ANNUAL REPORT OF HAIL STUDIES

BY

NEIL G, TOWERY AND RAND I OLSON

Report of Research Conducted

15 May 1976 - 14 May 1977

For

The Country Companies

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INTRODUCTION

In 1974, the Illinois State Water Survey began a research project for the Country Companies related to remote sensing of crop-hail damage. The results of the research in the May 1974 - Hay 1976 period are contained in two previous annual reports (Towery, et. al. 1976; Towery, et. al. 1975). The primary objective of developing a technique to quantify field losses based on aerial photography could not be fulfilled for several reasons. A secondary objective of developing methods by which adjusters could use aerial photography to improve their procedures was much more successful. As a result, the Country Companies formed an Aerial Survey Department to photograph areas of severe crop damage.

A computer mapping program was developed as part of the primary objective (quantifying field losses). The mapping program was necessary to determine areas of damage, field average, and final adjustment figures. The mapping program was used to perform some initial evaluation of the most optimum sample size and sampling method necessary to obtain a reasonably accurate assessment of field loss. The ability to use the mapping program to obtain field loss based on adjuster values and to evaluate optimum sampling procedures formed the basis of the 1976-1977 research.

RESEARCH OBJECTIVES

The objective of the May 15, 1976 - May 14, 1977 research was to develop a computer mapping system suitable for mapping crop-hail losses within a field based on loss assessments of an adjuster. The development of this system included: 1) testing of the number of assessments necessary from a field to obtain an accurate field loss; 2) adapting the program to map irregular shaped fields and, 3) comparisons of field losses obtained from several different sampling methods. The basic question to be answered was: "What is the best way to obtain an accurate field loss?".

COMPUTER MAPPING

The computer mapping routine used in this research is based upon a multiquadric equation in which a series of cones are mathematically fitted to the map surface. In using the multiquadric equation and input data (adjuster loss assessment values) points a value for each cell in the map is obtained through interpolation. In other words, the map produced represents an exact fit of the input and interpolated values. Once a value has been established mathematically, it is converted to a symbol to be displayed visually. Conversion of the values to symbols is based upon the classification scheme desired, e.g. 5 or 10% class intervals in which each class has its own symbol: 10 symbols for 10% classes or 20 symbols for 5% classes.

Calculation of the area occupied by each class is accomplished by summing the number of map symbols that fall into the class. The frequency obtained represents a percentage of the area of the entire map and is determined from the length, width, and scale variables entered.

Calculation of the average damage or loss is accomplished by summing all values of damage determined at each map point by the multiquadric equation and then dividing by the total number of map points. It is thus a true weighted mean value. For example, consider a map that is 12 inches wide and 10 inches long. The number of map values that would go into the mean would be 7200:

12 x 10 = 120 [computer prints 10 cols/inch for the width]

x

10 x 6 = 60 [computer prints 6 cols/inch for the length]

120 x 60 = 7200

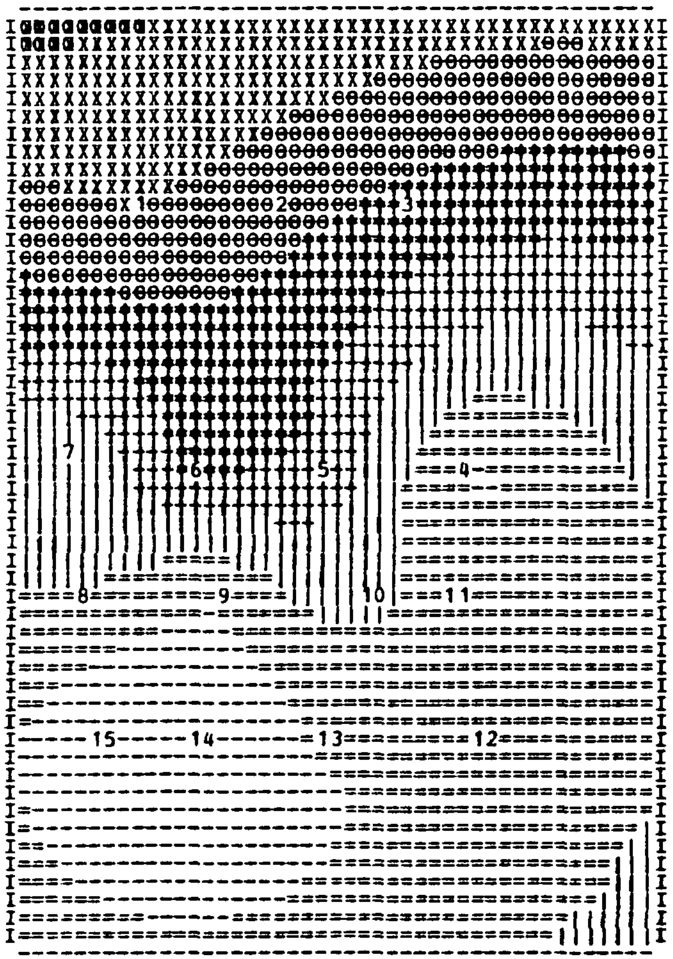
The mean field loss is therefore based on many loss values and a pattern of the damage is visually displayed. A sample map is shown in Figure 1.

DATA

The data used as the basis of this research were fields from which loss assessments had been obtained over the past three years. There were a total of 219 fields from which loss assessments had been obtained. However, only 72 fields met the criteria designed for this study. Those criteria were as follows: 1) the field had to be larger than 10 acres; 2) more than eight assessments had to be taken for each field, 3) the field had to be of a rectangular shape, 4) the average loss of yield for the field had to be greater than 5%, and 5) the loss assessments obtained by the adjusters had to be well distributed throughout the field. Twenty-five additional fields were slightly modified to meet the above criteria. This modification consisted of removing ends of fields to obtain an even areal distribution of adjuster assessments or to make the field rectangular (the original mapping routine was designed to handle only rectangular shaped fields). These modifications were generally

FIELD MAPPING OF CHARLESTON HAIL STORM -- JULY 17,1975

FIELD:	C09
PHOTO:	7-018
ALTIMETER:	3000
FILM TYPE:	MS
SCALE:	1"= 530.1
CROP:	CORN
CROP STAGE:	TASS
NO OBS:	15
XMIN:	0.0
XMAX:	2.50
YMIN:	0.0
YMAX:	3.60



SYMBOL	CLASS (% DAMAGE)	FREQUENCY (%)	AREA (ACRES)
	0- 10	0.0	0.0
---	10- 20	12.22	7.10
===	20- 30	32.18	18.68
|||	30- 40	11.97	6.95
+++	40- 50	8.80	5.11
+++	50- 60	12.82	7.44
θθθ	60- 70	11.88	6.90
XXX	70- 80	9.57	5.56
■■■	80- 90	0.56	0.32
●●●	90-100	0.0	0.0

58.06 = TOTAL ACREAGE

X-COORDINATE	Y-COORDINATE	Z-VALUE
0.43	0.72	70.00
1.04	0.73	63.00
1.54	0.73	57.00
1.75	1.73	19.00
1.17	1.73	48.00
0.69	1.72	55.00
0.18	1.70	31.00
0.22	2.21	31.00
0.77	2.22	21.00
1.36	2.23	36.00
1.73	2.23	21.00
1.82	2.81	21.00
1.18	2.81	21.00
0.66	2.80	11.00
0.27	2.79	13.00

AVERAGE OF % DAMAGE FOR ENTIRE FIELD BASED ON ALL EVALUATED MAP POINTS= 40.12 %

INSURED VALUE OF EACH ACRE= $200.00

TOTAL ADJUSTMENT= $ 4658.54

Figure 1. Computer map evaluated using a multi-quadric equation.

minor but they did improve the data set. Therefore, a total of 97 fields was used as the data base.

The 97 fields were almost equally divided between corn (49 fields) and beans (48 fields). Ten fields came from data collected in 1974, 36 fields came from 1975 data, and 51 came from one storm in 1976. The 97 fields represented 14 stages of corn and 9 stages of beans. Crop stages for corn ranged from 8 leaf to soft dough and bean stages ranged from V-1 to R-7. A wide variety of crop stages throughout the growing season reflected the different storm dates of the past three years. Loss of yield ranged from 5% to 100%. The number of loss assessments in each field ranged from 8 to 33 and the average number of assessments per field was 14. Fields ranged in size from 10 to 250 acres, however, 84% of the fields were between 2C and 80 acres. The average field size was 54 acres and the median size was 41 acres.

