST	ROBERTS	1	1249
227	354	2	45.61N	97.28W	SOUTH DAKOTA	NORTHEAST	ROBERTS	1	1250

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
227	354	3	45.80N	97.36W	SOUTH DAKOTA	NORTHEAST	MARSHALL	1	1251
227	354	4	45.86N	97.09W	SOUTH DAKOTA	NORTHEAST	ROBERTS	1	1252
227	355	1	45.29N	96.85W	SOUTH DAKOTA	NORTHEAST	GRANT	1	1253
227	355	2	45.24N	97.11W	SOUTH DAKOTA	NORTHEAST	GRANT	1	1254
227	355	3	45.42N	97.20W	SOUTH DAKOTA	NORTHEAST	ROBERTS	1	1255
227	355	4	45.48N	96.93W	SOUTH DAKOTA	NORTHEAST	ROBERTS	1	1256
227	356	1	44.92N	96.69W	SOUTH DAKOTA	NORTHEAST	DEUEL	1	1257
227	356	2	44.86N	96.95W	SOUTH DAKOTA	NORTHEAST	CODINGTON	1	1258
227	356	3	45.05N	97.03W	SOUTH DAKOTA	NORTHEAST	CODINGTON	1	1259
227	356	4	45.11N	96.77W	SOUTH DAKOTA	NORTHEAST	GRANT	1	1260
227	357	1	44.54N	96.53W	SOUTH DAKOTA	NORTHEAST	DEUEL	1	1261
227	357	2	44.49N	96.79W	SOUTH DAKOTA	EAST CENTRAL	BROOKINGS	1	1262
227	357	3	44.67N	96.87W	SOUTH DAKOTA	NORTHEAST	DEUEL	1	1263
227	357	4	44.73N	96.61W	SOUTH DAKOTA	NORTHEAST	DEUEL	1	1264
227	358	1	44.17N	96.37W	MINNESOTA	SOUTHWEST	PIPESTONE	1	1265
227	358	2	44.11N	96.63W	SOUTH DAKOTA	EAST CENTRAL	MOODY	1	1266
227	358	3	44.30N	96.71W	SOUTH DAKOTA	EAST CENTRAL	BROOKINGS	1	1267
227	358	4	44.36N	96.45W	SOUTH DAKOTA	EAST CENTRAL	CHARLES MIX	1	1268
227	359	1	43.80N	96.22W	MINNESOTA	SOUTHWEST	ROCK	1	1269
227	359	2	43.74N	96.48W	SOUTH DAKOTA	EAST CENTRAL	MINNEHAHA	1	1270
227	359	3	43.93N	96.56W	SOUTH DAKOTA	EAST CENTRAL	MOODY	1	1271
227	359	4	43.98N	96.30W	MINNESOTA	SOUTHWEST	PIPESTONE	1	1272
227	360	3	43.55N	96.40W	MINNESOTA	SOUTHWEST	ROCK	1	1273
227	360	4	43.61N	96.15W	MINNESOTA	SOUTHWEST	ROCK	1	1274
228	346	1	48.83N	97.86W	NORTH DAKOTA	NORTHEAST	PEMBINA	3	1275
228	346	2	48.76N	98.15W	NORTH DAKOTA	NORTHEAST	CAVALIER	1	1276
228	346	3	48.96N	98.24W	NORTH DAKOTA	NORTHEAST	CAVALIER	3	1277
228	347	1	48.44N	97.67W	NORTH DAKOTA	NORTHEAST	WALSH	1	1278
228	347	2	48.38N	97.96W	NORTH DAKOTA	NORTHEAST	WALSH	1	1279
228	347	3	48.57N	98.05W	NORTH DAKOTA	NORTHEAST	WALSH	1	1280
228	347	4	48.63N	97.76W	NORTH DAKOTA	NORTHEAST	PEMBINA	1	1281
228	348	1	48.06N	97.49W	NORTH DAKOTA	NORTHEAST	GRAND FORKS	1	1282
228	348	2	48.00N	97.77W	NORTH DAKOTA	NORTHEAST	GRAND FORKS	1	1283
228	348	3	48.19N	97.86W	NORTH DAKOTA	NORTHEAST	GRAND FORKS	1	1284
228	348	4	48.25N	97.58W	NORTH DAKOTA	NORTHEAST	WALSH	1	1285
228	349	1	47.68N	97.31W	NORTH DAKOTA	EAST CENTRAL	TRAILL	1	1286
228	349	2	47.62N	97.59W	NORTH DAKOTA	EAST CENTRAL	STEELE	1	1287
228	349	3	47.81N	97.68W	NORTH DAKOTA	NORTHEAST	GRAND FORKS	1	1288
228	349	4	47.87N	97.40W	NORTH DAKOTA	NORTHEAST	GRAND FORKS	1	1289
228	350	1	47.30N	97.14W	NORTH DAKOTA	EAST CENTRAL	TRAILL	1	1290
228	350	2	47.24N	97.42W	NORTH DAKOTA	EAST CENTRAL	CASS	3	1291
228	350	3	47.43N	97.50W	NORTH DAKOTA	EAST CENTRAL	STEELE	1	1292
228	350	4	47.49N	97.22W	NORTH DAKOTA	EAST CENTRAL	TRAILL	1	1293
228	351	1	46.92N	96.96W	NORTH DAKOTA	EAST CENTRAL	CASS	1	1294
228	351	2	46.86N	97.24W	NORTH DAKOTA	EAST CENTRAL	CASS	1	1295
228	351	3	47.05N	97.33W	NORTH DAKOTA	EAST CENTRAL	CASS	1	1296
228	351	4	47.11N	97.05W	NORTH DAKOTA	EAST CENTRAL	CASS	1	1297
228	352	1	46.54N	96.80W	NORTH DAKOTA	SOUTHEAST	RICHLAND	1	1298
228	352	2	46.48N	97.07W	NORTH DAKOTA	SOUTHEAST	RICHLAND	3	1299
228	352	3	46.67N	97.16W	NORTH DAKOTA	SOUTHEAST	RICHLAND	3	1300

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
228	352	4	46.73N	96.88W	NORTH DAKOTA	EAST CENTRAL	CASS	1	1301
228	353	1	46.16N	96.63W	NORTH DAKOTA	SOUTHEAST	RICHLAND	1	1302
228	353	2	46.10N	96.90W	NORTH DAKOTA	SOUTHEAST	RICHLAND	3	1303
228	353	3	46.29N	96.99W	NORTH DAKOTA	SOUTHEAST	RICHLAND	1	1304
228	353	4	46.35N	96.71W	NORTH DAKOTA	SOUTHEAST	RICHLAND	1	1305
228	354	1	45.78N	96.47W	MINNESOTA	WEST CENTRAL	TRAVERSE	1	1306
228	354	2	45.73N	96.74W	MINNESOTA	WEST CENTRAL	TRAVERSE	1	1307
228	354	3	45.91N	96.82W	SOUTH DAKOTA	NORTHEAST	ROBERTS	1	1308
228	354	4	45.97N	96.55W	MINNESOTA	WEST CENTRAL	TRAVERSE	1	1309
228	355	1	45.41N	96.31W	MINNESOTA	WEST CENTRAL	BIG STONE	1	1310
228	355	2	45.35N	96.58W	SOUTH DAKOTA	NORTHEAST	GRANT	1	1311
228	355	3	45.54N	96.66W	MINNESOTA	WEST CENTRAL	BIG STONE	1	1312
228	355	4	45.59N	96.39W	MINNESOTA	WEST CENTRAL	TRAVERSE	1	1313
228	356	1	45.03N	96.15W	MINNESOTA	WEST CENTRAL	LAC QUI PARLE	1	1314
228	356	2	44.97N	96.42W	MINNESOTA	WEST CENTRAL	LAC QUI PARLE	1	1315
228	356	3	45.16N	96.50W	SOUTH DAKOTA	NORTHEAST	GRANT	1	1316
228	356	4	45.22N	96.23W	MINNESOTA	WEST CENTRAL	BIG STONE	1	1317
228	357	1	44.65N	96.00W	MINNESOTA	WEST CENTRAL	YELLOW MEDICINE	1	1318
228	357	2	44.60N	96.27W	MINNESOTA	SOUTHWEST	LINCOLN	1	1319
228	357	3	44.79N	96.34W	MINNESOTA	WEST CENTRAL	YELLOW MEDICINE	1	1320
228	357	4	44.84N	96.08W	MINNESOTA	WEST CENTRAL	LAC QUI PARLE	1	1321
228	358	1	44.28N	95.85W	MINNESOTA	SOUTHWEST	LYON	1	1322
228	358	2	44.22N	96.11W	MINNESOTA	SOUTHWEST	LINCOLN	1	1323
228	358	3	44.41N	96.19W	MINNESOTA	SOUTHWEST	LINCOLN	1	1324
228	358	4	44.46N	95.93W	MINNESOTA	SOUTHWEST	LYON	1	1325
228	359	1	43.90N	95.70W	MINNESOTA	SOUTHWEST	MURRAY	1	1326
228	359	2	43.85N	95.96W	MINNESOTA	SOUTHWEST	MURRAY	1	1327
228	359	3	44.04N	96.04W	MINNESOTA	SOUTHWEST	MURRAY	1	1328
228	359	4	44.09N	95.78W	MINNESOTA	SOUTHWEST	MURRAY	1	1329
228	360	1	43.53N	95.56W	MINNESOTA	SOUTHWEST	NOBLES	1	1330
228	360	3	43.66N	95.89W	MINNESOTA	SOUTHWEST	NOBLES	1	1331
228	360	4	43.72N	95.63W	MINNESOTA	SOUTHWEST	NOBLES	1	1332
229	346	1	48.95N	97.27W	NORTH DAKOTA	NORTHEAST	PEMBINA	1	1333
229	346	2	48.89N	97.56W	NORTH DAKOTA	NORTHEAST	PEMBINA	1	1334
229	347	1	48.56N	97.09W	MINNESOTA	NORTHWEST	KITTSON	1	1335
229	347	2	48.50N	97.38W	NORTH DAKOTA	NORTHEAST	WALSH	1	1336
229	347	3	48.70N	97.47W	NORTH DAKOTA	NORTHEAST	PEMBINA	1	1337
229	347	4	48.76N	97.18W	NORTH DAKOTA	NORTHEAST	PEMBINA	1	1338
229	348	1	48.18N	96.92W	MINNESOTA	NORTHWEST	MARSHALL	1	1339
229	348	2	48.12N	97.20W	NORTH DAKOTA	NORTHEAST	GRAND FORKS	4	1340
229	348	3	48.31N	97.29W	NORTH DAKOTA	NORTHEAST	WALSH	1	1341
229	348	4	48.37N	97.00W	MINNESOTA	NORTHWEST	MARSHALL	1	1342
229	349	1	47.80N	96.74W	MINNESOTA	NORTHWEST	POLK	1	1343
229	349	2	47.74N	97.03W	NORTH DAKOTA	NORTHEAST	GRAND FORKS	1	1344
229	349	3	47.93N	97.11W	NORTH DAKOTA	NORTHEAST	GRAND FORKS	1	1345
229	349	4	47.99N	96.83W	MINNESOTA	NORTHWEST	POLK	1	1346
229	350	1	47.41N	96.57W	MINNESOTA	NORTHWEST	NORMAN	1	1347
229	350	2	47.36N	96.85W	NORTH DAKOTA	EAST CENTRAL	TRAILL	1	1348
229	350	3	47.55N	96.94W	NORTH DAKOTA	EAST CENTRAL	TRAILL	1	1349
229	350	4	47.61N	96.66W	MINNESOTA	NORTHWEST	POLK	1	1350

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
229	351	1	47.03N	96.41W	MINNESOTA	NORTHWEST	CLAY	1	1351
229	351	2	46.98N	96.69W	MINNESOTA	NORTHWEST	CLAY	1	1352
229	351	3	47.17N	96.77W	MINNESOTA	NORTHWEST	NORMAN	1	1353
229	351	4	47.22N	96.49W	MINNESOTA	NORTHWEST	NORMAN	1	1354
229	352	1	46.65N	96.24W	MINNESOTA	NORTHWEST	CLAY	1	1355
229	352	2	46.60N	96.52W	MINNESOTA	WEST CENTRAL	WILKIN	1	1356
229	352	3	46.79N	96.60W	MINNESOTA	NORTHWEST	CLAY	1	1357
229	352	4	46.84N	96.32W	MINNESOTA	NORTHWEST	CLAY	1	1358
229	353	1	46.27N	96.08W	MINNESOTA	WEST CENTRAL	OTTER TAIL	1	1359
229	353	2	46.22N	96.36W	MINNESOTA	WEST CENTRAL	WILKIN	1	1360
229	353	3	46.41N	96.44W	MINNESOTA	WEST CENTRAL	WILKIN	1	1361
229	353	4	46.46N	96.16W	MINNESOTA	WEST CENTRAL	OTTER TAIL	1	1362
229	354	1	45.89N	95.93W	MINNESOTA	WEST CENTRAL	GRANT	1	1363
229	354	2	45.84N	96.20W	MINNESOTA	WEST CENTRAL	GRANT	1	1364
229	354	3	46.03N	96.28W	MINNESOTA	WEST CENTRAL	GRANT	1	1365
229	354	4	46.08N	96.00W	MINNESOTA	WEST CENTRAL	GRANT	1	1366
229	355	1	45.51N	95.77W	MINNESOTA	WEST CENTRAL	STEVENS	1	1367
229	355	2	45.46N	96.04W	MINNESOTA	WEST CENTRAL	STEVENS	1	1368
229	355	3	45.65N	96.12W	MINNESOTA	WEST CENTRAL	STEVENS	1	1369
229	355	4	45.70N	95.85W	MINNESOTA	WEST CENTRAL	STEVENS	1	1370
229	356	1	45.14N	95.62W	MINNESOTA	WEST CENTRAL	SWIFT	1	1371
229	356	2	45.08N	95.89W	MINNESOTA	WEST CENTRAL	CHIPPEWA	1	1372
229	356	3	45.27N	95.96W	MINNESOTA	WEST CENTRAL	SWIFT	1	1373
229	356	4	45.32N	95.70W	MINNESOTA	WEST CENTRAL	SWIFT	3	1374
229	357	1	44.76N	95.47W	MINNESOTA	WEST CENTRAL	YELLOW MEDICINE	1	1375
229	357	2	44.71N	95.74W	MINNESOTA	WEST CENTRAL	YELLOW MEDICINE	1	1376
229	357	3	44.89N	95.81W	MINNESOTA	WEST CENTRAL	LAC QUI PARLE	1	1377
229	357	4	44.95N	95.55W	MINNESOTA	WEST CENTRAL	CHIPPEWA	1	1378
229	358	1	44.38N	95.33W	MINNESOTA	SOUTHWEST	REDWOOD	1	1379
229	358	2	44.33N	95.59W	MINNESOTA	SOUTHWEST	REDWOOD	1	1380
229	358	3	44.52N	95.66W	MINNESOTA	SOUTHWEST	LYON	1	1381
229	358	4	44.57N	95.40W	MINNESOTA	SOUTHWEST	REDWOOD	1	1382
229	359	1	44.01N	95.18W	MINNESOTA	SOUTHWEST	COTTONWOOD	1	1383
229	359	2	43.95N	95.44W	MINNESOTA	SOUTHWEST	COTTONWOOD	1	1384
229	359	3	44.14N	95.52W	MINNESOTA	SOUTHWEST	MURRAY	1	1385
229	359	4	44.19N	95.26W	MINNESOTA	SOUTHWEST	REDWOOD	1	1386
229	360	1	43.63N	95.04W	MINNESOTA	SOUTHWEST	JACKSON	1	1387
229	360	2	43.58N	95.30W	MINNESOTA	SOUTHWEST	JACKSON	1	1388
229	360	3	43.77N	95.37W	MINNESOTA	SOUTHWEST	JACKSON	1	1389
229	360	4	43.82N	95.11W	MINNESOTA	SOUTHWEST	JACKSON	1	1390
230	346	2	49.01N	96.98W	MINNESOTA	NORTHWEST	KITTSON	1	1391
230	347	1	48.68N	96.51W	MINNESOTA	NORTHWEST	KITTSON	3	1392
230	347	2	48.62N	96.80W	MINNESOTA	NORTHWEST	KITTSON	1	1393
230	347	3	48.81N	96.89W	MINNESOTA	NORTHWEST	KITTSON	1	1394
230	347	4	48.87N	96.60W	MINNESOTA	NORTHWEST	KITTSON	1	1395
230	348	1	48.29N	96.34W	MINNESOTA	NORTHWEST	MARSHALL	3	1396
230	348	2	48.24N	96.63W	MINNESOTA	NORTHWEST	MARSHALL	1	1397
230	348	3	48.43N	96.71W	MINNESOTA	NORTHWEST	MARSHALL	1	1398
230	348	4	48.49N	96.42W	MINNESOTA	NORTHWEST	MARSHALL	1	1399
230	349	1	47.91N	96.17W	MINNESOTA	NORTHWEST	RED LAKE	3	1400