DATA MANIPULATION

For each of the 97 fields, a map and weighted average loss for each field was produced using all of the adjusters assessments. The loss pattern map (with 5% class intervals) and weighted average of yield loss were considered correct. All field losses obtained by various sampling methods and techniques were compared against the weighted average of yield loss. The use of the weighted average as the correct value computed in this manner seemed appropriate because it was based on many adjuster-obtained assessments and the mapping routine generated additional loss assessments which were used to obtain the weighted average for the field.

Consultation with Country Companies personnel had revealed that it would be almost impossible, because of economic constraints, for adjusters to take many losses within a field as part of their normal procedures. The initial research in 1975-1976 had indicated that an 8 point sample provided reasonable accuracy and that an 8 point sample was significantly better than a 6 or 4 point sample. It was decided that sampling would continue in a similar fashion. Hopefully, the earlier analyses would be confirmed. The earlier analyses had been based on a sample size of 44 fields as compared to sample size of 97 fields used for this study.

Each of the 97 fields was systematically sampled for 8, 6, or 4 points according to the method exhibited in Figure 2. The locations were designed to represent equal area for a given sampling method. The loss values used at these locations were obtained from the map produced for the field using all of the adjusters loss assessments. The loss value used at a given location was the mid-point value of the class interval at that location. For instance, if the location of a loss assessment was in the 20-25% class interval then 22.5% was the loss value used at that location. These locations and losses were then used to generate a map and weighted average for each sample size for a given field. In other words, for each field, 4 maps and weighted averages were produced: for all points, and an 8 point, 6 point, and 4 point systematic sample. These maps and averages were labelled SYST (SURF) because the samples were systematically chosen and surface fitted maps of the data were prepared. The 8, 6, and 4 point values were also averaged in the normal fashion to obtain a straight average called SYST (AVG). The purpose of obtaining the SYST (AVG) was to compare it against the SYST (SURF) in tests to determine how much more (or less) accurate the weighted average is compared to a simple straight average.

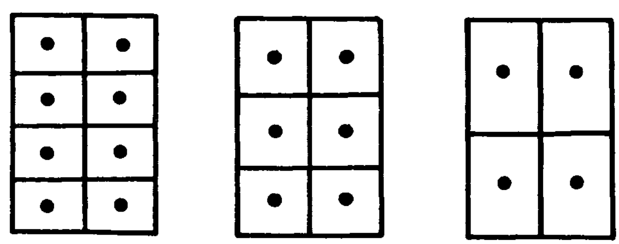


Figure 2. 8, 6, and 4 point 2-line systematic samples.

After the initial mapping and averages for the entire data set of 97 fields were completed, the data was then stratified in several ways: by crop type and field size. For the former, stratification was based on a corn and bean discrimination. For the latter, the field sizes were stratified into two groups: 10-40 acres and 41-80 acres. After the maps and averages were produced and various stratifications done the data had to be statistically tested. The statistical tests are described in the next section.

STATISTICAL TESTING

The only statistic that can be tested to see if there is a difference between the average percent losses derived using a differing number of data points (8, 6, 4) is the measure of despersion (σ) or spread of the average percent damages about the mean. The standard deviation difference test utilizes the measure of dispersion, i.e., the standard deviation, and was thus the primary statistic chosen to analyze the data. The objective of the testing was to find the number of points (loss assessments) which has the least dispersion or standard deviation (and hence reduces the error) and is significantly different from other numbers of sample points. The statistical formula necessary for this test are contained in Table 1.

PRIMARY RESULTS

The use of stratified and unstratified data has produced some interesting results, the most important will be discussed in this section. These primary results pertain to the following issues or questions: 1) the

Table 1. Statistical Formula used in 1976-1977 Research

Mean ($\bar{x}$):

$$x = \frac{\Sigma x}{N}$$

where: x = an observation value
N = total number of observations
$\sum$ = sigma notation with $\sum_{j=1}^{N}$ assumed counter

Standard Deviation (σ):

(sample) $$\sigma s = \sqrt{\frac{\Sigma x^2}{N} - \frac{\Sigma (x)^2}{N}}$$

(population estimate) $$\hat{\sigma}_p = \sigma s X \sqrt{\frac{N}{N-1}}$$

Standard Error of the Standard Deviation (σ_σ):

$$\sigma_\sigma = \frac{\hat{\sigma}_p}{\sqrt{2N}}$$

Unpooled Estimate of the Standard Error of the Difference of Standard Deviations ($\sigma_{\sigma-\bar{\sigma}}$):

$$\sigma_{\sigma-\bar{\sigma}} = \sqrt{\sigma_{\sigma_1}^{2} + \sigma_{\sigma_2}^{2}}$$

where the standard error of the standard deviations (σ_{σ_1} and σ_{σ_2}) are derived from independent samples.

t-Statistic for Standard Deviations Difference Test:

$$t = \frac{\sigma_{s1} - \sigma_{s2}}{\sqrt{\sigma_{\sigma_1}^{2} + \sigma_{\sigma_2}^{2}}}$$

number of sample points necessary to obtain an accurate estimate of the damage; 2) are the number of sample points significantly different from each other; 3) how much error occurs when the number of assessments varies; 4) does the computer mapping routine increase the accuracy of the field loss over a simple straight average; and 5) is the field loss obtained from computer mapping significantly different from that obtained by a simple straight average. The results will be presented with the use of a series of tables and/or graphs.

Table 2 presents results for the unstratified data (97 fields) comparing various number of sample points for two different sampling methods. For the SYST (SURF) method (computer mapping) the number of sample points are all significantly different from each other; in the case of the SYST (AVG) all are significantly different except when comparing 8 versus 6 points. However, this case approaches significance since the T-test value is 1.6955 and a value greater than 1.9600 is needed for significance. In testing methods, i.e. SYST (SURF) versus SYST (AVG), no significance was found using either an 8 point or 6 point sample size.

The data was then stratified by crop type for similar testing of the number of sample points and method of testing. The results are contained in Tables 3 and 4. For SYST (SURF) and SYST (AVG) 8 points are not different from 6 but both 6 and 8 points are significantly different from the 4 point sample. Again, we find no significant difference between the method of sampling for either crop, however, significance is approached in the case of the corn fields, especially for the 8 point samples. In the case of the 6 point samples no significant difference between sampling methods was found.

Table 2. Standard Deviations Difference Test for all Fields to Test the Number of Sample Points and Method of Sampling,

Sampling Method	# of points	Std. Dev. Difference	Unpooled Std. Error	t-table 0.05 level	t-test	Significant at 0.05 level
SYST (SURF)	8 points vs 6 points	0.3022	0.1341	1.9600	2.2534	yes
	8 points vs 4 points	1.9559	0.2394	1.9600	8.1713	yes
	6 points vs 4 points	1.6537	0.2478	1.9600	6.6737	yes
SYST (AVG)	8 points vs 6 points	0.2432	0.1434	1.9600	1.6955	no
	8 points vs 4 points	1.4171	0.2153	1.9600	6.5823	yes
	6 points vs 4 points	1.1739	0.2234	1.9600	5.2558	yes
SYST (SURF) vs SYST (AVG)	8 points vs 8 points	0.1243	0.1243	1.9600	1.000	no
	6 points vs 6 points	0.0653	0.1518	1.9600	0.4302	no

Table 3. Standard Deviation Difference T-Test:
48 Bean Fields
To Test the Number of Sample Points and Method of Sampling