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I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
230	349	2	47.85N	96.46W	MINNESOTA	NORTHWEST	RED LAKE	1	1401
230	349	3	48.05N	96.54W	MINNESOTA	NORTHWEST	POLK	1	1402
230	349	4	48.10N	96.25W	MINNESOTA	NORTHWEST	PENNINGTON	1	1403
230	350	1	47.53N	96.01W	MINNESOTA	NORTHWEST	POLK	1	1404
230	350	2	47.47N	96.29W	MINNESOTA	NORTHWEST	NORMAN	3	1405
230	350	3	47.66N	96.37W	MINNESOTA	NORTHWEST	POLK	1	1406
230	350	4	47.72N	96.09W	MINNESOTA	NORTHWEST	POLK	3	1407
230	351	1	47.14N	95.85W	MINNESOTA	NORTHWEST	MAHNOMEN	1	1408
230	351	2	47.09N	96.13W	MINNESOTA	NORTHWEST	BECKER	1	1409
230	351	3	47.28N	96.21W	MINNESOTA	NORTHWEST	NORMAN	3	1410
230	351	4	47.34N	95.93W	MINNESOTA	NORTHWEST	MAHNOMEN	1	1411
230	352	1	46.76N	95.69W	MINNESOTA	NORTHWEST	BECKER	3	1412
230	352	2	46.71N	95.97W	MINNESOTA	NORTHWEST	BECKER	3	1413
230	352	3	46.90N	96.05W	MINNESOTA	NORTHWEST	BECKER	1	1414
230	352	4	46.95N	95.77W	MINNESOTA	NORTHWEST	BECKER	3	1415
230	353	1	46.38N	95.53W	MINNESOTA	WEST CENTRAL	OTTER TAIL	3	1416
230	353	2	46.33N	95.81W	MINNESOTA	WEST CENTRAL	OTTER TAIL	3	1417
230	353	3	46.52N	95.89W	MINNESOTA	WEST CENTRAL	OTTER TAIL	3	1418
230	353	4	46.57N	95.61W	MINNESOTA	WEST CENTRAL	OTTER TAIL	3	1419
230	354	1	46.00N	95.38W	MINNESOTA	WEST CENTRAL	DOUGLAS	1	1420
230	354	2	45.95N	95.65W	MINNESOTA	WEST CENTRAL	DOUGLAS	1	1421
230	354	3	46.14N	95.73W	MINNESOTA	WEST CENTRAL	OTTER TAIL	1	1422
230	354	4	46.19N	95.46W	MINNESOTA	WEST CENTRAL	OTTER TAIL	1	1423
230	355	1	45.62N	95.23W	MINNESOTA	WEST CENTRAL	POPE	3	1424
230	355	2	45.57N	95.50W	MINNESOTA	WEST CENTRAL	POPE	1	1425
230	355	3	45.76N	95.58W	MINNESOTA	WEST CENTRAL	DOUGLAS	1	1426
230	355	4	45.81N	95.30W	MINNESOTA	WEST CENTRAL	DOUGLAS	1	1427
230	356	1	45.24N	95.08W	MINNESOTA	CENTRAL	KANDIYOHI	1	1428
230	356	2	45.19N	95.35W	MINNESOTA	WEST CENTRAL	SWIFT	1	1429
230	356	3	45.38N	95.43W	MINNESOTA	WEST CENTRAL	SWIFT	1	1430
230	356	4	45.43N	95.16W	MINNESOTA	WEST CENTRAL	POPE	3	1431
230	357	1	44.86N	94.94W	MINNESOTA	CENTRAL	KANDIYOHI	1	1432
230	357	2	44.81N	95.21W	MINNESOTA	CENTRAL	RENVILLE	1	1433
230	357	3	45.00N	95.28W	MINNESOTA	WEST CENTRAL	CHIPPEWA	1	1434
230	357	4	45.05N	95.01W	MINNESOTA	CENTRAL	KANDIYOHI	1	1435
230	358	1	44.48N	94.80W	MINNESOTA	CENTRAL	RENVILLE	1	1436
230	358	2	44.43N	95.06W	MINNESOTA	SOUTHWEST	REDWOOD	1	1437
230	358	3	44.62N	95.13W	MINNESOTA	CENTRAL	RENVILLE	1	1438
230	358	4	44.67N	94.87W	MINNESOTA	CENTRAL	RENVILLE	1	1439
230	359	1	44.11N	94.66W	MINNESOTA	SOUTH CENTRAL	BROWN	1	1440
230	359	2	44.06N	94.92W	MINNESOTA	SOUTHWEST	COTTONWOOD	1	1441
230	359	3	44.24N	94.99W	MINNESOTA	SOUTH CENTRAL	BROWN	1	1442
230	359	4	44.29N	94.73W	MINNESOTA	SOUTH CENTRAL	BROWN	1	1443
230	360	1	43.73N	94.52W	MINNESOTA	SOUTH CENTRAL	MARTIN	1	1444
230	360	2	43.68N	94.78W	MINNESOTA	SOUTH CENTRAL	MARTIN	1	1445
230	360	3	43.87N	94.85W	MINNESOTA	SOUTH CENTRAL	WATONWAN	1	1446
230	360	4	43.92N	94.59W	MINNESOTA	SOUTH CENTRAL	WATONWAN	1	1447
230	361	3	43.49N	94.72W	MINNESOTA	SOUTH CENTRAL	MARTIN	1	1448
230	361	4	43.54N	94.46W	MINNESOTA	SOUTH CENTRAL	MARTIN	1	1449
231	347	1	48.79N	95.92W	MINNESOTA	NORTHWEST	ROSEAU	1	1450

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
231	347	2	48.74N	96.22W	MINNESOTA	NORTHWEST	ROSEAU	1	1451
231	347	3	48.93N	96.30W	MINNESOTA	NORTHWEST	ROSEAU	3	1452
231	347	4	48.99N	96.01W	MINNESOTA	NORTHWEST	ROSEAU	1	1453
231	348	1	48.41N	95.76W	MINNESOTA	NORTHWEST	MARSHALL	1	1454
231	348	2	48.35N	96.05W	MINNESOTA	NORTHWEST	MARSHALL	3	1455
231	348	3	48.54N	96.13W	MINNESOTA	NORTHWEST	ROSEAU	3	1456
231	348	4	48.60N	95.84W	MINNESOTA	NORTHWEST	ROSEAU	1	1457
231	349	1	48.02N	95.60W	MINNESOTA	NORTHWEST	PENNINGTON	1	1458
231	349	2	47.97N	95.88W	MINNESOTA	NORTHWEST	PENNINGTON	1	1459
231	349	3	48.16N	95.97W	MINNESOTA	NORTHWEST	MARSHALL	1	1460
231	349	4	48.21N	95.68W	MINNESOTA	NORTHWEST	MARSHALL	3	1461
231	350	1	47.63N	95.44W	MINNESOTA	NORTHWEST	CLEARWATER	3	1462
231	350	2	47.58N	95.72W	MINNESOTA	NORTHWEST	POLK	1	1463
231	350	3	47.77N	95.80W	MINNESOTA	NORTHWEST	POLK	3	1464
231	350	4	47.83N	95.52W	MINNESOTA	NORTHWEST	CLEARWATER	3	1465
231	351	1	47.25N	95.28W	MINNESOTA	NORTHWEST	CLEARWATER	3	1466
231	351	2	47.20N	95.56W	MINNESOTA	NORTHWEST	MAHNOMEN	3	1467
231	351	3	47.39N	95.64W	MINNESOTA	NORTHWEST	MAHNOMEN	3	1468
231	351	4	47.44N	95.36W	MINNESOTA	NORTHWEST	CLEARWATER	3	1469
231	352	1	46.97N	95.13W	MINNESOTA	NORTH CENTRAL	HUBBARD	3	1470
231	352	2	46.81N	95.41W	MINNESOTA	NORTHWEST	BECKER	3	1471
231	352	3	47.01N	95.49W	MINNESOTA	NORTHWEST	BECKER	3	1472
231	352	4	47.06N	95.20W	MINNESOTA	NORTHWEST	BECKER	3	1473
231	353	1	46.48N	94.98W	MINNESOTA	CENTRAL	WADENA	3	1474
231	353	2	46.43N	95.26W	MINNESOTA	WEST CENTRAL	OTTER TAIL	3	1475
231	353	3	46.62N	95.33W	MINNESOTA	WEST CENTRAL	OTTER TAIL	3	1476
231	353	4	46.68N	95.05W	MINNESOTA	CENTRAL	WADENA	3	1477
231	354	1	46.10N	94.83W	MINNESOTA	CENTRAL	TODD	3	1478
231	354	2	46.05N	95.11W	MINNESOTA	CENTRAL	TODD	3	1479
231	354	3	46.24N	95.18W	MINNESOTA	WEST CENTRAL	OTTER TAIL	3	1480
231	354	4	46.29N	94.90W	MINNESOTA	CENTRAL	TODD	3	1481
231	355	1	45.72N	94.69W	MINNESOTA	CENTRAL	STEARNS	1	1482
231	355	2	45.67N	94.96W	MINNESOTA	CENTRAL	STEARNS	1	1483
231	355	3	45.86N	95.03W	MINNESOTA	CENTRAL	TODD	3	1484
231	355	4	45.91N	94.76W	MINNESOTA	CENTRAL	TODD	3	1485
231	356	1	45.34N	94.54W	MINNESOTA	CENTRAL	STEARNS	1	1486
231	356	2	45.29N	94.81W	MINNESOTA	CENTRAL	KANDIYOHI	1	1487
231	356	3	45.48N	94.89W	MINNESOTA	CENTRAL	STEARNS	1	1488
231	356	4	45.53N	94.62W	MINNESOTA	CENTRAL	STEARNS	1	1489
231	357	1	44.96N	94.41W	MINNESOTA	CENTRAL	MEEKER	1	1490
231	357	2	44.91N	94.67W	MINNESOTA	CENTRAL	MEEKER	1	1491
231	357	3	45.10N	94.74W	MINNESOTA	CENTRAL	MEEKER	1	1492
231	357	4	45.15N	94.47W	MINNESOTA	CENTRAL	MEEKER	1	1493
231	358	1	44.58N	94.27W	MINNESOTA	CENTRAL	SIBLEY	1	1494
231	358	2	44.53N	94.53W	MINNESOTA	CENTRAL	SIBLEY	1	1495
231	358	3	44.72N	94.60W	MINNESOTA	CENTRAL	RENVILLE	1	1496
231	358	4	44.77N	94.34W	MINNESOTA	CENTRAL	MC LEOD	1	1497
231	359	1	44.20N	94.14W	MINNESOTA	SOUTH CENTRAL	NICOLLET	1	1498
231	359	2	44.15N	94.40W	MINNESOTA	SOUTH CENTRAL	BLUE EARTH	1	1499
231	359	3	44.34N	94.47W	MINNESOTA	SOUTH CENTRAL	NICOLLET	1	1500

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
231	359	4	44.39N	94.20W	MINNESOTA	SOUTH CENTRAL	NICOLLET	1	1501
231	360	1	43.83N	94.00W	MINNESOTA	SOUTH CENTRAL	BLUE EARTH	1	1502
231	360	2	43.78N	94.26W	MINNESOTA	SOUTH CENTRAL	FARIBAULT	1	1503
231	360	3	43.97N	94.33W	MINNESOTA	SOUTH CENTRAL	BLUE EARTH	1	1504
231	360	4	44.01N	94.07W	MINNESOTA	SOUTH CENTRAL	BLUE EARTH	1	1505
231	361	3	43.59N	94.20W	MINNESOTA	SOUTH CENTRAL	FARIBAULT	1	1506
231	361	4	43.64N	93.94W	MINNESOTA	SOUTH CENTRAL	FARIBAULT	1	1507
232	347	1	48.90N	95.34W	MINNESOTA	NORTHWEST	ROSEAU	3	1508
232	347	2	48.85N	95.63W	MINNESOTA	NORTHWEST	ROSEAU	3	1509
232	348	2	48.46N	95.47W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1510
232	348	3	48.65N	95.55W	MINNESOTA	NORTHWEST	ROSEAU	3	1511
232	348	4	48.71N	95.26W	MINNESOTA	NORTHWEST	ROSEAU	3	1512
232	349	1	48.13N	95.02W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1513
232	349	2	48.07N	95.31W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1514
232	349	3	48.27N	95.39W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1515
232	349	4	48.32N	95.10W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1516
232	350	1	47.74N	94.86W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1517
232	350	2	47.69N	95.15W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1518
232	350	3	47.88N	95.23W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1519
232	351	1	47.35N	94.71W	MINNESOTA	NORTH CENTRAL	HUBBARD	3	1520
232	351	2	47.30N	95.00W	MINNESOTA	NORTH CENTRAL	HUBBARD	3	1521
232	351	3	47.49N	95.07W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1522
232	351	4	47.55N	94.79W	MINNESOTA	NORTH CENTRAL	BELTRAMI	3	1523
232	352	1	46.97N	94.57W	MINNESOTA	NORTH CENTRAL	CASS	3	1524
232	352	2	46.92N	94.85W	MINNESOTA	NORTH CENTRAL	HUBBARD	3	1525
232	352	3	47.11N	94.92W	MINNESOTA	NORTH CENTRAL	HUBBARD	3	1526
232	352	4	47.16N	94.64W	MINNESOTA	NORTH CENTRAL	CASS	3	1527
232	353	1	46.58N	94.42W	MINNESOTA	NORTH CENTRAL	CASS	3	1528
232	353	2	46.53N	94.70W	MINNESOTA	NORTH CENTRAL	CASS	3	1529
232	353	3	46.73N	94.77W	MINNESOTA	NORTH CENTRAL	CASS	3	1530
232	353	4	46.78N	94.49W	MINNESOTA	NORTH CENTRAL	CASS	3	1531
232	354	2	46.15N	94.55W	MINNESOTA	CENTRAL	MORRISON	3	1532
232	354	3	46.34N	94.63W	MINNESOTA	NORTH CENTRAL	CASS	3	1533
232	354	4	46.39N	94.35W	MINNESOTA	NORTH CENTRAL	CASS	3	1534
232	355	1	45.82N	94.14W	MINNESOTA	CENTRAL	MORRISON	3	1535
232	355	2	45.77N	94.41W	MINNESOTA	CENTRAL	MORRISON	3	1536
232	355	3	45.96N	94.48W	MINNESOTA	CENTRAL	MORRISON	3	1537
232	355	4	46.01N	94.21W	MINNESOTA	CENTRAL	MORRISON	3	1538
232	356	1	45.44N	94.00W	MINNESOTA	CENTRAL	SHERBURNE	3	1539
232	356	2	45.39N	94.27W	MINNESOTA	CENTRAL	STEARNS	3	1540
232	356	3	45.58N	94.34W	MINNESOTA	CENTRAL	STEARNS	3	1541
232	356	4	45.63N	94.07W	MINNESOTA	CENTRAL	BENTON	3	1542
232	357	1	45.06N	93.87W	MINNESOTA	CENTRAL	WRIGHT	1	1543
232	357	2	45.01N	94.14W	MINNESOTA	CENTRAL	WRIGHT	1	1544
232	357	3	45.20N	94.21W	MINNESOTA	CENTRAL	WRIGHT	1	1545
232	357	4	45.25N	93.93W	MINNESOTA	CENTRAL	WRIGHT	1	1546
232	358	1	44.68N	93.74W	MINNESOTA	CENTRAL	CARVER	1	1547
232	358	2	44.63N	94.00W	MINNESOTA	CENTRAL	SIBLEY	1	1548
232	358	3	44.82N	94.07W	MINNESOTA	CENTRAL	MC LEOD	1	1549
232	358	4	44.87N	93.80W	MINNESOTA	CENTRAL	CARVER	1	1550

I	J	K	LAT	LON	STATE	CROP REP. DIST.	COUNTY	SOIL CLASS	SEQUENTIAL NO.
232	359	1	44.30N	93.61W	MINNESOTA	SOUTH CENTRAL	LE SUEUR	1	1551
232	359	2	44.25N	93.87W	MINNESOTA	SOUTH CENTRAL	LE SUEUR	1	1552
232	359	3	44.44N	93.94W	MINNESOTA	CENTRAL	SIBLEY	1	1553
232	359	4	44.49N	93.67W	MINNESOTA	SOUTH CENTRAL	LE SUEUR	1	1554
232	360	1	43.92N	93.48W	MINNESOTA	SOUTH CENTRAL	WASECA	1	1555
232	360	2	43.87N	93.74W	MINNESOTA	SOUTH CENTRAL	WASECA	1	1556
232	360	3	44.06N	93.81W	MINNESOTA	SOUTH CENTRAL	WASECA	1	1557
232	360	4	44.11N	93.54W	MINNESOTA	SOUTH CENTRAL	WASECA	1	1558
232	361	1	43.54N	93.36W	MINNESOTA	SOUTH CENTRAL	FREEBORN	1	1559
232	361	2	43.50N	93.62W	MINNESOTA	SOUTH CENTRAL	FREEBORN	1	1560
232	361	3	43.68N	93.68W	MINNESOTA	SOUTH CENTRAL	FREEBORN	1	1561
232	361	4	43.73N	93.42W	MINNESOTA	SOUTH CENTRAL	FREEBORN	1	1562

APPENDIX II

EARTHSAT "SYSTEM" IMPLEMENTATION DISCUSSION

TABLE OF CONTENTS

INTRODUCTION

Implementation of the NASA AGMET System is divided into two major subtasks; definition and creation of libraries and load models; execution of the four programs which represents the NASA AGMET composite. A discussion of systematic NASA AGEMT operation then follows.

Source programs are provided in a tape medium, and the necessary job control language provided to create a load module library from which they are involved.

Job control language is also provided to execute the NASA AGMET System given the initial start conditions. The necessary files for this execution are provided on tape. Computer System specific necessities for smooth and efficient system operation are discussed but, because they are system specific, only in a general manner.

1.0 LACIE MODULE GENERATION

1.1 System Library Definition

Two necessary libraries must be defined prior to module generation. $6320.EARTHSAT.LOAD is the load library in which the major modules will be placed and $6320.EARTHSAT.LOAD is a macro library into which SETUP an EarthSat in-house macro necessary to Assembly of the Assembler modules will reside.

1.2 General Subroutines

Several general purpose subroutines are then compiled and placed in $6320.EARTHSAT.LOAD for use at LINK Edit by the Major modules.

1.3 Major Module Generation

METRUN, AGRUN, PREDRUN, DAYRUN are compiled and link edited into the LIBRARY and are available for future execution.

1.4 File Generation

Unload necessary data files and place in the specified locations. Unload RWA.STAIJ to system tape. Unload LACIE.START to system direct access storage. Unload HIST.GI to system direct access storage.

CONTENTS OF TAPE ESC040

File #	DSN	RECFM	LRECL	BLKSIZE	CONTENTS	TYPE
1	FILE1	FB	80	800	SETUP MACRO	ASM
2	FILE2	FB	80	800	READ SUBROUTINE	ASM
3	FILE3	FB	80	800	WRITE SUBROUTINE	ASM
4	FILE4	FB	80	800	BDAM SUBROUTINE	ASM
5	FILE5	FB	80	800	ABEND SUBROUTINE	ASM
6	FILE6	FB	80	800	METRUN	FORT
7	FILE7	FB	80	800	AGRUN 1	FORT
8	FILE8	FB	80	800	AGRUN 2	ASM
9	FILE9	FB	80	800	PREDRUN	FORT
10	FILE10	FB	80	800	DAYRUN	FORT
11	FILE11	F	40	40	HIST.G1	DATA
12	FILE12	FB	76	760	RWA.STAIJ	DATA
13	FILE13	F	108	108	LACIE.START	DATA

TABLE A-1

General Routine Description

SETUP	is a general purpose inhouse macro to insure addressability.
AGIN	is a general purpose subroutine to read using QSAM via fortran.
AGOUT	is a general purpose subroutine to write using QSAM via fortran.
UPDATE	is a general purpose routine to utilize assembler direct access via fortran.
ABED	is a special purpose routing to force a program to core dump.
METRUN	models meteorological data and produces map overlays of a specific ground area for meteorological parameters.
AGRUN	models daily growth of a given crop through the growing season.
PREDRUN	predicts the yield of a given crop using the daily meteorological and growth to date as input.
DAYRUN	is a report generator for AGRUN, which lists and maps the various parameters on a daily basis.

TABLE A-2

1.4a JCL for file generation

```
//E35RA JOB (5220,95,1,3,,,,,),'ANDERSON'
//STEP1 EXEC PGM=IEBGENER
//*
//*   REPRODUCE THE HISTORICAL FILE
//*
//SYSPRINT DD SYSOUT=A
//SYSUT1 DD DSN=FILE11,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(11,SL),DCB=(RECFM=F,BLKSIZE=40)
//SYSUT2 DD DSN=HIST.G1,DISP=(NEW,CATLG),
// UNIT=2314,SPACE=(CYL,(10),RLSE,CONTIG),
// VOL=SER=IPIWRK,
//  DCB=(RECFM=F,BLKSIZE=40)
//SYSIN DD DUMMY
//STEP3 EXEC PGM=IEBGENER
//*
//*    REPRODUCE THE INIIAL START CONDITIONS FOR AGRUN
//*
//SYSPRINT DD SYSOUT=A
//SYSUT1 DD DSN=FILE13,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(13,SL),DCB=(RECFM=F,BLKSIZE=108)
//SYSUT2 DD DSN=LACIE.START,DISP=(NEW,CATLG),
// UNIT=2314,SPACE=(CYL,(10),RLSE,CONTIG),
// VOL=SER=IPIWRK,
//   DCB=(RECFM=F,BLKSIZE=108)
//SYSIN DD DUMMY
//
```

1.5 JCL for Module Operation

```
//PGMGEN JOB (BR9001.745),ANDERSON.CLASS=F
//STEP1     EXEC PGM=IEFBR14
//*
//*      DEFINE LOAD LIBRARY
//*
//SYSUT1 DD DSN=$6320.EARTHSAT.LOAD,DISP=(NEW,CATLG),
// UNIT=2314,VOL=SER=SCRT02,SPACE=(CYL,(10,2,20)),
//  DCB=(RECFM=U,BLKSIZE=7294,DSORG=PO)
//STEP2 EXEC PGM=IEBGENER,REGION=80K
//*
//*   DEFINE MACRO LIBRARY AND ENTER MEMBER SETUP
//*
//SYSPRINT DD SYSOUT=A
//SYSUT1 DD DSN=FILE1.DISP=(OLD,KEEP.KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(1,SL),
// DCB=(RECFM=FB,LRECL=80.BLKSIZE=800)
//SYSUT2 DD DSN=$6320.EARTHSAT.MACLIB,DISP=(NEW,CATLG),
// UNIT=2314,VOL=SER=SCRT02,SPACE=(CYL,(1,1,20)),
//    DCB=(RECFM=FB,LRECL=80.BLKSIZE=1600,DSORG=PO)
//SYSIN DD *
 GENERATE MAXNAME=1
 MEMBER NAME=SETUP
```

YOUR PRIVATE PACK

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

```
//STEP3    EXEC ASMFCL,PARM.ASM='LOAD,NODECK',PARM.LKED='LET,XREF'
//*
//*       LOAD SUBROUTINE AGIN
//*
//ASM.SYSLIB DD
//                DD DSN=$6320.EARTHSAT.MACLIB,DISP=SHR
//ASM.SYSIN DD DSN=FILE2,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(2,SL),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//LKED.SYSLMOD DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR,
// SPACE=(CYL,(10,2,20))
//LKED.SYSIN DD *
 ALIAS OPENAG,AGREAD
 NAME AGIN(R)
/*
//STEP4    EXEC ASMFCL,PARM.ASM='LOAD,NODECK',PARM.LKED='LET,XREF'
//*
//*       LOAD SUBROUTINE AGOUT
//*
//ASM.SYSLIB DD
//                DD DSN=$6320.EARTHSAT.MACLIB,DISP=SHR
//ASM.SYSIN DD DSN=FILE3,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(3,SL),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//LKED.SYSLMOD DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR,
// SPACE=(CYL,(10,2,20))
//LKED.SYSIN DD *
 ALIAS AGOPEN,ERRWRT,METWRT
 NAME AGOUT(R)
```

```
//STEP5  EXEC ASMFCL,PARM.ASM='LOAD,NODECK',PARM.LKED='LET,XREF'
//*
//*   LOAD SUBROUTINE RDAM
//*
//ASM.SYSLIB DD
//         DD DSN=$6320.EARTHSAT.MACLIB,DISP=SHR
//ASM.SYSIN DD DSN=FILE4,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(4,SL),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//LKED.SYSLMOD DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR,
// SPACE=(CYL,(10,2,20))
//LKED.SYSIN DD *
       ALIAS  HSTOPN,HSTCLS,HSTRD,HSTWRT
       NAME UPDATE(R)
//STEP6  EXEC ASMFCL,PARM.ASM='LOAD,NODECK',PARM.LKED='LET,XREF'
//*
//*   LOAD SUBROUTINE ABEND
//*
//ASM.SYSLIB DD
//         DD DSN=$6320.EARTHSAT.MACLIB,DISP=SHR
//ASM.SYSIN DD DSN=FILE5,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(5,SL),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//LKED.SYSLMOD DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR,
// SPACE=(CYL,(10,2,20))
//LKED.SYSIN DD *
 ALIAS ABED
 NAME RWA(R)
```

```
//STEP7    EXEC FORTGCL,PARM.FORT='MAP,ID',PARM.LKED='LET,XREF'
//*
//*        LOAD MODULE METRUN
//*
//FORT.SYSIN DD DSN=FILE6,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(6,SL),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//LKED.SYSLIB DD
//               DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR
//LKED.SYSLMOD DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR,
// SPACE=(CYL,(10,2,20))
//LKED.SYSIN DD *
 NAME METRUN(R)
```

```
//STEP6    EXEC FORTGCL,PARM.FORT='MAP,ID'.PARM.LKED=NCAL
//*
//*      LOAD FIRST HALF OF AGRUN
//*
//FORT.SYSIN DD DSN=FILE7,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(7,SL),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//LKED.SYSLMOD DD DSN=$6320.EARTHSAT.LOAD.DISP=SHR,
// SPACE=(CYL,(10,2,20))
//LKED.SYSIN DD *
 ALIAS SMTBGT,OPENAG,DAILY,RMTDAY
 NAME AGSUB(R)
//STEP9    EXEC ASMFCL,PARM.ASM='LOAD,NODECK',PARM.LKED='XREF,LET'
//*
//*      LAOD MODULE AGRUN
//*
//ASM.SYSLIB DD
//              DD DSN=$6320.EARTHSAT.MACLIB,DISP=SHR
//ASM.SYSIN DD DSN=FILE8,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(8,SL),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//LKED.SYSLIB DD DSN=SYS1.FORTLIB,DISP=SHR
//              DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR
//LKED.SYSLMOD DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR,
// SPACE=(CYL,(10,2,20))
//LKED.SYSIN DD *
 ENTRY ASMMAIN
 NAME AGRUN(R)
```

```
//STEP10  EXEC FORTGCL,PARM.FORT='MAP,ID',PARM.LKED='LET,XREF'
//*
//*       LOAD MODULE PREDRUN
//*
//FORT.SYSIN DD DSN=FILE9,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(9,SL),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//LKED.SYSLIB DD
//                DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR
//LKED.SYSLMOD DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR,
// SPACE=(CYL,(10,2,20))
//LKED.SYSIN DD *
 NAME PREDRUN(R)
```

```
//STEP11  EXEC FORTGCL,PARM.FORT='MAP,ID',PARM.LKED='LET,XREF'
//*
//*    LOAD MODULE DAYRUN
//*
//FORT.SYSIN DD DSN=FILE10,DISP=(OLD,KEEP,KEEP),
// UNIT=2400,VOL=(PRIVATE,RETAIN,,SER=ESC040),
// LABEL=(10,SL),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=800)
//LKED.SYSLIB DD
//            DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR
//LKED.SYSLMOD DD DSN=$6320.EARTHSAT.LOAD,DISP=SHR,
// SPACE=(CYL,(10,2,20))
//LKED.SYSIN DD *
 NAME DAYRUN(R)
//
```

2.0 NASA/AGMET EXECUTION

2.1 METRUN

Purpose: To model meteorological data and display it. To produce a precipitation, TEMP MAX-MIN, ETP estimate as input to AGRUN.

Data Files

a) FT32F001: Data for days processed in present cycle becomes input in the following cycle.

b) FT29F001: Data for days processed in previous cycle; last day initializes model for first day in this cycle.

c) FT31F001: 6 hr data with daily summation, used for error analysis of MET model.

d) FT30F001: Initialization file for region specific constants.

e) FT05F001: Station & Satellite data.

f) FT09F001: Map overlay data for output display.

g) FT06F001: Printer display file.

2.2 AGRUN

Purpose: Agronomic growth model using meteorological data, plant phenology, and region specific characteristics.

Data Files

a) FT05F001: dummy file.

b) FT06F001: Fortran error messages only.

c) HISTORIC: Historical file which contains region specific agronomic parameters.

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d) ARCHIVE: Previous CYCLE's last day for initialization of this CYCLE. (initially set for first CYCLE as file LACIE.START)

e) METFILE: Sorted Daily meteorological data for use in AGRUN.

f) TEMPARCH: This CYCLE's last day file.

g) NEWARCH: Daily file for error analysis.

2.3 PREDRUN

Purpose: Predicts yield using Region specific parameters and AGRUN growth parameter. Produces map of yield by I,J, aggregates yield by State, county, crop reporting district.

Data files

a) FT05F001: Map overlay, state, county vectors.

b) FT06F001: Map I,J output.

c) FT10F001: Aggregate listings.

d) FT29F001: Last day status from AGRUN.

e) HISTORIC: Historical region specific characteristics.

2.4 DAYRUN

Purpose: Daily masters list of I,J's and associated growth parameters area. Produces maps of selected quantities.

DATA files

a) FT05F001: Map overlay data for output display.

b) FT06F001: Map print file.

c) FT10F001: I,J listing print file.

d) FT09F001: Days to process in I2 format.

e) FT29F001: Sorted agronomic daily status file.