Sampling Method	# of points	Std. Dev. Difference	Unpooled Std. Error	t-table at 0.05 level	t-test	Significant at 0.05 level
SYST (SURF)	8 points vs 6 points	0.3101	0.1907	1.9900	1.6260	no
	8 points vs 4 points	2.4373	0.3877	1.9900	6.2872	yes
	6 points vs 4 points	2.1272	0.3986	1.9900	5.3372	yes
SYST (AVG)	8 points vs 6 points	0.2977	0.2033	1.9900	1.4642	no
	8 points vs 4 points	1.7956	0.3378	1.9900	5.3152	yes
	6 points vs 4 points	1.4979	0.3506	1.9900	4.2727	yes
SYST (SURF) vs SYST (AVG)	8 points vs 8 points	0.1836	0.1737	1.9900	1.0568	no
	6 points vs 6 points	0.0812	0.2181	1.9900	1.3723	no
	Corn and Bean:; Comparison					
SYST (SURF) vs SYST (AVG)	8 points vs 8 points	0.0212	0.1674	1.9900	0.1267	no
	8 points vs 8 points	0.0737	0.1849	1.9900	0.3986	no

Table 4. Standard Deviation Difference T-Test:
49 Corn Fields
To Test the Number of Sample Points and Method of Sampling

Sampling Method	# of points	Std. Dev. Difference	Unpooled Std. Error	t-table 0.05 level	t-test	Significant at 0.05 level
SYST (SURF)	8 points vs 6 points	0.2917	0.1903	1.9900	1.5332	no
	8 points vs 4 points	1.3576	0.2835	1.9900	4.7888	yes
	6 points vs 4 points	1.0659	0.2972	1.9900	3.5863	yes
SYST (AVG)	8 points vs 6 points	0.1792	0.2025	1.9900	0.8849	no
	8 points vs 4 points	0.9312	0.2651	1.9900	3.5133	yes
	6 points vs 4 points	0.7520	0.2747	1.9900	2.7377	yes
SYST (SURF) vs SYST (AVG)	8 points vs 8 points	0.3461	0.1789	1.9900	].9343	no
	6 points vs 6 points	0.0036	0.2126	1.9900	0.1580	no

A stratification of the data by field size was performed. The data were divided into two groups of field sizes: 10-40 acres and 41-80 acres. The results are contained in Table 5. For fields in the 10-40 acre size both sampling methods using an 8 point sample are not significantly different from the 6 point sample. There is no significant difference between the sampling methods for either 8 or 6 point samples.

For the fields in 41-80 acre class all sample sizes were significantly different from each other. As for the 10-40 acre sample the sampling methods were not significantly different from each other.

The above tests were used to determine if there was any significant difference in sampling method or sample sizes. They did not give any indication as to the difference in accuracy of one method or sample size as compared to the others. That information is contained in Table 6. This table indicates the average error $(\overline{X})$ and standard deviation (σ) between the weighted average of all the values and the values obtained for the two sampling methods using different sample size. For instance, for all 97 fields when comparing the all weighted values against an 8 point SYST (SURF) sample we find that the SYST (SURF) sample overplays by 0.7912% and has a standard deviation of 1.1540. The SYST (AVG) sample underplays by 0.6678% and has a standard deviation of 1.2783. Inspection of 6 and 4 point samples shows an increase in the average error $(\overline{X})$ and standard deviation. This is generally true whether the samples are stratified by crop type or field size. Furthermore, the standard deviation is usually larger for the SYST (AVG) than the SYST (SURF). This is an indication that the SYST (AVG) has more of a tendency to have large errors in it than the SYST (SURF) because the standard deviation is a

Table 5. Standard Deviation Difference T-Test:
Fields Stratified by Number of Acres
To Test the Number of Sample Points and Methods of Sampling

Sampling Method	# of points	Std. Dev. Difference	Unpooled Std. Error	t-table 0.05 level	t-test	Significant at 0.05 level
	10 - 40 Acres: 46 Fields					
SYST (SURF)	8 points vs 6 points	0.0404	0.2337	1.9900	0.1729	no
SYST (AVG)	8 points vs 6 points	0.0274	0.2457	1.9900	0.1115	no
SYST (SURF)	8 points vs 8 points	0.0571	0.1991	1.9900	0.2868	no
vs SYST (AVG)	6 points vs 6 points	0.0701	0.1940	1.9900	0.3613	no
	41 - 80 Acres: 39 Fields					
SYST (SURF)	8 points vs 6 points	0.5844	0.2253	1.9930	2.5937	yes
SYST (AVG)	8 points vs 6 points	0.6459	0.2304	1.9930	2.8034	yes
SYST (SURF)	8 points vs 8 points	0.0051	0.1724	1.9930	0.0296	no
vs SYST (AVG)	6 points vs 6 points	0.2072	0.2722	1.9930	0.2072	no
	10 - 40 Acres, 41 - 80 Acres					
SYST (SURF)	8 points vs 8 points	0.2413	0.1841	1.9900	1.3107	no
SYST (AVG)	8 points vs 8 points	0.3035	0.1883	1.9900	1.6116	no

Table 6. Summary Statistics for Various Sampling Methods
Based on Unstratified and Stratified Data

		All vs 8		All vs 6		All vs 4	
	Statistic	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
<u>All Fields</u>	SYST (SURF)	-0.7912	1.1540	-1.1966	1.4562	-3.3972	3.1099
	SYST (AVG)	0.6678	1.2783	1.0337	1.5215	1.3088	2.6954
	N = 97						
<u>Corn</u>	SYST (SURF)	-0.7784	1.1644	-1.1320	1.4561	-3.0624	2.5220
	SYST (AVG)	0.7649	1.3105	1.2008	1.4897	1.7245	2.2417
	N = 49						
<u>Beans</u>	SYST (SURF)	-0.8044	1.1432	-1.2625	1.4533	-3.7390	3.5805
	SYST (AVG)	0.5687	1.2368	0.8631	1.5345	0.8844	3.0324
	N = 48						
<u>10-40 Acres</u>	SYST (SURF)	-0.8396	1.3068	-1.2146	1.2664	-3.4051	3.1050
	SYST (AVG)	0.8672	1.3639	1.3487	1.3365	1.9183	2.9128
	N = 46						
<u>41-80 Acres</u>	SYST (SURF)	-0.7574	1.0655	-1.2440	1.6499	-3.3572	3.1075
	SYST (AVG)	0.4544	1.0604	0.7656	1.7063	1.0228	2,3792
	N = 39						

$\bar{X}$ = Mean

σ = Standard Deviation

statistic that reflects extreme values. This is very important when one considers that the adjuster's goal is accuracy in every field.

A graphical display of the variations in the means and errors are shown in Figures 3 through 5. Figure 3 shows the percent difference from a weighted average for all points as compared to 8, 6, and 4 point samples for two sampling methods. The computer mapping routine [SYST (SURF)] has a tendency to overpay and the straight average [SYST (AVG)] to underpay. The important thing to note is the change in the width of the percent difference as the number of sample points is reduced. For the 8 point sample approximately 57% (55 of the 97 samples) are within 2% of the correct value. Only about 27% of the 4 point samples are within 2% of the true value. There are no cases of 6% errors for the 8 point samples and both the 6 and 4 point samples indicate some errors larger than 6%.

Figures 4 and 5 show the number of cases versus the absolute percent error for computer mapping [SYST (SURF)] and straight average [SYST (AVG)]. These figures simply show that more cases of small error occur with the larger sample sizes and more cases of large error occur with the smaller sample size.