Systems Considerations for NASA/AGMET Generation and Execution

IBM Compatible Comparable With

1) STANDARD system utilities
2) STANDARD sort-merge facilities
3) STANDARD system catalogues
4) STANDARD link editor and loader
5) STANDARD MACRO library
6) FORTRAN G compiler
7) ASSEMBLE F assembler
8) STANDARD procedures (FORTGCL, ASMFCL)

TABLE 5-3

2.5 JCL for Program Execution

```
//METSTEP EXEC PGM=METRUN,REGION=140K
//*
//*         METEROLOGICAL PROGRAM
//*
//STEPLIB DD DSN=$6320.EARTHSAT.LOAD,UNIT=2314,VOL=SER=IPIWRK,
// DISP=SHR
//FT05F001 DD DDNAME=SYSIN
//FT06F001 DD SYSOUT=A
//FT07F001 DD SYSOUT=B
//FT29F001 DD DUMMY,DCB=BLKSIZE=20
//FT30F001 DD DSN=FILE12,UNIT=2400,VOL=SER=ESC040,
// LABEL=(12,SL),
// DISP=(OLD,KEEP,KEEP),DCB=(RECFM=FB,LRECL=76,BLKSIZE=760)
//FT31F001 DD DUMMY,DCB=BLKSIZE=20
//FT32F001 DD DSN=&&MET,UNIT=SYSDA,DISP=(NEW,PASS),
// SPACE=(CYL,(10,4),RLSE),
//  DCB=(RECFM=F,BLKSIZE=20)
//SYSUDUMP DD SYSOUT=A
//FT09F001 DD *
```

```
//SORTMET EXEC PGM=IERRC000,PARM='MSG=AP',REGION=60K
//*
//*  METERLOGICAL SORT FOR INPUT TO AGRUN
//*
//SYSOUT DD SYSOUT=A
//SYSPRINT DD SYSOUT=A
//SORTLIB DD DSNAME=SYS1.SORTLIB,DISP=SHR
//SORTIN DD DSN=&&MET,DISP=(OLD,DELETE),
// DCB=(RECFM=F,LRECL=20,BLKSIZE=20)
//SORTOUT DD DSN=&&METS,UNIT=SYSDA,
// SPACE=(CYL,(8,4),RLSE),
// DISP=(NEW,PASS,DELETE),DCB=(RECFM=F,LRECL=20,BLKSIZE=20)
//SORTWK01 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SORTWK02 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SORTWK03 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SORTWK04 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SORTWK05 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SYSIN DD *
 SORT FIELDS=(1,2,A,3,2,A,19,2,A),FORMAT=BI
//AGSTEP EXEC PGM=AGRUN,PARM='02'
//*
//*  AGRONAUMIC GROWTH PROGRAM
//*
//STEPLIB DD DSN=$6320.EARTHSAT.LOAD,UNIT=2314,VOL=SER=IP1WRK,
// DISP=SHR
//FT05F001 DD DDNAME=SYSIN
//FT06F001 DD SYSOUT=A
//HISTORIC DD DSN=HIST.61,DISP=(OLD,KEEP,KEEP),
// UNIT=2314,VOL=SER=IPIWRK
//ARCHIVE DD DSN=LACIE.START,DISP=(OLD,KEEP,KEEP),
// UNIT=2314,VOL=SER=IPIWRK
//NEWARCH DD DSN=&&NEW,DISP=(NEW,PASS),
// SPACE=(CYL,(10,4),RLSE),
// UNIT=SYSDA,DCB=(RECFM=F,BLKSIZE=108)
//TEMPARCH DD DSN=&&ARCH2,DISP=(NEW,PASS),
// SPACE=(CYL,(10,4),RLSE),
// UNIT=SYSDA,DCB=(RECFM=F,BLKSIZE=108)
//METFILE DD DSN=&&METS,DISP=(OLD,DELETE)
//SYSUDUMP DD SYSOUT=A
```

```
//PREDSTEP EXEC PGM=PREDRUN,REGION=66K
//*
//*      PREDICTION PROGRAM
//*
//STEPLIB DD DSN=$6320.EARTHSAT.LOAD,UNIT=2314,VOL=SER=IPIWRK,
// DISP=SHR
//FT05F001 DD DDNAME=SYSIN
//FT06F001 DD SYSOUT=A
//FT10F001 DD SYSOUT=C,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330)
//FT29F001 DD DSN=&&ARCH2,DISP=(OLD,DELETE)
//HISTORIC DD DSN=HIST.61,DISP=(OLD,KEEP,KEEP),
// UNIT=2314,VOL=SER=IPIWRK
//SYSUDUMP DD SYSOUT=A
//SYSIN DD *
```

```
//SORTAG EXEC PGM=IERRC000,PARM='MSG=AP',REGION=80K
//*
//* AGRONOMIC DATA SORT FOR INPUT TO DAILY LISTING
//*
//SYSOUT DD SYSOUT=A
//SYSPRINT DD SYSOUT=A
//SORTLIB DD DSNAME=SYS1.SORTLIB,DISP=SHR
//SORTIN DD DSN=&&NEW,DISP=(OLD,DELETE),
//                DCB=(RECFM=F,BLKSIZE=108)
//SORTOUT DD DSN=&&AG,DISP=(NEW,PASS),
// UNIT=SYSDA,SPACE=(108,(21168,10),RLSE),
// DCB=(RECFM=F,LRECL=108,BLKSIZE=108)
//SORTWK01 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SORTWK02 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SORTWK03 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SORTWK04 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SORTWK05 DD UNIT=2314,SPACE=(CYL,(5),,CONTIG)
//SYSIN DD *
 SORT FIELDS=(13,4,A,1,4,A,5,4,A,9,4,A),FORMAT=BI
//DAYSTEP EXEC PGM=DAYRUN
//*
//*      DAILY STATUS PROGRAM
//*
//STEPLIB DD DSN=$6320.EARTHSAT.LOAD,UNIT=2314,VOL=SER=IPIWRK,
// DISP=SHR
//FT05F001 DD DDNAME=SYSIN
//FT06F001 DD SYSOUT=A
//FT10F001 DD SYSOUT=C,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=1330),
//    SPACE=(CYL,(30,10),RLSE)
//FT09F001 DD *
02
//FT29F001 DD DSN=&&AG,DISP=(OLD,DELETE,KEEP)
//SYSIN DD *
```

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3.0 SYSTEMATIC OPERATION

3.1 Master Files

The following Data sets can be defined to allow efficient data storage and error recovery capability by creating master tapes with a file representing each CYCLE.

a) FT32F001

b) NEWARCH

3.2 Generation Data Groups

Generation data groups improve operational efficiency by reducing bookkeeping and improving significantly error recovery. Data sets defined as such should have the characteristic. Old Master - New Master. The following have this characteristic:

	Old Master	New Master
1)	FT29F001	FT32F001
2)	ARCHIVE	TEMPARCH

AN EXPLANATION OF METRUN COMPUTER OUTPUTS

EarthSat Daily Weather Diagnostic maps cover a region extending from Central Montana to Western Minnesota and from Southern Saskatchewan and Manitoba to Northern Wyoming and Nebraska.

The boundaries of the Dakotas, part of Montana and Minnesota, are outlined on the map by asterisks. The topmost horizontal line on the map specifies the I values of the met cells ($206 \geqslant I \leqslant 232$); the leftmost column specifies the J values ($335 \geqslant J \leqslant 362$).

Shown at the bottom left corner surrounded by asterisks, are the meteorological parameters for Manhattan, Kansas and Akron, Colorado, the two lysimeter sites which fall outside the diagnostic area.

The map headings at the top right give the following information:

	Example
Page number (always 1)	PAGE 1
Julian Day (1-365	DAY215
End time of map (GMT)	TIME 6 GMT
Map number	MAP 1
Time interval of map	00-06 GMT
Parameter mapped	PREC
Units and multiplier	MM*10

Eleven maps are printed daily and an additional map of total precipitation is produced at the end of the seven days. Each map can be identified by the heading at the top right. Following is a list of these maps and an interpretation of the heading:

Heading	Clarification
MAP 1 00-06 GMT PREC MM*10	Estimated precipitation in units of millimeters times ten for the indicated GMT period.
MAP 2 06-12 GMT PREC MM*10	
MAP 3 12-18 GMT PREC MM*10	
MAP 4 18-24 GMT PREC MM*10	
MAP 5 00-24 GMT PREC MM*10	
MAP 6 00-24 GMT NET RAD LY/DAY	Net radiation in langleys per day (calories per square centimeter per day).
MAP 7 00-24 GMT ETP MM*10	Potential evapotranspiration for 24 hours, in millimeters times ten.
MAP 8 00-24 GMT TMAX DEG C*10	Maximum (minimum) temperature occurring in the 24 hour interval, in degrees Celsius times ten.
MAP 9 00-24 GMT TMIN DEG C*10	
MAP 10 00-24 GMT BMT*100	Biometeorological time (x 100) at the end of the GMT day. BMT ranges from 0 at planting to 5 at ripe and is set to -1 at harvest.
MAP 11 00-24 GMT SOLAR RAD LY/DAY	Solar radiation in langleys per day.
MAP 12 TOTAL PRECIP (MM) 7 DAYS	Estimated precipitation in millimeters for seven day period.

Preceding each of the six hour precipitation maps is a one page listing of the satellite cloud cover data and synoptic station data that have been utilized to calculate precipitation, ETP, radiation, maximum and minimum temperatures, and BMT.

The satellite information contains day, GMT times of images, in eigths different cloud types, number of corners (K) of the cloud polygon analyzed, and latitude - longitudes of cloud polygon vertices.

The ground station information contains the WMO station number, date and time of observation and cloud, precipitation, temperature, dew point information encoded according to a standard WMO teletype transmission procedure.

DEFINITIONS - VOL. 2 AGRUN

A number of abbreviations are included in the VOL. 2 AGRUN listing report. The following discussion will seek to define each of the abbreviations.

COL - Column (I) in the I,J,K matrix. I=206 defines the extreme western boundary. I=232 defines the eastern most boundary.

ROW - Row (J) in the I,J,K matrix. J=336 defines the northernmost row while J=362 defines the southernmost.

1/4 - Cell (K), numbered 1-4 from lower right to upper right around each I,J)Column, Row) location. Each cell (K) is approximately 12.5 x 12.5 nautical miles N.M. in size. (The I,J grid interval is 25N.M.)

JUL - Julian day. J=151 = 31 May.

BMT - Biometeorological Time. This is a clock which represents growth stages of the spring wheat crop.

0 - Planting

1 - Emergence

2 - Jointing

3 - Heading

4 - Soft Dough

5 - Ripe

These values represent the 50 percent level for a county. Some variances to the 50 percent range will be experienced at the cell (K) level.

SM (1),...(3) -

Soil Moisture in millimeters for the zones which define the soil moisture profile. The zones are defined on the basis of available water in percent of capacity. Three soil categories are employed.

Soil Cat. 1	175 mm
Soil Cat. 3	115 mm
Soil Cat. 4	75 mm

ET (1), (3) -

Actual transpiration represented through removal of moisture from the soil profile. Rooting coefficients access each of the three layer zones as a function of BMT (growth stage). Adjustments are included in the rooting pattern for dry soil in the upper zones.

ETP - Potential evapotranspiration for a 24 hour period. This value represents atmospheric demand on the soil/plant system.

ETPAV - The average ETP for the period from planting to the current growth stage.

Prec - The amount of rainfall for the 24 hour period ending at 2400 GMT on the listing J-day (JUL).

Stress -

The difference in the ratio of ET (actual transpiration) to ETP (potential evapotranspiration) from one (unity) for the J day.

TMAX - 24 hour maximum temperature in degrees Centigrade.

TMIN- 24 hour minimum temperature in degrees Centigrade.

CRNOFF -

The amount of water which would accumulate on a flat surface, if;

(a) the rainfall exceeds 25 mm in a single 24 hour period

(b) the field capacity of all zones is at capacity and the rainfall for 24 hours exceeds the ETP

STRS 1 -

Total stress (1 - ET/ETP) Planting to emergence (BMT= 0-1)

STRS 2 -

Total stress (1 - ET/ETP) Emergence to Jointing (BMT= 1-2)

STRS 3 -

Total stress (1 - ET/ETP) Jointing to Heading (BMT= 2-3)

STRS 4 -

Total stress (1 - ET/ETP) Heading to Soft Dough (BMT= 3-4)

STRS 5 -

Total stress (1 - ET/ETP) Soft Dough to Ripe (BMT= 4-5)

ND 1....5 -

Total number of days with stress in the periods 0-1, 1-2, 2-3, 3-4, and 4-5.

CRPD - Total number of days since planting

TSIT - Indicator of a test site location. (Not used in the current operating mode, since test sites are handled as a separate, off-line, activity.

RAD - Net radiation

APPENDIX III

Soil Moisture
Subcontract Reports

from

North Dakota State University
Montana State University

SOIL MOISTURE MEASUREMENTS REPORT

conducted by

Soils Department
North Dakota Agricultural Experiment Station

submitted to

Earth Satellite Corporation
contract no. NAS 9-14655

10/14/75

Dr. B. K. Worcester, project leader
Date

Charles M Smith
10/14/75

Dr. C. M. Smith, Department Chairman
Date

Report of Soil Moisture Measurements

by

B. K. Worcester

This report is submitted to Earth Satellite Corporation in fulfillment of contract number NAS 9-14655 dated July 28, 1975. This contract required measurements of soil moisture profiles at given locations through harvest of the crops and a report of data by October 1, 1975. However, as the season progressed it became apparent that harvest of the grain would be delayed at some sites and to meet the October 1 schedule, data collection would be incomplete. Dr. A. B. Park of Earth Satellite Corporation was informed of this situation and a decision was made to continue data collection through the harvest thereby delaying submission of this report.

Subsequent to receipt of the contract, sites were selected corresponding as closely as possible to the specifications provided. This was accomplished by visual observation of the crop and soil. Certain geomorphic considerations entered into site selection. It was decided that, in order to avoid complications arising from aspect of the sites, they would be selected as nearly as possible on level upland areas. This eliminated to a large degree, differences in the angle of incidence of sunlight and therefore soil temperature and moisture variation more attributable to aspect than climatic conditions. Soil moisture access tubes were installed at each site with a hydraulic soil coring machine. The samples were retained for analysis to provide data on soil characteristics which could have an influence on soil moisture and crop performance and yield.

Soil moisture measurements were made at weekly intervals through harvest time. A Troxler soil moisture neutron probe was used. Each time soil moisture was measured, the growth stage of the crop was recorded using the standard Feekes scale.

Properties of the sites were determined in the laboratory and are presented in Tables 1, 2, and 3. Size fractions were determined by the pipette method (Kilmer and Alexander, 1949). Clay is defined as having an effective particle diameter of less than two microns, silt size is from two to 50 microns and sand size particles are greater than 50 microns in diameter. This is in accordance with standard USDA terminology (Soil Survey Staff, 1951). The sand content was determined by wet sieving. Bulk density, D_B, was determined by the clod method (Blake, 1965). Moisture content at 1/3 and 15 atmosphere tension was determined on pressure plate apparatus (Richards, 1954). Available water content was defined as the diference between these tensions. Available water content, gravimetric percent, times bulk density provides available water content on a volumetric basis. The amount of available water capacity in each layer is then easily calculated. The electrical conductivity in millimhos was measured on a 1:1 soil-water extract. Osmotic pressure of the solution can be approximated by the equation:

$$O.P. = 0.36 \times EC \times 10^3$$ (Richards, 1972).

This value would represent the osmotic potential of the soil solution at a saturation moisture content. Obviously, as the moisture content decreases, the concentration of salts, and the osmotic potential, will increase. Furthermore, the inclusion of osmotic pressure considerations into available water contents would require construction of moisture characteristic curves with points such as 1/10, 1/3, 5, 10 and 15 atmosphere moisture contents. This appeared to be beyond the scope of the project.

In Divide County (Table 1), site 1 was designated as a loam site.

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There are 22.72 cm available water content in the upper 100 cm of soil and 29.52 cm in the 130 cm section. This site is located in NW ¼ sec. 36, T. 163 N., R. 97 W. Wells durum wheat was seeded with rows running east-west on May 20, 1975, and harvested September 16, 1975. The field was unfertilized and showed no hail or insect damage. The yield was 30 bushels per acre. This was the first year this field had been seeded following summer fallow.

Site 2 was selected to represent a sandy textured soil. The soil has an available water capacptiy of 14.94 cm in 100 cm depth and 20.89 cm in 130 cm. It is located in SW ½ sec. 35, T. 102 N., R. 96 W. Ward durum wheat was seeded with east-west rows on May 22, 1975, and was harvested August 30, 1975. The field received 40 pounds per acre of 18-48-0 fertilizer at seeding, showed no hail or insect damage and yielded 13 bushels per acre. This crop followed summer fallow in 1974.

Site 3 was selected as a loam textured soil showing salt effects on the crop. The salt effects which were visible were a spotty appearance of the crop and, where the crop was short, it exhibited a definate blueish color. At the time of observation, this soil appeared very moist. The crop actually seemed to be suffering from drought conditions when the access tubes were installed but the soil was saturated at a depth of about 40 cm. The available water content is 19.41 cm in 100 cm and 24.96 cm in 130 cm. EC values indicated that salts were present (Table 1). The field is located in NE ¼ sec. 1, T. 162 N., R. 97 W. Ward durum wheat was planted May 24, 1975, and harvested September 12, 1975. Rows were oriented north and south. The field was fertilized at seeding with 40 pounds per acre of 34-0-0. No hail or insect damage was observed and a yield 15 bushels per acre was reported. This was the third consecutive crop on this field. It is interesting to note that the moisture status of this field was not markedly different from field 1 which had been summer fallowed the previous year.

Site 4 is located in SE ½, sec. 2, T. 162 N., R. 97 W. The available water content was 19.40 cm in 100 cm and 20.65 cm in 130 cm. Rolette durum wheat was planted with east-west row orientation on May 25, 1975, and at harvest, September 13, 1975, yielded 25 bushels per acre. No hail or insect damage was observed. No fertilizer was applied to this crop following summer fallow in 1974. This field did show salt influence on this crop.

In Burke County (Table 2), site 1 was selected to represent a loam texture. The soil had an available water content of 16.50 cm in 100 cm and 23.46 cm in 130 cm. It is located in NW ¼ sec. 32, T. 163 N., R. 88 W. Rolette durum wheat was planted with north-south row orientation, on May 27, 1975, and yielded 30 bushels per acre at harvest on September 13, 1975. The crop was uneffected by hail or insects and was unfertilized.

Site 2 was selected as a loam soil and had an available water content of 17.60 cm in 100 cm and 24.94 cm in 130 cm. The site is located in NE ¼ sec. 33, T. 103 H., R. 89 W. Rolette durum wheat was planted on June 2, 1975, and harvested on September 23, 1975. The rows were oriented east and west. 16-20-0 fertilizer was applied but the rate was unreported. No hail or insects damaged the field and the yield was 30 bushels per acre.

Site 3 was selected as sandier textured. The available water holding capacity was 11.89 cm in 100 cm and 15.82 in 130 cm. It is located in SE ¼ sec. 29, T. 163 N., R. 89 W. Chris hard red spring wheat was planted May 30, 1975, and harvested September 26, 1975. Rows were oriented east-west. The field was not fertilized and no damage was observed from hail or insects. The yield was reported at 30 bushels per acre.

Site 4 was selected as a salt affected loam textured soil. The available water capacity was 20.17 cm in 100 cm and 26.73 cm in 130 cm.

Waldron hard red spring wheat, east-west row orientation, was seeded on May 16, 1975, and harvested August 31, 1975. The field was fertilized at an undetermined rate with 18-28-0. The field was undamaged and yielded 20 bushels per acre.

The soils in the Williams County area were extremely uniform in texture and were not salty. Therefore, all four sites were selected as loam textured (Table 3). Site 1 was located in NE ¼ sec. 17, T. 150 N., R. 99 W. The available water holding capacity was 15.41 cm in 100 cm and 20.47 in 130 cm. The field was planted May 27, 1975, and harvested between September 9 and 15, 1975. Waldron hard red spring wheat was planted around the edge for 72 feet and Olaf semi-dwarf hard red spring wheat was planted in the center. Rows were North-South. The reason for this strange planting is unclear. The field was not fertilized and yielded 29 bushels per acre.

Site 2 was located in NE ¼ sec. 15, T. 156 N., R. 99 W. The available water holding capacity was 11.89 cm in 100 cm and 15.82 cm in 130 cm. The reason is the sandy loam texture from 60 to 130 cm. The planting date was May 22, 1975, and no fertilizer was applied. This field was planted the opposite of site 1, with Olaf around the edge and Waldron hard red spring wheat in the middle. Rows were east-west oriented. No hail or insect damage was observed and no yield was reported.

Site 3 was located in NW ¼ sec. 14, T. 150 N., R. 99 W. The available water holding capacity was 15.89 cm in 100 cm and 21.52 cm in 130 cm. The field was seed to Waldron hard red spring wheat with north-south rows on May 6, 1975, and was harvested between August 27 and September 3, 1975. No fertilizer was applied and no hail or insect damage was descernable. The yield was 25 bushels per acre.

Site 4 was located in NE ¼ sec. 13, T. 150 N., R. 99 W. The available water holding capacity was 15.54 cm in 100 cm and 20.87 cm in 130 cm.

Waldron hard red spring wheat was planted with east-west rows, on May 27, 1975, and harvested between September 3 and 9, 1975. The field was fertilized with 34-0-0 at a rate of 30 pounds per acre. No damage was observed and no yield was reported.

The moisture profiles are reported in tables 4, 5, and 6. All values are in volumetric percent by date and stage of growth.

The sites were reviewed by Dr. A. B. Park of Earth Satellite Corporation in August, 1975. During discussions at that time, it was felt desireable that future efforts be initated early enough to encompass the entire growing season. Access tubes should be placed no later than mid-May. In addition, it would seem adviseable to determine the fertility status of the sites. Such an inclusion would do much to complete the picture of yield.

LIST OF TABLES

Table 1. Properties of Sites in Divide County, North Dakota.

Site	Depth, cm	Site Fractions, %			USDA Text.	D_B, gm/cc	Water Content, %				cm in Layer	EC, mmhos	O.P. ATM.
		Sand	Silt	Clay			1/3 ATM.	15 ATM.	A.W.	Vol.			
1	0-10	28.05	60.69	11.26	SiCL	1.19	41.80	15.41	26.39	31.40	3.14	0.54	0.19
	10-25	26.31	60.67	13.02	SiL	1.22	32.62	15.38	17.24	21.03	3.15	0.33	0.12
	25-40	28.10	59.12	12.78	SiCL	1.31	29.52	13.18	16.34	21.40	3.21	0.38	0.14
	40-60	26.78	44.17	17.39	L	1.37	32.69	15.93	16.76	22.96	4.59	0.55	0.20
	60-100	26.19	55.94	17.87	SiL	1.38	31.59	15.95	15.64	21.58	8.63	0.52	0.19
	100-130	25.03	41.72	33.25	L	1.51	29.98	14.96	15.02	22.68	6.80	0.33	0.12
2	0-10	56.28	37.27	6.25	SL	1.31	18.14	8.41	9.73	12.75	1.27	0.19	0.07
	10-25	46.30	50.30	3.40	SiL	1.36	15.94	7.36	8.58	11.67	1.75	0.12	0.04
	25-40	47.13	43.06	9.21	L	1.33	19.28	9.52	9.76	11.09	1.66	0.17	0.06
	40-60	38.40	51.29	10.31	SiL	1.28	23.88	10.51	13.37	17.11	3.42	0.17	0.06
	60-100	33.21	51.17	15.62	SiL	1.35	23.60	10.94	12.66	17.09	6.84	0.26	0.09
	100-130	47.10	42.44	10.46	L	1.42	25.76	11.79	13.97	19.84	5.95	2.20	0.79
3	0-10	37.74	54.37	7.89	SiL	1.22	23.23	8.61	14.62	17.84	1.78	0.25	0.09
	10-25	35.14	49.60	15.26	L	1.27	23.44	11.50	11.99	15.23	2.28	0.33	0.12
	25-40	43.47	45.31	11.22	L	1.32	25.70	10.73	14.97	19.76	2.96	0.83	0.30
	40-60	38.68	58.76	2.56	SiL	1.34	26.03	11.51	14.52	19.46	3.89	3.40	1.22
	60-100	22.90	72.89	4.21	SiL	1.41	28.63	13.56	15.07	21.25	8.50	7.30	2.63
	100-130	22.94	70.59	6.47	SiL	1.43	29.13	16.19	12.94	18.50	5.55	9.60	3.46
4	0-10	31.26	60.85	7.89	SiL	1.30	21.41	8.78	12.63	16.42	1.64	0.43	0.15
	10-25	44.02	51.36	4.62	SiL	1.33	27.90	8.32	19.58	26.04	3.90	0.18	0.06
	25-40	50.11	46.29	3.60	L	1.39	30.54	7.06	23.48	32.64	4.89	0.15	0.05
	40-60	49.84	41.71	8.45	L	1.42	24.53	9.14	15.19	16.61	3.32	0.91	0.33
	60-100	24.60	7.88	3.52	L	1.58	22.78	13.84	8.94	14.12	5.65	7.00	2.52
	100-130	22.91	76.05	1.04	L	1.61	18.62	16.03	2.59	4.17	1.25	10.50	3.78

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

Table 2. Properties of Sites in Burke County, North Dakota.

Site	Depth, cm	Site Fractions, %			USDA Text.	D_B, gm/cc	Water Content, %				cm in Layer	EC, mmhos	O.P. ATM.
		Sand	Silt	Clay			1/3 ATM.	15 ATM.	A.W.	Vol.			
1	0-10	27.67	61.51	10.82	SiL	1.13	30.89	12.07	18.82	21.27	2.13	0.42	0.15
	10-25	29.31	61.11	9.58	SiL	1.17	24.50	12.68	11.82	13.83	2.07	0.18	0.06
	25-40	36.33	48.72	14.94	L	1.23	24.09	14.27	9.82	12.08	1.81	0.25	0.09
	25-60	41.01	46.29	12.70	L	1.31	21.56	10.01	11.55	15.13	3.03	2.40	0.86
	60-100	27.97	68.93	3.60	SiL	1.36	23.74	10.03	13.71	18.84	7.46	5.50	1.98
	100-130	20.26	73.09	6.65	SiL	1.41	28.18	11.73	16.45	23.19	6.96	6.20	2.23
2	0-10	36.46	53.32	10.22	SiL	1.18	24.65	12.07	12.58	14.84	1.48	0.40	0.14
	10-25	31.38	56.11	12.50	SiL	1.21	25.44	12.66	12.78	15.56	2.32	0.28	0.10
	25-40	23.29	58.88	17.83	SiL	1.23	25.31	12.14	13.17	16.20	2.43	2.30	0.83
	40-60	22.61	63.81	13.58	SiL	1.27	22.35	9.78	12.57	15.96	3.19	2.10	0.76
	60-100	21.73	67.01	11.26	SiL	1.36	28.30	13.26	15.04	20.45	8.18	0.74	0.27
	100-130	15.46	75.69	8.85	SiL	1.44	29.62	12.63	16.99	24.46	7.34	3.50	1.26
3	0-10	29.39	57.35	13.26	SiL	1.28	31.99	14.06	17.93	22.95	2.29	0.35	0.13
	10-25	33.98	55.52	10.50	SiL	1.31	23.22	10.04	13.18	17.26	2.59	0.12	0.04
	25-40	27.67	58.79	13.54	SiL	1.36	21.99	10.97	11.02	14.99	2.25	0.15	0.05
	40-60	23.40	60.42	16.18	SiL	1.33	25.36	13.17	12.19	16.21	3.24	0.16	0.06
	60-100	55.80	36.79	7.41	SL	1.37	18.10	7.76	10.34	14.16	5.67	0.45	0.16
	100-130	8.54	81.08	10.32	Si	1.42	23.02	9.95	13.07	18.56	5.57	1.14	0.41
4	0-10	31.98	53.68	14.34	SiL	1.16	29.47	13.56	15.91	18.45	1.84	3.60	1.30
	10-25	29.77	66.06	4.17	SiL	1.23	31.32	17.08	14.24	17.52	2.63	4.40	1.58
	25-40	27.65	67.10	5.25	SiL	1.25	29.09	14.00	15.09	18.86	2.83	5.00	1.80
	40-60	38.32	55.63	6.05	SiL	1.31	26.90	12.22	14.68	19.23	3.85	5.40	1.94
	60-100	22.85	72.58	4.57	SiL	1.34	28.42	11.59	16.83	22.55	9.02	4.90	1.76
	100-130	27.39	68.40	4.21	SiL	1.42	27.60	12.19	15.41	21.88	6.56	5.90	2.12

Table 3. Properties of Sites in Williams County, North Dakota

Site	Depth, cm	Site Fractions, %			USDA Text.	D_B, gm/cc	Water Content, %				cm in Layer	EC, mmhos	O.P. ATM.
		Sand	Silt	Clay			1/3 ATM.	15 ATM.	A.W.	Vol.			
1	0-10	34.06	53.72	12.22	SiL	1.27	25.75	18.28	12.47	15.84	1.58	0.70	0.25
	10-25	35.64	53.45	10.91	SiL	1.31	23.93	13.28	10.65	13.95	2.09	0.31	0.11
	25-40	33.95	53.00	13.05	SiL	1.28	23.91	15.88	8.03	10.28	1.54	0.37	0.13
	40-60	50.39	36.63	12.98	SiL	1.31	18.59	9.75	8.84	11.58	2.32	0.57	0.20
	60-100	29.00	48.68	22.32	L	1.51	25.78	12.74	13.04	19.69	7.88	0.52	0.19
	100-130	21.21	60.72	18.07	SiL	1.53	23.24	12.35	10.89	16.66	5.00	0.65	0.23
2	0-10	31.01	57.13	11.86	SiL	1.22	24.96	11.90	13.06	15.93	1.59	0.41	0.15
	10-25	31.36	57.10	11.54	SiL	1.23	22.84	11.45	13.39	16.47	2.47	0.23	0.08
	25-40	20.87	59.71	11.42	SiL	1.30	22.66	12.24	10.42	13.55	2.03	0.16	0.06
	40-60	31.80	54.30	13.90	SiL	1.39	22.72	12.27	10.45	14.52	2.90	0.31	0.11
	60-100	68.87	26.68	4.45	SL	1.27	12.04	6.34	5.70	7.24	2.90	0.24	0.09
	100-130	59.56	33.91	6.53	SL	1.40	17.51	8.16	9.35	13.09	3.93	0.31	0.11
3	0-10	41.28	47.02	11.70	L	1.25	22.45	12.38	10.07	12.59	1.26	0.32	0.11
	10-25	37.32	45.65	17.03	L	1.31	23.61	14.64	8.97	11.75	1.76	0.24	0.09
	25-40	32.32	46.97	20.71	L	1.33	22.39	12.78	9.61	12.78	1.92	0.20	0.07
	40-60	31.64	60.51	7.85	SiL	1.42	24.96	13.49	11.47	16.29	3.26	0.24	0.09
	60-100	32.80	61.63	5.57	SiL	1.47	25.69	12.61	13.08	19.23	7.69	0.23	0.08
	100-130	33.35	62.08	4.57	SiL	1.52	24.77	12.42	12.35	18.77	5.63	0.27	0.10
4	0-10	39.66	44.19	16.14	L	1.19	24.62	13.41	11.21	13.34	1.33	0.26	0.09
	10-25	34.81	44.12	21.07	L	1.23	26.63	13.64	12.99	15.98	2.40	0.20	0.07
	25-40	32.34	44.98	22.87	L	1.31	28.08	13.39	14.69	19.24	2.89	0.25	0.09
	40-60	27.98	50.66	21.35	SiL	1.27	25.95	13.84	12.11	15.38	3.07	0.24	0.09
	60-100	34.08	60.79	5.13	SiL	1.35	23.10	12.26	10.84	14.63	5.85	0.25	0.09
	100-130	32.77	51.24	15.98	SiL	1.48	24.17	12.16	12.01	17.77	5.33	0.31	0.11