PRIMARY RECOMMENDATIONS

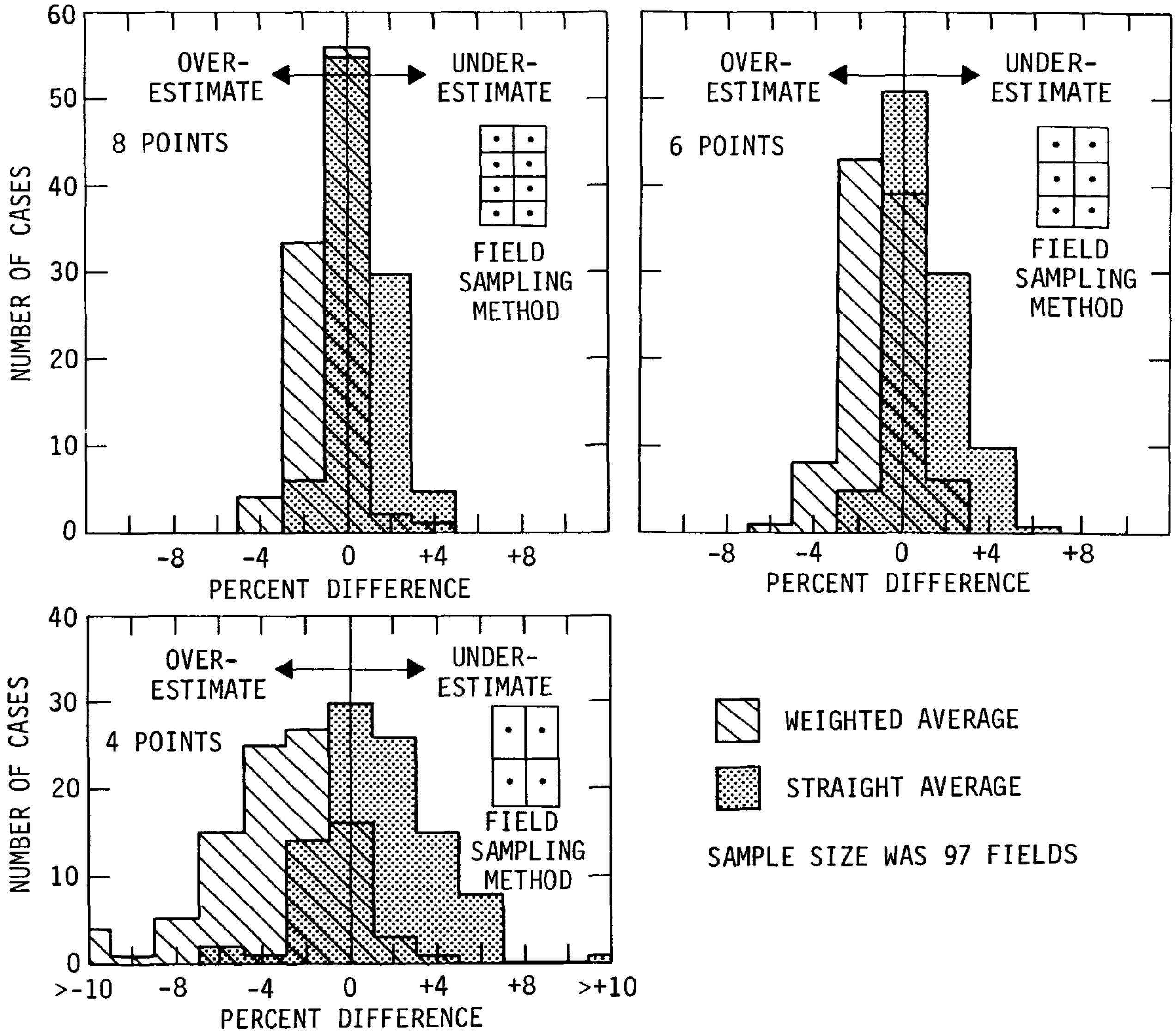
Considerable analyses have been performed using the computer mapping and statistical tests to determine the best sampling methods to be used by the adjuster. Some of the results have been somewhat contradictory. After careful assessment of all the results the following sampling procedures are recommended:

1) systematic samples as indicated in Figure 2 are recommended.

2) Four point samples are not recommended except in extremely small fields.

Figure 3.

PERCENT DIFFERENCE FROM A WEIGHTED AVERAGE OF ALL THE POINTS AS COMPARED TO 8, 6, AND 4 POINT SAMPLES



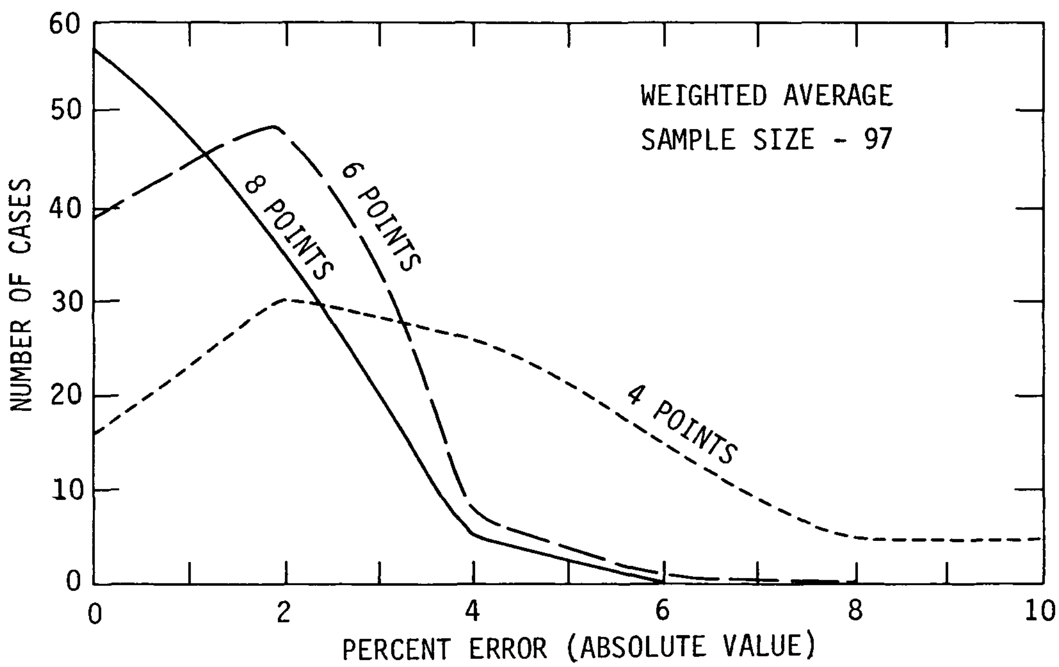


Figure 4. The number of cases versus absolute percent error for 8, 6, and 4 point samples (weighted average).

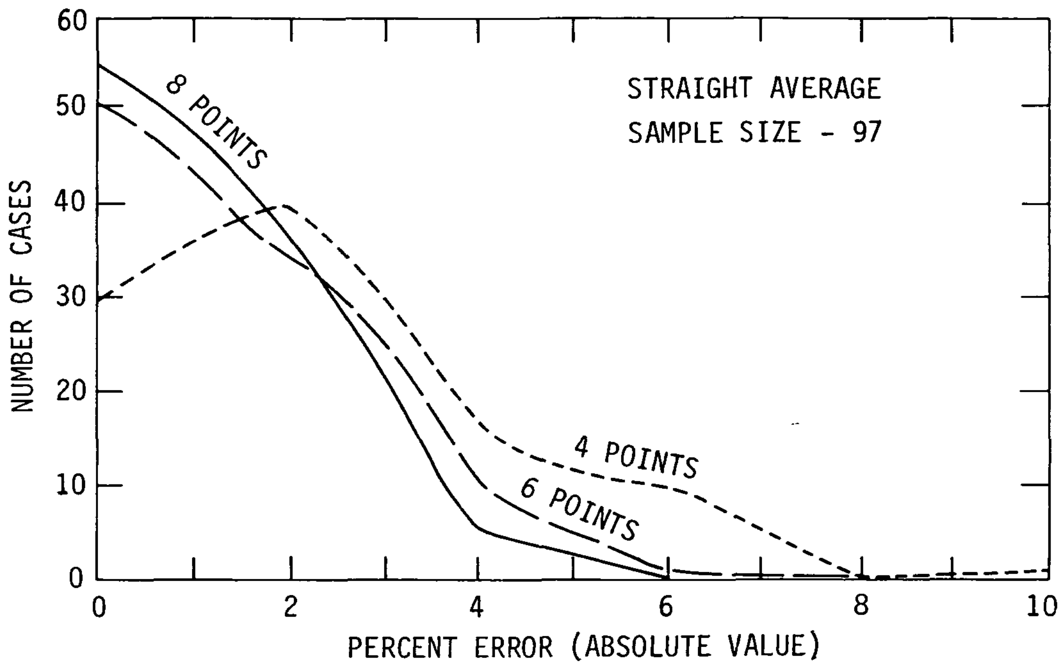


Figure 5. The number of cases versus absolute percent error for 8, 6, and 4 point samples (straight average).

3) Six point samples are recommended for fields in the 10-40 acre size.

4) Eight point samples should be used for fields in the 41-80 acre size,

5) There were few fields larger than 80 acres and firm conclusions can not be made concerning large fields, however, it would seem appropriate to have at least one loss assessment per 10 acres.

6) If aerial photography is available and a high degree of variability in the damage is indicated more assessments should be taken than those recommended above.

7) Computer mapping of the fields will increase the overall accuracy and is therefore recommended. However, experience with the program might indicate that some discretion could be used. For instance, if after the assessments have been taken and very little variability in the damage is indicated then mapping might not be necessary.

SECONDARY RESULTS AND RECOMMENDATIONS

One of the goals of the project was to make a 3-way comparison of loss values obtained by the Illinois State Water Survey assigned adjuster, an audit adjuster, and the settling adjuster who used the aerial photography. The intent was to determine what effect, if any, the photography had on the final adjustment. This goal could not be accomplished because 80% of the fields selected for audit were settled by the same team of adjusters. This completely biased the sample and made it unuseable.

In addition to taking systematic samples of 8, 6, and 4 points another method of selecting sample location was attempted. The purpose of this test was to determine if aerial photography could be used to determine the sampling location to obtain an accurate loss of yield for the field. The principal investigator looked at the photography and decided where the loss assessments should be taken. The values for 33 of the 97 fields were mapped [PHOTO (SURF)] and a straight average by [PHOTO (AVG)] obtained. SYST (SURF) and SYST (AVG) values had already been computed for the original data and the results of all 4 methods were compared. The results when using photography (Tables A and B, Appendix) were much worse than the systematic samples. Therefore, using the photography alone to determine assessment locations is not recommended. However, for fields with extreme variability, a combination of a systematic sample and use of the photographs is recommended.

An attempt was made to determine what changes would occur if 8 or 6 point samples obtained from 3 or 4 lines through the field were used instead of the two line samples. Some of the research and knowledge of how the mapping routine works had indicated that more accuracy might be obtained by having an 8 or 6 point sample obtained from 3 or 4 line samples through the field. This revolved mainly around trying to control "edge effects" that occur with any kind of mapping routine. Edge effects occur when there aren't enough control points at the edges of fields or areas being mapped. A three or four line sample essentially had the effect of moving sample points closer to the edges of the field. Also, re-sampling according to 3 or 4 line samples would give some indication as to the importance of adjuster location in the field (i.e. how critical is it that his sample be chosen from an exact location). There were 9 fields selected for this test. They were chosen because of the high number of loss assessments (average of 22) per field and the excellent areal distribution of the assessments. Figure A in the Appendix displays various methods of obtaining the 3 and 4 line systematic samples. The results contained in Table C in the Appendix, showed that very little difference occurred. For example, using 3 variations of 8 point - 3 line samples, the maximum average difference for any method was 1.67% and the minimum average difference was 0.81%, the absolute maximum difference was 4.73%. The 2 line samples provided more values close to the true value than any of the 3 or 4 line samples. Although the results are based on a small sample of fields it is probably fair to conclude that not much accuracy is gained by using a method different than the 8 point systematic sample illustrated in Figure 2. Also, accurate location of the adjuster is not extremely critical. In other words, it is not necessary for the adjuster to accurately measure distances to his locations; however, he should attempt to be close to the locations.

The original computer mapping routine had the capability of mapping only rectangular fields. It is been modified to map irregular shaped areas provided the area boundaries are supplied to it. A revised version of the program and instructions can be found in the Appendix (Figure B).

The capability to map irregular boundaries makes it ideal for mapping entire storm areas. It would require that the boundaries be provided along with many sample points. A sample map of an entire storm is shown in Figure 6. The map could be prepared soon after the storm, prior to actual field loss settlement, by having personnel obtain losses at many locations throughout the storm. The mapping routine would compute an average loss for the storm. This weighted average combined with the company knowledge of the percent of

CHAMHANA STORM---CORN FIELDS

AVERAGE OF % DAMAGE FOR ENTIRE FIELD BASED ON ALL EVALUATED MAP POINTS= 35.41 %

INSURED VALUE OF EACH ACRE= $250.00

TOTAL ADJUSTMENT= $ 1444502.00

% AREA COVERED IN STORM= 45.00

TOTAL PAYMENT BASED ON CC ACRES COVERED= 65C026.00

AVERAGE OF % DAMAGE FOR ENTIRE FIELD BASED ON INPUT MAP POINTS= 36.74 %

Figure 6. Computer map for an entire storm utilizing the irregular border option of the mapping routine.

acres covered in the storm and approximate insured value per acre could be used to predict the total cost of the storm. This would be extremely valuable to hail managers who must make an estimate of the funds necessary to cover loss payments. These funds are withdrawn from investment or savings accounts which are accruing a great deal of interest on a daily basis. An overestimate of funds withdrawn could be very expensive in lost interest.

SUMMARY

The objectives of this research were to develop a computer mapping system suitable for mapping crop hail losses. This development included: 1) testing of the number of assessment points necessary from a field to obtain an accurate field loss; 2) adapting the mapping program to map irregular shaped fields and 3) comparison of fielded loss obtained from several different sampling methods.

The results and recommendation contained in the previous sections concluded that six to eight point systematic samples, depending on field size, are sufficient to obtain a reasonably accurate loss assessment for a field. Computer mapping of the field is not necessary but will likely increase the accuracy. The combined use of aeral photography and computer mapping would be advisable in fields where a high degree of loss variability is indicated, either from the photography or from actual loss assessments.

The computer mapping routine has been developed for mapping regular or irregular shaped fields. The flexibility of using it for any shaped field makes the routine much more useful than the original routine.

The computer mapping routine can be used to map an entire storm if the necessary input values are provided. The entire storm mapping and weighted average can be valuable to crop-hail claims managers in several ways. One way is to combine the average storm loss with company knowledge of insured acreage to determine the amount of funds to be withdrawn from savings accounts or investments to pay losses. Another possible use would be to use the storm map as a pre-audit of the adjusters. For instance, if an adjuster determines a field loss to be 70% and the field lies in a 20% area according to the storm map supervisory personnel might want to have this field re-checked.

The 1977-78 research consists of performing some final checks on the computer mapping routine and training selected personnel within The Country Companies to use the program. This work will be completed during the summer of 1977. The principal investigator will be available 20% time from August 1977 to May 1978 for consultation with The Country Companies. The consultation will be related to areal photography of crop damage, the computer mapping system, and associated subjects.

REFERENCES

Towery, N. G., J. R. Eyton, S. A. Changnon, Jr., and C. L. Daily, 1975: Remote Sensing of Crop Hail Damage, Report of research May 15, 1974 to May 14, 1975 for The Country Companies, 29 pp.

Towery, N. G., J. R. Eyton, C. L. Daily, D. E. Luman: Annual Report of Remote Sensing of Crop-Hail Damage, Report of research May 15, 1975 to May 14, 1976 for The Country Companies.

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Roy Whiteman, Louis Rediger, and Donald Bradshaw of The Country Companies have offered suggestions concerning the project and made decisions related to the continued funding of the project. John Williams, Carroll Kries, and Robert Weiser of The Country Companies obtained the loss assessments from the fields.