Table 4. Moisture Profiles for Sites in Divide County, North Dakota

Date	Growth Stage	Site 1					
		Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-15	7	13.73	20.60	24.83	29.85	38.27	44.16
7-22	10	43.08	22.17	24.52	28.52	38.04	42.90
7-29	10.5.4	15.34	19.40	22.57	28.28	37.05	43.65
8-4	10.5.4	19.53	19.34	22.83	29.17	40.23	46.93
8-11	11.1	17.23	20.38	23.73	32.18	38.15	42.90
8-19	11.2	30.08	27.89	22.99	24.64	35.24	40.11
8-27	11.2	27.77	31.90	25.90	27.43	35.14	39.76
9-5	11.3	27.37	33.04	30.02	32.75	34.93	39.99
9-10	11.4	20.32	30.37	27.73	32.18	34.22	39.18
9-16	(Harvested)	24.56	30.28	28.76	33.62	35.76	39.18

Date	Growth Stage	Site 2					
		Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-15	10.5	8.41	18.43	19.53	21.38	28.04	20.34
7-22	10.5.4	15.93	19.07	19.47	20.34	26.39	20.17
7-29	11.1	14.49	18.34	18.78	19.61	24.96	20.38
8-4	11.2	11.61	18.32	18.85	19.32	24.58	20.60
8-11	11.3	12.98	19.82	21.88	27.66	24.71	38.61
8-19	11.4	17.49	23.97	21.74	19.30	24.83	20.95
9-4	(Harvested)	14.99	26.61	26.32	21.38	25.97	20.68
9-10	-	15.85	18.98	24.27	24.96	22.62	19.18
9-16	-	17.88	22.68	25.56	24.83	26.32	21.12

Table 4 (con't)

Date	Growth Stage	Site 3					
		Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-15	10	4.84	18.27	21.60	25.69	31.71	34.22
7-22	10.5.4	18.14	21.51	24.45	25.09	31.90	34.42
7-29	11.1	8.48	18.41	22.27	26.32	31.81	33.92
8-4	11.2	9.34	18.85	23.38	28.93	35.66	37.27
8-11	11.3	13.41	19.64	23.73	30.63	34.73	37.60
8-19	11.4	28.54	24.52	25.36	29.59	34.52	38.72
8-27	11.4	22.67	33.72	25.97	28.44	32.09	34.52
9-4	11.4	23.81	35.14	27.35	27.66	31.53	32.94
9-10	11.4	14.77	32.09	26.39	27.73	32.09	34.02
9-16	(Harvested)	19.93	30.81	27.05	27.97	32.75	34.52

Date	Growth Stage	Site 4					
		Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-15	10/3	9.04	17.12	18.36	25.83	42.77	42.77
7-22	10.5.4	16.21	18.36	19.03	25.56	43.27	41.30
7-29	10.5.4	12.86	15.25	18.33	23.44	41.30	37.71
8-4	11.1	8.74	18.12	18.37	28.85	45.07	38.49
8-11	11.1	12.84	18.20	18.36	27.12	42.52	35.03
8-19	11.2	27.57	19.27	18.32	24.77	38.38	32.87
8-27	11.3	24.58	24.52	19.15	26.39	39.99	32.27
9-5	11.4	22.33	28.20	24.27	23.67	39.99	33.62
9-10	11.4	18.29	25.09	20.07	29.42	37.82	33.92
9-16	(Harvested)	24.43	24.21	20.87	25.76	38.95	33.82

Table 5. Moisture Profiles for Sites in Burke County, North Dakota

		Site 1					
Date	Growing Stage	Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-300
7-14	10.5.2	9.01	18.36	18.87	23.44	29.68	37.60
7-22	10.5.4	17.56	18.93	18.93	20.20	29.17	36.94
7-29	11.1	10.82	18.85	19.45	20.42	29.26	38.49
8-5	11.1	11.23	19.25	19.32	23.38	33.33	46.26
8-11	11.2	19.42	23.67	20.34	22.12	30.19	41.30
8-19	11.3	27.47	23.85	21.08	22.89	31.81	42.40
8-27	11.3	21.83	23.05	20.45	22.57	29.51	40.82
9-4	11.4	25.66	30.45	26.32	24.27	29.85	40.82
9-10	11.4 (Swathed)	18.47	28.44	25.22	25.49	30.37	40.23
9-16	(Harvested)	20.77	26.54	25.42	24.71	29.59	39.18
9-27	-	27.94	31.90	30.28	30.54	33.23	45.33

		Site 2					
Date	Growing Stage	Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-14	8	11.04	19.97	23.22	24.33	30.90	42.28
7-22	10.5.2	22.63	21.20	24.45	24.33	32.46	38.83
7-29	10.5.3	13.68	18.82	22.42	23.05	30.72	39.06
8-5	11.1	11.09	20.42	22.27	24.21	31.53	42.77
8-11	11.1	21.73	23.91	23.79	23.79	30.81	41.18
8-19	11.2	27.34	27.12	23.44	23.56	29.76	39.64
8-27	11.2	20.25	23.33	22.89	22.89	29.09	37.49
9-4	11.4	21.89	26.76	25.29	23.61	28.04	37.49
9-10	11.4	16.68	23.44	24.09	23.11	28.04	35.45
9-16	11.4 (Swathed)	19.49	23.05	23.85	24.03	29.34	36.83
9-27	(Harvested)	19.98	25.16	26.18	26.61	31.08	41.66

Table 5 (con't)

Date	Growth Stage	Site 3					
		Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-14	6	11.96	18.36	20.56	29.76	30.02	40.34
7-22	10.3	22.67	19.32	21.38	30.11	28.60	40.82
7-29	10.5.3	15.49	18.29	19.88	27.73	26.61	37.93
8-5	10.5.4	15.46	18.41	21.60	27.58	25.69	40.58
8-11	11.1	22.69	19.82	21.88	27.66	24.71	38.61
8-19	11.1	31.45	21.29	22.57	27.89	25.16	40.70
8-27	11.2	26.65	20.42	20.72	25.49	23.38	37.60
9-4	11.2	26.20	25.56	22.07	26.25	23.22	34.32
9-10	11.4	20.28	21.97	24.83	24.83	22.62	35.34
9-16	11.4 (Swathed)	26.07	21.05	22.37	25.49	22.73	35.03
9-27	(Harvested)	29.66	29.26	31.08	29.26	24.03	34.02

Date	Growing Stage	Site 4					
		Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-14	10.5.2	13.26	26.39	32.09	32.18	35.66	42.90
7-22	10.5.4	21.45	24.15	30.90	29.85	34.12	41.30
7-29	11.1	17.87	22.17	30.54	29.09	33.52	39.52
8-5	11.2	17.38	29.76	31.17	31.99	37.71	44.94
8-11	11.3	23.05	29.59	31.08	29.42	33.23	39.29
8-19	11.4	29.34	34.02	30.54	30.81	34.73	40.58
8-27	11.4	25.02	33.52	29.34	28.76	33.13	38.72
9-4	(Harvested)	26.47	32.75	28.93	28.36	31.62	36.08
9-10	-	19.34	25.85	29.42	28.93	31.71	37.93
9-16	-	21.29	30.37	29.26	29.26	33.13	37.93
9-27	-	25.68	32.18	33.43	34.02	35.97	44.42

Table 6. Moisture Profiles for Sites in Williams County, North Dakota

Date	Growing Stage	Site 1					
		Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-15	10.2	8.85	18.24	18.46	18.38	28.04	30.11
7-22	10.5.2	11.32	18.27	18.37	18.35	25.03	27.81
7-29	11.1	8.81	18.22	18.34	18.27	21.46	27.73
8-4	11.1	15.91	18.40	18.35	18.33	26.47	30.02
8-11	11.2	16.47	18.75	18.33	18.28	23.79	26.83
8-19	11.2	11.90	18.42	18.35	18.32	24.77	28.12
8-27	11.3	19.51	18.82	18.32	18.28	23.27	26.32
9-3	11.4	22.91	29.51	24.96	22.73	25.76	26.83
9-9	11.4	15.91	26.76	24.03	21.08	25.97	27.89
9-15	(Harvested)	19.61	25.29	21.93	20.07	27.05	26.18

Date	Growing Stage	Site 2					
		Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-15	10.5	7.72	18.22	18.37	18.28	18.27	23.44
7-22	10.5.3	10.41	18.22	18.33	18.26	18.25	23.05
7-29	11.1	9.34	17.25	18.28	18.24	18.21	21.55
8-4	11.1	13.93	18.29	18.33	18.24	18.23	24.39
8-11	11.2	16.78	21.04	21.42	19.58	18.45	23.27
8-19	11.3	13.14	19.34	20.56	19.07	18.36	23.44
8-27	11.3	19.42	19.58	19.97	18.82	18.30	21.97
9-3	11.4	19.80	23.61	20.17	19.25	18.29	20.91
9-9	11.4	15.35	20.60	19.91	19.11	18.28	21.04
9-15	(Harvested)	17.47	20.04	20.07	18.61	18.30	22.89

Table 6 (con't)

Date	Growth Stage	Site 3					
		Depth, cm					
		0-10-	10-25	25-40	40-60	60-100	100-130
7-15	10.5	7.25	10.22	18.36	18.43	27.89	28.60
7-22	10.5.3	10.72	18.26	18.34	18.41	26.54	28.60
7-20	10.5.4	8.79	17.63	18.28	18.29	23.27	29.01
8-4	11.1	13.28	18.25	18.28	18.33	25.76	30.11
8-11	11.2	20.94	20.38	18.56	18.78	25.90	28.28
8-19	11.2	13.22	19.18	19.22	18.68	26.61	29.85
8-27	11.4	21.21	19.82	18.91	18.52	26.76	28.20
9-3	(Harvested)	24.66	23.97	19.76	18.51	26.11	28.12
9-9	-	15.72	21.74	20.45	18.60	26.47	28.36
9-15	-	17.28	20.95	20.01	18.05	26.32	29.76

Date	Growing Stage	Site 4					
		Depth, cm					
		0-10	10-25	25-40	40-60	60-100	100-130
7-15	10.5.2	5.03	18.25	18.43	18.41	24.90	25.04
7-22	10.5.3	7.85	18.20	18.35	19.45	24.45	24.64
7-29	11.1	6.79	15.12	18.24	18.98	24.33	25.36
8-4	11.1	9.02	18.20	18.31	20.24	24.96	27.12
8-11	11.2	11.90	18.66	18.40	20.17	23.61	27.35
8-19	11.2	9.65	18.36	18.50	21.55	24.21	26.68
8-27	11.3	16.83	21.29	18.46	20.01	23.50	24.83
9-3	11.4	14.91	25.36	20.07	19.73	23.33	25.69
9-9	(Harvested)	12.95	22.89	20.76	20.76	23.67	26.04
9-15	-	10.68	22.12	21.08	21.12	23.79	25.76

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SOIL MOISTURE MEASUREMENTS
FOR THE LACIE SPRING WHEAT SYSTEMS

FINAL REPORT TO EARTH SATELLITE CORPORATION
WASHINGTON, D. C.

BY
JOSEPH M. CAPRIO
PLANT AND SOIL SCIENCE DEPARTMENT

MONTANA AGRICULTURAL EXPERIMENT STATION
MONTANA STATE UNIVERSITY, BOZEMAN

OCTOBER 31, 1975

MONTANA STATE UNIVERSITY

FINAL REPORT
TO
EARTH SATELLITE CORPORATION

October 31, 1975

SOIL MOISTURE MEASUREMENTS FOR THE LACIE SPRING WHEAT SYSTEMS

Mr. Earl Merritt
Earth Satellite Corporation
Washington, D. C.

Dear Mr. Merritt:

We wish to submit this Final Report as per our contract agreement stated in your letter dated May 27, 1975 and your purchase order No. 75-2422. We believe this information was recorded and prepared in accordance with your directions and reflects a sound, scientific approach.

Sincerely yours,

Joseph M. Caprio

Joseph M. Caprio, Project Leader
Plant & Soil Science Dept.
Montana State University
Bozeman, Montana

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I. INTRODUCTION

This work was initiated under an agreement with Earth Satellite Corporation, Washington, D. C., which has contract commitments in connection with the Large Area Crop Inventory Experiment (LACIE). The terms of the agreement were outlined by Earl S. Merritt in his letter to Joseph M. Caprio dated May 27, 1975. The purchase order carries Earth Satellite Corporation identity No. 75-2422. The letter, purchase order, project statement and material on NASA disclosure provisions for earth resources data are presented in the Appendix.

Soil moisture measurements using the neutron probe method were to be made in spring wheat fields by the Plant and Soil Science Department, Montana State University, at about weekly intervals during the 1975 crop year in four specified experimental areas (dimensions 2 by 10 miles) located in Glacier, Hill, Liberty and Toole counties, in northern Montana. Several soil moisture observation sites were to be located in each of these four areas. The soils at experimental areas were to differ, within a given range, in water holding capacity and in osmotic potential. It was necessary to work with heavier soils having higher available water holding capacities than specified in the original plans since light (sandy) soils were generally unavailable in the four designated experimental areas of Montana. The neutron probe was to be the basis for determining soil moisture down to a depth of about four feet. This work was to contribute information for use in the Large Area Crop Inventory Experiment (LACIE) which is a cooperative program between National Aeronautics and Space Administration, United States Department of Agriculture and National Oceanographic and Atmospheric Administration to study the feasibility of conducting agricultural inventories using satellite data.

Field work did not begin until the last week in June when spring wheat was already in the tillering stage because of the late spring initiation date of the contract. Farm operations this year were several weeks later than normal in Montana due to a cold, wet spring and the harvest period was also late by several weeks. In all, ten spring wheat soil moisture sampling sites were established in the four counties, two each in Glacier and Liberty counties and three sites each in Hill and Toole counties. Table 1 gives the specific location of each site.

In view of the long distance to the sites from Bozeman and the two days of travel and work involved for each trip, it was desirable to include a relatively large number of individuals in the project so that no one would be required to work every weekend. Observations had to be made on weekends because neutron probes in the Plant and Soil Science Department were already committed to other projects during regular working days.

Early in the season it was necessary to send a team of two men to record neutron probe counts, make site location measurements, and to familiarize additional personnel with site locations and measurement procedures. Later in the season observations were sometimes made by only one technician.

A total of 13 observations were made between June 27-28, 1975 and September 27-28, 1975. The dates of observation were as follows:

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Table 1. Locations of the ten observation sites in Montana.

Site	County	Township	Range	Section	Distance and Direction in from Edge of Field
G-1	Glacier	33	8W	16 SE/SE	75'W
G-2	Glacier	33	8W	11 SW/SE	89'N
H-1	Hill	34N	13E	24 SE	71'E
H-2	Hill	34N	14E	18 SE	44'E
H-3	Hill	34N	14E	17 SW	74'E
L-1	Liberty	35	6E	35 NW/NW	71'S
L-2	Liberty	34	7E	6 NW/NW	46'N
T-1	Toole	36N	2W	16 SE/NW	61'E
T-2	Toole	36N	2W	10 SE/SW	55'N
T-3	Toole	36N	1W	11 SW/SW	37'N

Observation No.	Date	Observation No.	Date
1	June 27-28	8	Aug. 16-17
2	July 7	9	Aug. 23
3	July 12	10	Aug. 30-31
4	July 19	11	Sept. 6-9
5	July 26	12	Sept. 13-14
6	Aug. 2	13	Sept. 27-28
7.	Aug. 9		

The entire run from Bozeman and return required a motor vehicle trip averaging about 920 miles. Runs were usually made either from Friday afternoon through late Saturday or all day Saturday and part of Sunday.

Those involved in field work during the summer were:

Joseph M. Caprio (Professor and Agricultural Climatologist-Bozeman)

Harold A. R. Houlton (Assistant Soil Scientist-Northern Agricultural Research Center)

Charles M. Jones (Graduate Student)

Alfons G. Lazarewicz (Senior)

Douglas V. Lovely (Senior)

Paul R. Rebich (Senior)

Steve Klobofski (Technician)

Kim Kucera (Technician)

Computer processing of data was accomplished by Paul R. Rebich who is a senior at Montana State University majoring in Computer Science. Robert D. Snyder, who holds university degrees in statistics and computer science, did much of the laboratory work which included making photo-interpretative estimates of (1) phenological phases, (2) percent of ground covered with vegetation and (3) percent of crop which had lost its green color.

II. PROCEDURES OF FIELD INSTALLATION

A neutron access tube was installed at each of the ten sites at a reasonable distance from the edge of the field to minimize border effects. Holes were bored in the soil with a Giddings soil sampling machine mounted on a pickup truck. The 3.370 cm. diameter soil cores were laid horizontally on a platform and cut into soil sample segments corresponding to the following depths:

Centimeters	Feet	Centimeters	Feet
1-10	0-.33	40-70	1.31-2.30
10-25	.33-.82	70-100	2.30-3.28
25-40	.82-1.31	100-130	3.28-4.27

A 1-5/8 inch inside diameter steel conduit pipe of 5-foot length served as the neutron access tube. It was inserted in the hole with the top projecting about 6 inches above the soil surface. The bottom inch of each tube was cut in eight places and bend inward to prevent soil intrusion.

A v-shaped wedge about 1/4-inch deep was cut on two sides of the top of the neutron access tube for the purpose of positioning a 6-foot long camera stand. The camera stand recessed ~~1~~2-1/2 feet into the neutron access tube allowing same-frame photographs to be taken at a height of about 4 feet above the ground surface.

Soil core samples were taken to a depth of 130 cm. during the first run on June 27 and 28 and again during the last run on September 27 and 28. Some difficulties were encountered during the June run because of very wet soil conditions.

The soil samples were placed in bags, returned to Bozeman and oven dried at 60°C (140°F) for four days. Weight loss by oven drying was used to calculate water fraction by weight. The weight of oven-dried soil in each core was computed by subtracting tare bag weight (14.5g).

Caution was necessary when taking samples near the surface where the soil core tended to crumble and at greater depths where the soil tended to compact. Bulk density values used in this study were derived from smooth curves drawn by eye through the sequence of bulk density measurements made at each site on June 27-28 and September 27-28. Bulk densities for all sites and depths are given in Table 2.

There was some variation between sites in the height that the neutron access tubes projected above the soil surface which appeared to influence neutron counts at the 0-10 cm. depth. The heights of the top of the neutron access tubes above the soil surface were measured on the north and south sides of the tube during Observation No. 12 (September 13-14). The average of these two height measurements is given as follows:

Table 2. Bulk density of soil (grams/cm^3)*.

	Soil Depth (cm)					
	0-10	10-25	25-40	40-70	70-100	100-130
Site						
G-1	1.32	1.34	1.36	1.41	1.51	1.63
G-2	1.34	1.38	1.43	1.54	1.65	1.73
H-1	1.39	1.36	1.23	1.22	1.51	1.61
H-2	1.28	1.29	1.32	1.42	1.50	1.55
H-3	1.47	1.48	1.48	1.47	1.47	1.52
L-1	1.51	1.54	1.59	1.54	1.49	1.44
L-2	1.42	1.52	1.53	1.45	1.45	1.47
T-1	1.29	1.39	1.30	1.33	1.40	1.45
T-2	1.31	1.37	1.41	1.44	1.47	1.58
T-3	1.33	1.38	1.46	1.58	1.60	1.67

*Grams of oven-dried soil per cubic centimeter.

Site	Height (cm)
G-1	12.95
G-2	8.65
H-1	10.20
H-2	15.95
H-3	15.80
L-1	16.05
L-2	14.30
T-1	13.90 (estimated from photographs)
T-2	14.00
T-3	16.50

For each of the Observations 1 through 9, the average of the usual three neutron counts for each level at each site was computed. The lowest of these averages for each level at each site was selected from the nine observations. An average of these selected lowest values for a given level was computed and this average was divided by each site value to obtain a ratio. This same procedure was followed using median values of each of the sites. The two resulting ratios for each site (a low and a median) were added and these values were used in correlation against height of the tubes above the ground. These values are presented on page 29. Correlations, as described above, were determined for both Level 1 and Level 2. The results were as follows:

Level 1 (0-10 cm)	+ 0.6840	Significant at 5% level
Level 2 (10-25 cm)	+ 0.0107	Not significant

The correlations suggest that the different heights of the neutron access tubes were a factor in neutron counts for Level 1 but not for greater depths.

III. FIELD MEASUREMENTS

The neutron counter (scaler) time employed was 0.25 minutes (15 seconds). The background count was always made at each site before making counts in the soil. The neutron probe was placed on its wooden box container (set on edge) for all background readings except during Observation No. 6 (August 2) when the background was made with the instrument positioned on top of the neutron access tube at sites H-1, H-2, and H-3. The student observer indicated that this tube-top position gave about the same background readings as when the instrument was placed on top of the instrument box, but no other background readings were made in this way.

During the first observation (June 27-28) only two neutron counts were recorded. Three counts were actually made in the field during this first run but the count which deviated most from the others was erased from the record book. During the remainder of the season three neutron counts were recorded. Sometimes, when a neutron count was not in close agreement with the others, an additional count was made and the deviant value was not recorded.

The scalers and neutron moisture probes used in this work were all manufactured by Troxler Electronic Laboratories, Inc., Raleigh, North Carolina. The neutron moisture probe utilizes an Americium-Beryllium source. In regular use was scaler Model No. 2651 (Serial No. 932) and neutron moisture probe Model No. 1257 (Serial No. AM 191). The "regular" Troxler was not available for Observations No. 10 and No. 11. Alternate instruments used for Observations No. 10 and No. 11 were scaler Model No. 1651 (Serial No. 675) and another neutron moisture probe (Serial No. 317) of the same model as the regular probe. Conversion of counts was made based on readings of both neutron probe and scaler sets during Observation No. 13, except for the three Hill County sites where both instrument sets were read during Observation No. 12. The ratio of the counts made with each instrument set for background and for all six levels at each site served as multiplicative factors to adjust readings of Observations No. 10 and No. 11 to the regular neutron probe and scaler. Thus, a different multiplicative correction factor was applied for each of the six levels at each of the ten sites for conversion of counts for Observations No. 10 and No. 11.

The heights of five randomly selected plants were measured in the field to the nearest centimeter. Plant heights were recorded by measuring plants held in a vertical position, except during Observation No. 2 (July 7) when the observer measured the height of the plants as they stood in the field. Plant heights are presented in Table 3.

The soils across the area are generally of glacial till origin and they tend to be quite heavy. Soils at both Glacier County sites have been classified as Fairfield gravely loam. Detailed soil surveys for Hill, Liberty and Toole counties have not been made. However, Telstad-Phillips clay loam is common in the Hill County area, Telstad clay loam and Joplin clay loam in the Liberty County area, and Joplin clay loam and Sprole sandy loam in the Toole County area.

Table 3. Height of spring wheat plants (cm).

		Site									
Ob. No.	Date	G1	G2	H1	H2	H3	L1	L2	T1	T2	T3
1	6/27-28	22	19	30	25	34	26	28	19	16	17
2	7/7	--	--	30	33	48	25	41	--	--	--
3	7/12	35	39	56	60	82	40	57	45	32	29
4	7/19	58	42	84	78	99	54	73	36	32	40
5	7/26	70	75	84	78	98	54	76	80	61	52
6	8/2	66	74	84	81	99	54	74	76	65	77
7	8/9	68	73	74	82	99	51	77	78	70	75
8	8/16-17	68	77	82	82	102	66	78	78	76	83
9	8/23	72	72	--	--	--	65	77	76	77	80
10	8/30-31	68	79	79	79	99	55	71	77	73	75
11	9/6-9	64	71	--	--	--	62	--	77	68	74
12	9/13-14	59	--	--	--	--	48	--	--	69	71
13	9/27-28	--	--	--	--	--	--	--	--	--	78

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Photographs were taken with a Minolta 7s Hi-matic camera using 35 mm colored Ektachrome ASA 64 film. The 6-foot long camera stand recessed 1-1/2 feet into the neutron access tube and was positioned into a north facing direction by two one-quarter inch v-shaped notches cut into the top of the tube. Thus, the camera was set at a height of four feet above the surface of the ground. Pictures were taken toward the north in a horizontal position (at infinity setting) and at an angle of 30 degrees down from the horizontal (at 10-foot setting). The latter position provided a ground center point in the wheat about seven feet away from the base of the camera stand.

Observations No. 2 (July 7) and No. 9 (August 23) were not completed due to onset of heavy rains. Travel to northern Montana for Observations No. 2 (July 7) and No. 6 (August 2) was accomplished with a Cessna 172 airplane, the first flight landing at Chester and the second flight landing at Havre. Charles M. Jones (graduate student) piloted the plane. In each of these cases motor vehicles were available at or near the airports to make the run from there. The Soil Conservation Service provided the vehicle at Chester and the Northern Agricultural Research Center provided the vehicle at Havre. Observation No. 12 (September 13) was not made at Site T-1 because the top of the neutron access tube had been bent inward by farm implements during the harvest. During Observation No. 7 (August 7) grasshoppers were logged as "rather abundant" on Sites H-1, H-2 and T-2. From 25 to 30 grasshoppers per square yard were counted during Observation No. 10 (August 31) at Sites H-1, H-2 and H-3 and 12 per square yard at T-2.

Most of the fields were harvested by combine, but for at least one of the sites (T-2) the wheat was first windrowed in the field with a swather to permit drying of the late maturing grain.

Information on crops and soils at the 10 observation sites are presented in Table 4. Phenological phases of spring wheat using the Feekes Scale were estimated for each observation and these are presented in Table 5. Estimates of percent of ground surface covered with green vegetation are given in Table 6.

Information was not solicited from farmers on the amount of fertilizer they had applied to the fields. However, it is likely that the stand at Site G-1 was thin because very little, if any, fertilizer had been applied this year. Generally, some of the differences in yields between sites are due to management practices.

Table 4. Information on crops and soils at the ten observation sites in Montana*.

Site	Planting Date	Harvest Date	Yield BU/A	Available Water Capacity (0-100 cm) MM	Osmotic Water (0-100 cm) MM
G-1	May 10	Sept. 28	22	165	2
G-2	May 30	Sept. 22	20**	154	2
H-1	May 21	Sept. 1	22	204	16
H-2	May 15	Aug. 29	28	178	9
H-3	May 16	Aug. 29	30	229	4
L-1	May 20	Sept. 22	31***	133	56
L-2	May 14	Sept. 5	35	157	18
T-1	May 21	Sept. 21	32	156	16
T-2	May 31	Oct. 2	38	205	4
T-3	May 30	Oct. 31	30	239	9

* The spring wheat variety, Fortuna, was grown at all sites

** This may be too low

*** This applies for the entire large field. Yield at observation site was probably much lower because it was within 80 feet of the edge of a saline seep

Table 5. Spring wheat phases (Feekes Scale) and percent of crop which has lost its green color.

	Site									
Date	G-1	G-2	H-1	H-2	H-3	L-1	L-2	T-1	T-2	T-3
6/27-28	5-6	4-5	5-6	5	5-6	5-6	5-6	4-5	3-4	3-4
7/7	M	M	6-7	6-7	6-7	6-7	6-7	M	M	M
7/12	8-10	7-8	10-10.1	10-10.1	10-10.1	10-10.1	10.1-10.5	6-8	4-6	4-6
7/19	10.5-11	8-9	10.5-11	10.5-11	10.5-11	10.1-10.5	10.1-11	10.1-10.5	8-10	8-10
7/26	11 (35%)	10.5-11	11 (25%)	M	11 (0%)	10.1-11	10.5-11	11 (5%)	10.1-10.5	10.1-10.
8/2	11 (40%)	11 (15%)	11 (35%)	11 (35%)	11 (5%)	11 (40%)	11 (40%)	11 (5%)	11 (0%)	11 (0%)
8/9	11 (70%)	11 (15%)	M	M	M	M	M	M	M	M
8/16-17	11 (95%)	11 (40%)	11 (90%)	11 (95%)	11 (55%)	11 (95%)	11 (95%)	11 (40%)	11 (15%)	11 (10%)
8/23	11 (99%)	11 (65%)	M	M	M	11 (99%)	11 (99%)	11 (50%)	11 (25%)	11 (20%)
8/30-31	11 (100%)	11 (90%)	11 (100%)	H	11 (100%)	11 (100%)	11 (100%)	11 (85%)	11 (65%)	11 (50%)
9/6-7	11 (100%)	11 (99%)	H	H	H	11 (100%)	H	11 (95%)	11 (80%)	11 (60%)
9/13-14	11 (100%)	H	H	H	H	11 (100%)	H	M	11 (95%)	11 (90%)
9/27-28	H	H	H	H	H	H	H	H	H	11 (99%)

H = harvested
M = missing

Table 6. Percent of ground covered with green vegetation.

Ob. No.	Date	G-1	G-2	H-1	H-2	H-3	L-1	L-3	T-1	T-2	T-3
1	7/27-28	30	25	40	30	45	45	45	20	15	20
2	7/7	M	M	80	55	80	50	75	M	M	M
3	7/12	50	55	85	75	85	65	80	60	30	40
4	7/19	55	65	85	85	90	70	80	85	55	70
5	7/26	45	65	65	M	90	60	80	80	65	70
6	8/2	35	60	55	60	90	45	60	80	75	70
7	8/9	20	50	M	M	M	M	M	M	M	M
8	8/16-17	5	40	15	5	45	5	5	55	55	55
9	8/23	T	20	M	M	M	T	5	30	45	50
10	8/30-31	T	10	0	T	T	0	5	20	35	45
11	9/6-9	T	5	0	T	T	0	5	15	30	40
12	9/13-14	T	5	0	0	T	0	M	M	15	15
13	9/27-28	T	T	0	0	0	0	5	T	T	T

T = less than 5 percent

M = missing

IV. LABORATORY TESTS

Laboratory tests were conducted to determine water fraction (weight of water/weight of oven-dried soil) at 0.3 and 15 atmospheres using the pressure plate extractor. These were converted to water fraction by volume (multiplication by soil bulk density). Table 7 and Table 8 lists the amount of moisture held in the soil at 0.3 and 15 atmospheres, respectively.

Soil moisture at 15 atmospheres was assumed to be the threshold of water availability for plants. The difference between water fraction by volume at 0.3 and 15 atmospheres was assumed to be the crop available moisture capacity for each cubic centimeter of soil exclusive of the moisture made unavailable by soil salinity. This information is presented in Table 9.

In order to determine the amount of soil moisture made unavailable by the salt content of the soil (osmotic potential), electrical conductivity tests were performed in the laboratory on 2:1 water-soil extracts by weight and these values were converted to values for saturated solution extracts. Electrical conductivity determinations were not made for samples at Levels 1 and 6. Values for electrical conductivity at Levels 2 and 5 were considered applicable for Levels 1 and 6, respectively. The results, given in Table 10, are expressed in millimhos per centimeter at 25°C. The relation between osmotic potential in atmospheres (Y) and electrical conductivity (X) was computed by the following equation:

$$Y = .3600\ X \quad \text{(See reference below)}$$

Atmospheres of osmotic pressure computed in this way are presented in Table 11.

Saline and Alkali Soils. Agricultural Handbook No. 60, (Chapter 2), United States Department of Agriculture. Edited by L. A. Richards, February 1954.

Table 7. Amount of water held in soil at 0.3 atmospheres (cm^3 water/cm^3 soil).

	Soil Depth (cm)					
Site	0-10	10-25	25-40	40-70	70-100	100-130
G-1	.2243	.2277	.3748	.2632	.3589	.3875
G-2	.2344	.2414	.2813	.3442	.3435	.3602
H-1	.2959	.2895	.4526	.2951	.4320	.4606
H-2	.3325	.3351	.4536	.4040	.4056	.4191
H-3	.3699	.3724	.6040	.4666	.4811	.4975
L-1	.3751	.3825	.4562	.4689	.3896	.3766
L-2	.3712	.3973	.4237	.4697	.4157	.4214
T-1	.3607	.3886	.4011	.3407	.3602	.3731
T-2	.2923	.3056	.2988	.3132	.4307	.4629
T-3	.3486	.3617	.4704	.4024	.4530	.4728

Table 8. Amount of water held in soil at 15 atmospheres (cm^3 water/cm^3 soil).