APPENDIX

Table A. Statistical Summary for 33 Selected Corn and Bean Fields

	Statistic	$\overline{X}$	σ	$\overline{X}$	σ
	SYST (SURF)	-1.1618	1.2605	-1.2773	1.5902
Sampling Method	SYST (AVG)	0.7367	1.4588	1.5673	1.5970
	PHOTO (SURF)	-1.7642	2.5211	-2.5445	2.4801
	PHOTO (AVG)	-0.1370	3.2114	-0.4152	2.6392

Sample Size = 33

Table B. Standard Deviation Difference T-Test:
33 Selected Fields
To Test the Number of Points and Method of Sampling

Sampling Method	# of points	Std. Dev. Difference	Unpooled Std. Error	t-table 0.05 level	t-test	Significant at 0.05 level
SYST (SURF)	8 points vs 6 points	0.3297	0.2537	2.0000	1.2996	no
SYST (AVG)	8 points vs 6 points	0.1382	0.2703	2.0000	0.5112	no
PHOTO (SURF)	8 points vs 6 points	0.0410	0.4420	2.0000	0.0928	no
PHOTO (AVG)	8 points vs 6 points	0.5222	0.5235	2.0000	0.9975	no
S (S) vs S (A)	8 points vs 8 points	0.1983	0.2410	2.0000	0.8229	no
S (S) vs P (S)	8 points vs 8 points	1.2606	0.3523	2.0000	3.5780	yes
S (S) vs P (A)	8 points vs 8 points	1.9509	0.4312	2.0000	4.5240	yes
S (A) vs P (S)	8 points vs 8 points	1.0623	0.3640	2.0000	2.9181	yes
S (A) vs P (A)	8 points vs 8 points	1.7526	0.4409	2.0000	3.9754	yes
P (S) vs P (A)	8 points vs 8 points	0.6903	0.5103	2.0000	1.3527	no

S (S) = SYST (SURF)
S (A) = SYST (AVG)
P (S) = PHOTO (SURF)
P (A) = PHOTO (AVG)

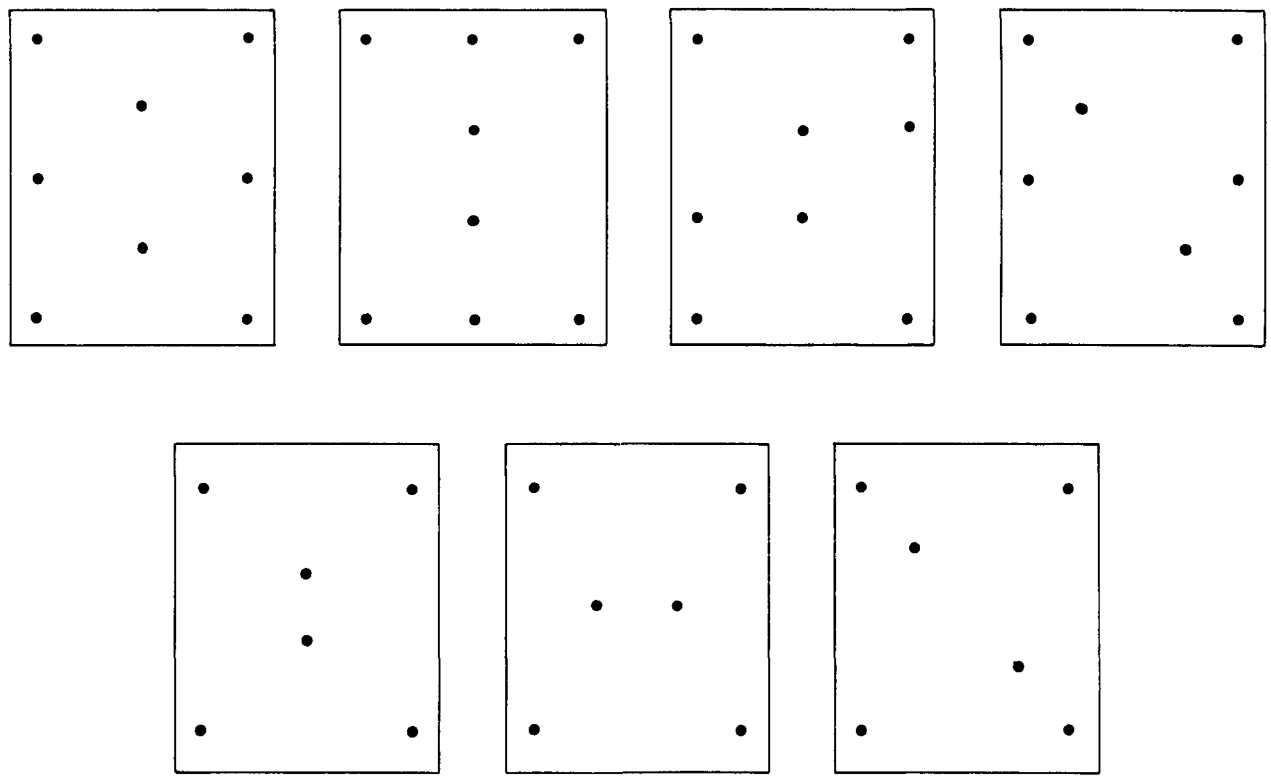

Figure A. 8 and 6 point systematic samples using 3 and 4 lines through the field.

Table C. Weighted Average Losses Using a Variety of Systematic Sampling Methods

Field #	Crop	Acres	# Counts	All Points	8 pt. sample 2 lines	8 pt. sample 3 lines	8 pt. sample 4 lines	6 pt. sample 2 lines	6 pt. sample 3 lines	6 pt. sample 4 lines	4 pt. sample 2 lines	Change from 2 to 3 line (8 pt. sample)
NC 10	Bean	124	20	11.47	11.53*	11.66 10.19 11.79	12.91	12.07	11.01	13.95 11.71	11.58	0.13 1.34 0.26
NC 17	Corn	80	33	42.91	45.00	44.06 40.27 44.18	43.83	45.00	41.74	42.24* 40.94	49.39	0.94 4.73 0.82
NC 64	Bean	75	16	10.59	10.66*	10.66* 11.48 11.37	10.92	10.87	12.41	10.79 12.40	11.57	0.0 0.82 0.71
NC 35	Corn	36	17	80.53	81.11	80.50* 82.67 81.13	77.90	82.48	82.74	79.08 78.94	85.53	0.61 1.56 0.02
NC 22	Bean	68	16	10.73	11.43	11.59 11.22 10.94	10.55*	11.67	11.96	9.90 10.90	13.07	0.16 0.21 0.49
SO 2	Corn	80	21	33.21	33.58*	36.71 32.63 32.50	37.71	36.75	32.71	35.94 34.83	35.01	3.13 0.95 1.08
SO 5	Bean	119	32	28.89	30.21	26.78 26.15 28.51	30.98	28.55*	33.37	37.66	35.92	3.43 4.06 1.7
DO 4	Corn	33	14	60.21	60.85	62.49 60.40 61.53	60.69	64.11	60.23*	66.32 57.02	63.81	1.64 0.45 0.68
C 4	Bean	116	29	87.98	88.63*	89.21 89.57 90.15	86.65	90.18	90.84	89.47. 85.67	89.67	0.58 0.94 1.52

$\bar{X}$ = 1.22

Method	Max. Change	$\bar{X}$
1	4.73	1.18
2	1.7	0.81
3	3.43	1.67

* Value closest to all point value.

Figure B. Complete listing of the computer mapping program including a list of instructions.

```
C   FIVE CONTROL CARDS ARE NECESSARY TO RUN THIS PROGRAM:
C   CARD1: MAP CARD TO IDENTIFY NUMBER OF MAPS TO BE RUN
C   CARD2: TITLE CARD
C   CARD3: VARIABLE FORMAT CARD FOR X & Y COORDINATES AND ASSOCIATED
C      LOSS VALUES
C   CARD4: FIELD INFORMATION CARD SET UP AS FOLLOWS:
C      FI= FIELD NAME...A-FORMAT (COLS 1-4)
C      PH1,PH2= PHOTO NUMBER...A-FORMAT (COLS 5-9)
C      IA= ALTIMETER****I-FORMAT****RIGHT JUSTIFY (COLS 11-14)
C      FT= FILM TYPE...A-FORMAT (COLS 16-17)
C      SA= SCALE  1 INCH =    FEET...F-FORMAT (COLS 19-24)
C      CR= CROP TYPE...A-FORMAT (COLS 25-28)
C      SC= CROP STAGE...A-FORMAT (COLS 30-33)
C      NP= NUMBER OF COUNTS****I-FORMAT****RIGHT JUSTIFY (COLS 35-36)
C      XMIN= 0.0...F-FORMAT (COLS 40-49)
C      XMAX= WIDTH  OF FIELD IN INCHES...F-FORMAT (COLS  50-59)
C      YMIN= 0.0...F-FORMAT (COLS 60-69)
C      YMAX= LENGTH OF FIELD IN INCHES...F-FORMAT (COLS 70-79)
C      NC= BLANK (COL 80)
C   CARD5: POINT CARD SET UP AS FOLLOWS:
C      NUM= ENTER A 1 IN AS MANY COLUMNS AS THERE ARE COUNTS (COLS 1-50)
C      XSIZE= DESIRED WIDTH OF MAP IN INCHES---LENGTH AUTOMATICALLY SCALED
C             TO WIDTH...F-FORMAT (COLS 61-70)
C      ADJ= INSURED VALUE OF EACH ACRE (F-FORMAT)
C      NBORD= 1 IF IRREGULAR BOUNDARY: 0 IF REGULAR SHAPED FIELD (COL 80)
C   THESE 5 CARDS FOLLOW THE PROGRAM AND ARE IN TURN FOLLOWED BY DATA
C      CARDS--- 1 PAIR OF X & Y COORDINATES AND ASSOCIATED LOSS
C      VALUE PER CARD.  IF NBORD = 1  THEN INCLUDE X & Y COORDINATES
C      FOR BORDER POINTS....IF NBORD=0 NO BORDER POINTS ARE NECESSARY
C   REPEAT CARDS 2-5 FOR EACH ADDITIONAL MAP DESIRED INCLUDING
C      APPROPRIATE DATA CARDS
        DIMENSION XX(50),YY(50),ZZ(50)
        DIMENSION NUM(50),NV(50)
        DIMENSION X(50),Y(50),Z(50),CCM(66)
        DIMENSION ID(20),FORM1(20)
        DIMENSION XMPC(10),NX(10)
           COMMON TOTAR,WA
        REAL*8 CCM
C   NMAPS=NUMBER OF MAPS TO BE EVALUATED FROM 01 TO 99
C   NSW=SWITCH; 1=MOE; 2=TREND SURFACE---USE 1
C   NDD=DEGREE OF TREND SURFACE (1-9)--- USE 0
C   IIPUN=SWITCH FOR PUNCHING COEFFICIENTS FOR TREND SURFACE: 0=NO; 1=YES
           READ(5,10) NMAPS,NSW,NDD
    10     FORMAT(I2,1X,I1,1X,I1)
           DO 1000 NM=1,NMAPS
        READ(5,11)(ID(J),J=1,20)
        READ(5,11)(FORM1(J),J=1,20)
    11  FORMAT(20A4)
        READ(5,21) FI,PH1,PH2,IA,FT,SA,CR,SC,NP,XMIN,XMAX,YMIN,YMAX,NC
    21  FORMAT(A4,A4,A1,1X,I4,1X,A2,1X,F6.1,A4,1X,A4,1X,I2,3X,4F10.2,I1
       *)
        READ(5,26)(NUM(J),J=1,50),XSIZE,ADJ,NBORD
    26  FORMAT(50I1,2F10.2,I1)
        DO 30 J=1,NP
    30  READ(5,FORM1) XX(J),YY(J),ZZ(J)
    40  WRITE(6,41)(ID(J),J=1,20)
    41  FORMAT('1',20A4,///)
        WRITE(6,51) FI,PH1,PH2,IA,FT,SA,CR,SC,NP,XMIN,XMAX,YMIN,YMAX
    51  FORMAT(1X,'FIELD: ',A4/1X,'PHOTO: ',A4,A1/1X,'ALTIMETER: ',I4/1X,'
```

```
     *FILM TYPE: ',A2/1X,'SCALE: 1"= ',F6.1/1X,'CROP: ',A4/1X,'CROP STAG
     *E: ',A4/1X,'NO  OBS: ',I2/1X,'XMIN: ',F10.2/1X,'XMAX: ',F10.2/1X,'
     *YMIN: ',F10.2/1X,'YMAX: ',F10.2////1X,' X-COORDINATE     Y-COORDI
     *NATE     Z-VALUE',/)
      IF(NC.EQ.0) GO TO 59
      IF(NC.EQ.1) NC=10
      READ(5,52)(XMPC(J),J=1,NC)
   52 FORMAT(10F8.2)
      DO 54 J=1,NP
      N=Z(J)
   54 Z(J)=XMPC(N)
   59 K=0
      DO 110 J=1,50
      IF(NUM(J).EQ.1) GO TO 100
      GO TO 110
  100 K=K+1
      NV(K)=J
  110 CONTINUE
      XNP=NP
      SUMZ=0.
      NOBS=K
      DO 120 J=1,NOBS
      X(J)=XX(NV(J))
      Y(J)=YY(NV(J))
      Z(J)=ZZ(NV(J))
  120 SUMZ=SUMZ+Z(J)
      AVGZ=SUMZ/XNP
      DO 60 J=1,NOBS
   60 WRITE(6,61) X(J),Y(J),Z(J)
   61 FORMAT(3X,F8.2,9X,F8.2,6X,F8.2)
         IF(NSW.EQ.2) GO TO 65
      CALL MOESLV(X,Y,Z,CCM,NOBS)
         GO TO 69
  65     IIPUN=0
         DO 68 J=1,10
  68     NX(J)=0
         NX(NDD)=1
         CALL POLYM(X,Y,Z,NOBS,IIPUN,NX,CCM)
   69 CALL MAP(CCM,ID,X,Y,XMIN,XMAX,YMIN,YMAX,NOBS,SA,ADJ,NV,XSIZE,NDD,
     *NSW,NBORD)
      WRITE(6,70)AVGZ
   70 FORMAT(1X,///41X,'AVERAGE OF % DAMAGE FOR ENTIRE FIELD BASED ON IN
     *PUT MAP POINTS= ',F6.2,' %')
 1000    CONTINUE
         STOP
         END
```

```
      SUBROUTINE MOESLV(X,Y,Z,CCI,NR)
      DIMENSION X(50),Y(50),Z(50),AA(50,50),CCI(66),ZA(50)
      INTEGER*4 IDUM(50)
      REAL*8 AA,DSQRT,XX1,YY1,XX2,YY2,CCI,ZA
      DO 10 I=1,NR
      XX2=X(I)
      YY2=Y(I)
      DO 10 J=1,NR
      XX1=X(J)
      YY1=Y(J)
   10 AA(I,J)=DSQRT((XX1-XX2)**2+(YY1-YY2)**2)
      DO 20 I=1,NR
   20 ZA(I)=Z(I)
      IER=1
      CALL GAUSZ(AA,NR,50,ZA,CCI,IDUM,IER)
      RETURN
      END
```

```
      SUBROUTINE MAP(CCI,ID,X,Y,XMIN,XMAX,YMIN,YMAX,NP,SA,ADJ,NV, XSIZE
     *,NDD,NSW,NBORD)
      DIMENSION NC1(20),NC2(20),PT(20),AA(20)
      DIMENSION X(50),Y(50),CCI(66),ID(20),NCOUNT(20),MAP1(130),MAP2(130
     *),MAP3(130),ISX1(20),ISX2(20),ISX3(20)
      DIMENSION NV(50),NX(50),NY(50)
      DIMENSION NSF(10),NBR(1000),NBC(1000)
      REAL*8 CCI
         COMMON TOTAR,WA
      DATA MINUS/'-'/
      DATA IBD/'I'/
      DATA NSF/'1','2','3','4','5','6','7','8','9','0'/
         DATA ISX1/' ','A','-','B','=','C','|','D','|','E','|','F','0','G
     *',' ','H','0','I','0','J'/