	Soil Depth (cm)					
	0-10	10-25	25-40	40-70	70-100	100-130
Site						
G-1	.1588	.1612	.1484	.1197	.1201	.1296
G-2	.1725	.1776	.1472	.1392	.1492	.1564
H-1	.1653	.1617	.1336	.1137	.1475	.1573
H-2	.2095	.2112	.2430	.1962	.1986	.2052
H-3	.2061	.2075	.2393	.2284	.2596	.2684
L-1	.2108	.2150	.2366	.2472	.2301	.2223
L-2	.2485	.2660	.2479	.2438	.2538	.2573
T-1	.2265	.2441	.2196	.1424	.1918	.1987
T-2	.1610	.1684	.1279	.1234	.1230	.1323
T-3	.1758	.1824	.1501	.1563	.1792	.1870

Table 9. Amount of soil moisture available to plants between 0.3 and 15 atmospheres assuming no soil salinity (cm^3 water/cm^3 soil).

	Soil Depth (cm)					
Site	0-10	10-25	25-40	40-70	70-100	100-130
G-1	.0655	.0665	.2264	.1435	.2388	.2579
G-2	.0619	.0638	.1341	.2050	.1943	.2038
H-1	.1306	.1278	.3190	.1814	.2845	.3033
H-2	.1230	.1239	.2106	.2078	.2070	.2139
H-3	.1638	.1649	.3647	.2382	.2215	.2291
L-1	.1643	.1675	.2196	.2217	.1595	.1543
L-2	.1227	.1313	.1758	.2259	.1619	.1641
T-1	.1342	.1445	.1815	.1983	.1684	.1744
T-2	.1313	.1372	.1709	.1898	.3077	.3306
T-3	.1728	.1793	.3203	.2461	.2738	.2858

Table 10. Electrical conductivity of soil (millimhos/centimeter)[1,2]

	Soil Depth (cm)					
	0-10	10-25	25-40	40-70	70-100	100-130
Site						
G-1	.4	(.45)	.5	(.50)	.5	(.5)
G-2	.5	(.45)	.4	(.45)	.5	(.5)
H-1	.4	1.4	.8	.6	6.7	11.2
H-2	1.0	1.8	.8	1.3	6.1	12.7
H-3	1.0	(.85)	.7	(.8)	.9	(.9)
L-1	2.0	3.7	.6	1.0	.6	.7
L-2	.5	.7	1.0	.7	12.7	15.1
T-1	1.3	1.0	1.0	4.0	7.6	8.2
T-2	1.2	(.85)	.5	(.65)	.8	(.8)
T-3	.6	(.60)	.6	(.60)	.6	(.6)

1. Values are conversion to saturated paste extracts based on 2:1 water-soil extracts (from previously correlated values).

2. Values in parentheses are interpolated from adjacent depths.

Table 11. Soil salinity expressed as atmospheres of osmotic pressure*.

	Soil Depth (cm)					
	0-10	10-25	25-40	40-70	70-100	100-130
Site						
G-1	0.1	0.2	0.2	0.2	0.2	0.2
G-2	0.2	0.2	0.1	0.2	0.2	0.2
H-1	0.1	0.5	0.3	0.2	2.4	4.0
H-2	0.4	0.6	0.3	0.5	2.2	4.6
H-3	0.4	0.3	0.3	0.3	0.3	0.3
L-1	0.3	0.6	1.7	5.3	8.2	9.4
L-2	0.2	0.3	0.4	0.3	4.6	5.4
T-1	0.5	0.4	0.4	1.4	2.7	3.0
T-2	0.4	0.3	0.2	0.2	0.3	0.3
T-3	0.2	0.2	0.2	0.2	0.2	0.2

*Computed by multiplying electrical conductivity in millimhos per centimeter by the value 0.36. For reference see "Saline and Alkali Soil", Agricultural Handbook No. 60 U.S.D.A.

Water content per atmosphere for the 14.7 atmospheres range (0.3 to 15 atmospheres) was computed using the laboratory test data given in Tables 7 and 8. After determining water content per atmosphere, it was possible to estimate the amount of soil moisture made unavailable to the plant by any given number of atmospheres of osmotic pressure. Some laboratory tests of water content at 0.3 atmospheric pressure which appeared to be unusually high were repeated, and in all cases the repeated tests corresponded closely with the originals. For the following sites and depths (in parentheses), the average of two laboratory tests were utilized in the computations: G-2 (70-100); G-3 (25-40); H-1 (25-40); H-2 (70-100); H-3 (25-40); T-2 (70-100); T-3 (25-40). The amount of soil moisture estimated to be unavailable to plants because of soil salinity is given in Table 12. These amounts were subtracted from values given in Table 9 to compute crop available soil moisture capacity per cubic centimeter given in Table 13 and per core length given in Table 14.

Soil pH was not needed for these analyses, but it was determined in the laboratory utilizing 2:1 water-soil extracts by weight and the information is presented in Table 15.

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Table 12. Amount of soil moisture unavailable to plants because of soil salinity (cm^3 water/cm^3 soil).

	Soil Depth (cm)					
Site	0-10	10-25	25-40	40-70	70-100	100-130
G-1	.0004	.0009	.0031	.0019	.0033	.0035
G-2	.0008	.0009	.0009	.0028	.0017	.0018
H-1	.0009	.0044	.0061	.0025	.0464	.0824
H-2	.0033	.0050	.0043	.0071	.0168	.0364
H-3	.0045	.0034	.0067	.0049	.0045	.0047
L-1	.0034	.0068	.0254	.0800	.0892	.0988
L-2	.0017	.0027	.0048	.0046	.0507	.0603
T-1	.0046	.0039	.0049	.0188	.0310	.0357
T-2	.0036	.0028	.0023	.0026	.0065	.0070
T-3	.0023	.0024	.0043	.0034	.0039	.0039

Table 13. Crop available soil moisture capacity taking into account effect of soil salinity (cm^3 water/cm^3 soil).

	Depth (cm)					
	0-10	10-25	25-40	40-70	70-100	100-130
Site						
G-1	.0651	.0656	.2233	.1416	.2355	.2544
G-2	.0611	.0629	.1332	.2022	.1926	.2020
H-1	.1297	.1234	.3129	.1789	.2381	.2209
H-2	.1197	.1189	.2063	.2007	.1902	.1775
H-3	.1593	.1615	.3580	.2333	.2170	.2244
L-1	.1609	.1607	.1942	.1417	.0703	.0555
L-2	.1210	.1286	.1710	.2213	.1112	.1038
T-1	.1296	.1406	.1766	.1795	.1374	.1387
T-2	.1277	.1344	.1686	.1872	.3012	.3236
T-3	.1705	.1769	.3160	.2427	.2699	.2819

Table 14. Crop available soil moisture capacity taking into account effect of soil salinity (cm^3 water/core length).

	Depth (cm)						Sum
Site	0-10	10-25	25-40	40-70	70-100	100-130	0-100
G-1	.6510	.9840	3.3495	4.2480	7.0650	7.6320	16.2975
G-2	.6110	.9435	1.9980	6.0660	5.7780	6.0600	15.3965
H-1	1.2970	1.8510	4.6935	5.3670	7.1430	6.6270	20.3515
H-2	1.1970	1.7835	3.0945	6.0210	5.7060	5.3250	17.8020
H-3	1.5930	2.4225	5.3700	6.9900	6.5100	6.7320	22.8855
L-1	1.6090	2.4105	2.9130	4.2510	2.1090	1.6650	13.2925
L-2	1.2100	1.9290	2.5650	6.6390	3.3360	3.1140	15.6790
T-1	1.2960	2.1090	2.6490	5.3850	4.1220	4.1610	15.5610
T-2	1.2770	2.0160	2.5290	5.6160	9.0360	9.7080	20.4740
T-3	1.7050	2.6535	4.7400	7.2810	8.0970	8.4570	24.4765

Table 15. Soil pH by laboratory determinations*.

	Soil Depth (cm)					
	0-10	10-25	25-40	40-70	70-100	100-130
Site						
G-1	7.4	---	7.9	---	8.2	---
G-2	7.3	---	8.1	---	8.5	---
H-1	8.1	8.2	8.3	8.5	8.2	8.4
H-2	7.8	7.9	8.5	9.0	8.4	8.2
H-3	8.0	---	8.4	---	8.7	---
L-1	8.6	8.2	8.9	8.5	8.6	8.4
L-2	8.3	8.2	8.7	8.2	8.4	8.3
T-1	8.3	8.2	8.4	7.9	8.2	8.4
T-2	8.3	---	8.5	---	9.0	---
T-3	8.3	---	8.4	---	8.8	---

*Extracts of 2:1 water-soil ratio by weight were used.

V. DATA PROCESSING AND COMPUTER OUTPUT FORMS

Level 1

The average relation between water fraction by volume (Y), expressed as cm^3/cm^3 , and neutron count ratio (X) for this level was determined as $Y_1 = 1.638 X$.

These results were then adjusted by a factor which partially relates to the small differences in height that neutron access tubes projected above the soil surface. These multiplicative factors were derived as previously explained on page 9. The following factors were applied for each site:

Site	Factor	Site	Factor
G-1	1.5833	L-1	1.2625
G-2	.7341	L-2	.9280
H-1	.6306	T-1	1.0639
H-2	1.2338	T-2	.9437
H-3	1.6215	T-3	1.3591

Level 2

The same method that was employed for Levels 3 to 6, described in the following paragraph, was used for Level 2 except the results were multiplied by the factor, 1.222.

It appears that this factor relates to the proximity of the neutron probes to the surface when making Level 2 readings. Field test data indicate that multiplication by this factor is necessary to make Level 2 readings comparable with readings from Levels 3 through 6. The mathematical equation is

$$Y_2 = 1.222 (+ .5237X - .0300)$$

Levels 3 to 6

The following calibration equation (provided with this instrument by Troxler Company) was employed to estimate soil moisture at Levels 3 through 6.

$$Y_{(3-6)} = + .5237X - .0300$$

Field data made this year, under unusually moist conditions for Montana, indicate that the actual amount of water in the soil may tend to be somewhat less than indicated by the Troxler calibration curve. However, since spring wheat is known to extract water from the soil down to near 30 atmospheres (rather than the 15 atmospheres assumed in our computations), the difference would tend to be compensated for in estimates of crop available moisture by the additional water available between 15 and 30 atmospheres.

The additional products of this study are presented (attached) in four computer output forms. Some of the information included on each of the forms is indicated below.

Form 1

A. Individual neutron counts

B. Averages of neutron counts

C. Standard deviation of neutron counts

Form 2

A. Average of neutron counts at each depth

B. Average of neutron counts for background

C. Ratio A/B

D. Milliliters of water per cm^3 of soil

Form 3

A. Grams of soil per cm^3 of soil (bulk density)

B. Milliliters of water trapped by soil per cm^3 of soil

C. Milliliters of water trapped by salt (osmotic pressure) per cm^3 of soil

D. Milliliters of water unavailable per cm^3 of soil

Form 4

A. Milliliters of water (total) per cm^3 of soil

B. Milliliters of water unavailable per cm^3 of soil

C. Milliliters of water available per cm^3 of soil

VI. REMOVAL OF FIELD EQUIPMENT AND TERMINATION

Cooperating farmers were informed by letter that the tubes would be removed from their fields by October 31, at the latest, and to therefore take precautions to circumnavigate the structures during harvest.

All neutron access tubes and field markers were removed from the spring wheat fields during the last run on September 27 and 28.

This was a very late year for crop development. Since the harvest period continued until the last week of October, it was necessary to request an extension of the termination date of the project from October 1 to November 1.

VII. APPENDIX

EARTH SATELLITE CORPORATION

Ref: C-1052

May 27, 1975

Dr. Joseph M. Caprio
Plant and Soil Science Dept.
Montana State University
Bozeman, Montana 59715

Dear Dr. Caprio:

This letter will confirm my recent phone calls regarding a potential soil moisture data gathering subcontract in support of our "Spring Wheat Yield System" test during the 1975 crop year.

Our requirements for the subcontract includes the following:

(1) Neutron probe soil moisture profile measurements in,
  (a) Three soil categories
    I. Fine Textured Loam
      >150 mm Field Crop Available
    II. Course Texture Sandy Loam
      100-150 mm Field Crop Available
    III. Saline Mixtures with less than 100 mm water available to plant
  (b) Depth SFC - 10 cm, 10-40 cm, 40 cm-1M
  (c) Timing weekly or at:

Emergence	Soft dough
Jointing	Ripe
Heading	Harvest

(2) Locations desired for the measurements (select those sites specific to your state)

State	County	Center	Coord.
Montana	Hill	48° 42.0'	109° 55.0'
Montana	Glacier	48° 37.5'	112° 33.4'
Montana	Liberty	48° 44.0'	110° 51.0'
Montana	Toole	48° 53.0'	111° 46.5'
North Dakota	Burke	48° 53.2'	102° 10.0'
North Dakota	Divide	48° 53.6'	103° 10.9'
North Dakota	Williams	48° 19.2'	103° 24.7'
South Dakota	Hand	48° 35.0'	98° 58.0'
South Dakota	Hand	44° 21.0'	98° 45.7'
Minnesota	W. Polk	47° 49'	96° 41'

I have already received responses to these questions from certain of the listed states. I certainly appreciate your response. I do require a written quotation in as short a time as possible.

I expect that I will receive word from NASA on a go-ahead for you by 1 June. I will call if there is any change in this schedule.

Thank you for your assistance. I am looking forward to meeting with each of you during the coming summer.

Sincerely,

Earl S. Merritt
Director
Food Resources Group

Title: Soil Moisture and Spring Wheat Phenology in Glacier, Hill, Liberty and Toole Counties of Montana (LACIE PROJECT).

Objectives:

1. To install equipment at four test sites in northern Montana for use in evaluating concurrent conditions of soil moisture and spring wheat phenology.
2. To make soil moisture measurements and spring wheat phenological observations in target sites situated in Glacier, Hill, Liberty and Toole counties.
3. To process, analyze and disseminate the data for possible use in research, extension, and education.

Justification:

In order to evaluate wheat-environmental relations in the "Spring Wheat Yield System" (a component of the LACIE PROJECT) it will be necessary for the Earth Satellite Corporation to obtain data on spring wheat phenology and concurrent soil moisture conditions in four test sites located in Glacier, Hill, Liberty and Toole counties of Montana. It is essential that soil moisture determinations be made by the neutron method and that local personnel and equipment be used to make the intergrated soil moisture and phenological measurements. Both the equipment and the expertise in the Plant and Soil Science Department at Montana State University will be used to achieve these objectives.

Procedure:

The following is an outline of the soil moisture measurements which will be made at approximately weekly (7-day) intervals throughout the spring wheat growing season:

(1) Neutron probe soil moisture profile measurements in,

(a) Three soil categories

I. Fine Textured Loam
\> 150 mm Field Crop Available

II. Course Texture Sandy Loam
100-150 mm Field Crop Available

III. Saline Mixtures with less than 100 mm water available to plant

(b) Depth SFC - 10 cm, 10-40 cm, 40 cm-1M

(c) Timing weekly or at:

Emergence
Jointing
Heading
Soft Dough
Ripe
Harvest

(2) Locations desired for the measurements

State	County	Center	Coordinates
Montana	Hill	48° 42.0'	109° 55.0'
Montana	Glacier	48° 37.5'	112° 33.4'
Montana	Liberty	48° 44.0'	110° 51.0'
Montana	Toole	48° 53.0'	111° 46.5'

These measurements will be made at intervals of approximately one week from the onset of the program until the spring wheat is harvested in the autumn of 1975. Concurrent observations on wheat phenology will also be made. This data will be submitted to Earth Satellite Corporation and will also be available for use by students and faculty at Montana State University for research, extension and education.