         DATA ISX2/'.',' ',' ',' ',' ',' ',' ',' ',' ','-',' ','+',' ','-','
     *','X',' ','X',' ','=',' '/
         DATA ISX3/' ',' ',' ',' ',' ',' ',' ',' ',' ',' ','=',' ',' ','
     *',' ',' ',' ',' ','+',' '/
      NCOLS=XSIZE*10.
      XDIF=XMAX-XMIN
      YDIF=YMAX-YMIN
      XNY=(YDIF/XDIF*NCOLS)*.8+.5
      YI=YDIF/(XNY-1.)
      XI=XDIF/(NCOLS-1)
      NYY=XNY
      DIF=(130-NCOLS)/2.
      NDIF=DIF
      IF(NBORD.EQ.0) GO TO 20
      CALL BORDER(NBR,NBC,NEWOBS,XMIN,XMAX,YMIN,YMAX,NCOLS)
   20 DO 10 J=1,NP
      NX(J)=(X(J)-XMIN)/XI+1.5
   10 NY(J)=(Y(J)-YMIN)/YI+1.5
      DO 25 J=1,10
   25 NCOUNT(J)=0
      WRITE(6,31)(ID(J),J=1,20)
   31 FORMAT('1',20A4,///)
       DO 300 J=1,130
  300 MAP1(J)=ISX1(1)
      DO 310 J=1,NCOLS
      K=J+NDIF
  310 MAP1(K)=MINUS
      WRITE(6,58)(MAP1(K),K=1,130)
      L1=-1
      L2=0
      CT=0.
         SUM=0.0
      DO 55 K=1,NYY
      IF(NBORD.EQ.0) GO TO 80
      DO 42 J=1,130
      MAP1(J)=ISX1(1)
      MAP2(J)=ISX1(1)
   42 MAP3(J)=ISX1(1)
         IF(K.GT.NBR(NEWOBS)) GO TO 90
         IF(K.LT.NBR(1)) GO TO 90
   48    L1=L1+2
         L2=L2+2
         N1=NBC(L1)
         N2=NBC(L2)
         GO TO 43
```

```
   80     N1=1
          N2=NCOLS
   43     YB=YMIN+(K-1)*YI
       DO 50 J=N1,N2
       XB=XMIN+(J-1)*XI
          IF(NSW.EQ.2)GO TO 372
       ZC=0.
       DO 370 L=1,NP
  370  ZC=ZC+CCI(L)*SQRT((X(L)-XB)**2+(Y(L)-YB)**2)
          GO TO 373
  372     ZC=ZIP(CCI,XB,YB,NDD)
  373     IF(ZC.GT.100.) ZC=100.
          IF(ZC.LT.0.) ZC=0.
          SUM=SUM+ZC
          CT=CT+1.
       NSPP=ZC/5.+1
       IF(NSPP.LT.1) NSPP=1
       IF(NSPP.GT.20) NSPP=20
       NSP=ZC/10.+1
       IF(NSP.LT.1) NSP=1
       IF(NSP.GT.10) NSP=10
       NCOUNT(NSP)=NCOUNT(NSP)+1
       I=J+NDIF
       MAP1(I)=ISX1(NSP)
       MAP2(I)=ISX2(NSP)
   50  MAP3(I)=ISX3(NSP)
       L3=L2+1
       IF(NBR(L2).EQ.NBR(L3)) GO TO 48
   90  CONTINUE
       NZZ=NCOLS+1+NDIF
       MAP1(NZZ)=IBD
       MAP1(NDIF)=IBD
       DO 51 L=1,NP
       IF(NY(L).EQ.K) GO TO 52
       GO TO 51
   52  IF(NV(L).LT.10) GO TO 53
       NF=NV(L)/10
       NS=NV(L)-NF*10
       IF(NS.EQ.0) NS=10
       GO TO 54
   53  NF=NV(L)
   54  KL=NX(L)+NDIF
       IF(NX(L).EQ.NCOLS.AND.NV(L).GT.10) KL=NCOLS-1
       MAP1(KL)=NSF(NF)
       MAP2(KL)=ISX1(1)
       MAP3(KL)=ISX1(1)
       IF(NV(L).LT.10) GO TO 51
       KL=KL+1
       MAP1(KL)=NSF(NS)
       MAP2(KL)=ISX1(1)
       MAP3(KL)=ISX1(1)
   51  CONTINUE
       WRITE(6,58)(MAP1(J),J=1,130)
       WRITE(6,59)(MAP2(J),J=1,130)
   55  WRITE(6,59)(MAP3(J),J=1,130)
   58  FORMAT(1X,130A1)
   59  FORMAT('+',130A1)
       DO 200 J=1,130
  200  MAP1(J)=ISX1(1)
```

```
      DO 210 J=1,NCOLS
      K=J+NDIF
  210 MAP1(K)=MINUS
      WRITE(6,58)(MAP1(K),K=1,130)
      TOTFRE=0.
      DO 150 J=1,10
  150 TOTFRE=TOTFRE+NCOUNT(J)
        TOTAR=(CT/(NCOLS*NYY)*XDIF*YDIF*SA**2)/43560.
      DO 151 J=1,10
      NC1(J)=(J-1)*10
      NC2(J)=NC1(J)+10
      PT(J)=NCOUNT(J)/TOTFRE*100.
      AA(J)=PT(J)/100.*TOTAR
  151 XNC1=NC1(J)
      WRITE(6,66)
   66 FORMAT(1X,///,40X,'SYMBOL',8X,'CLASS',7X,'FREQUENCY',9X,'AREA',/51
     *X,'(% DAMAGE)',8X,'(%)',11X,'(ACRES)',/)
      DO 100 J=1,10
      DO 70 II=1,3
      WRITE(6,60) ISX1(J),ISX1(J),ISX1(J)
      IF(II.EQ.2) GO TO 71
      WRITE(6,61) ISX2(J),ISX2(J),ISX2(J)
      GO TO 72
   71 WRITE(6,62) ISX2(J),ISX2(J),ISX2(J),NC1(J),NC2(J),PT(J),AA(J)
   72 WRITE(6,61) ISX3(J),ISX3(J),ISX3(J)
   70 CONTINUE
      WRITE(6,77)
   77 FORMAT(1X,/)
  100 CONTINUE
        WA=(SUM/CT)
        TADJ=ADJ*TOTAR*WA/100.
        WRITE(6,63) TOTAR
   63 FORMAT('0',82X,F10.2,' = TOTAL ACREAGE')
      WRITE(6,111) WA
  111 FORMAT(1X,///41X,'AVERAGE OF % DAMAGE FOR ENTIRE FIELD BASED ON AL
     *L EVALUATED MAP POINTS= ',F6.2,' %')
   64 FORMAT(1X,///41X,'INSURED VALUE OF EACH ACRE= $',F6.2,//41X,'TOTAL
     * ADJUSTMENT= $',F12.2)
      WRITE(6,64) ADJ,TADJ
   60 FORMAT(41X,3A1)
   61 FORMAT('+',40X,3A1)
   62 FORMAT('+',40X,3A1,9X,I2,'-',I3,8X,F6.2,8X,F8.2)
      RETURN
      END
```

```
      SUBROUTINE POLYM(X,Y,Z,NDT,IIPUN,NX,CCI)
C        GENERALIZED MULTIPLE CURVILINEAR CORRELATION AND REGRESSION
C        ONE DEPENDENT,TWO INDEPENDENT VARIABLES,UP TO TEN DEGREES
      DIMENSION X(NDT),Y(NDT),Z(NDT),AA(66,66),BB(66,66),G(66),ISX(10),
     *A(66),CCI(66),ND(10),ZP(200),R(200),NC(66),NX(10)
      REAL*8 AA,BB
      REAL*8 ARX,ARY,XX,YY,A,ZZ,G,CI,CCI
      REAL*8 XMAX,XMIN,XTEST
      INTEGER*4 IDUM(66)
      LOGICAL *1 LASTPT
      DATA ISX/3,6,10,15,21,28,36,45,55,66/
      L=0
      DO 42 J=1,10
      K=11-J
      IF(NX(K).EQ.1) GO TO 45
      GO TO 42
   45 L=L+1
      ND(L)=K
      NF=L
   42 CONTINUE
      NDD=ND(1)
      NTT=ISX(NDD)
      DO 46 L=1,NTT
      DO 46 K=1,NTT
   46 AA(L,K)=0.
      DO 48 K=1,NTT
   48 G(K)=0.
      J=1
   50 CONTINUE
      L=2
      DO 60 NJ=1,NDD
      N=NJ+1
      DO 60 K=1,N
      JX1=N-K
      JX2=K-1
      XX=X(J)
      YY=Y(J)
      IF(XX.EQ.0..AND.JX1.EQ.0) GO TO 82
      ARX=XX**JX1
      GO TO 84
   82 ARX=1.
   84 IF(YY.EQ.0..AND.JX2.EQ.0) GO TO 86
      ARY=YY**JX2
      GO TO 88
   86 ARY=1.
   88 A(L)=ARX*ARY
      L=L+1
   60 CONTINUE
      A(1)=1.
      DO 70 K=1,NTT
      ZZ=Z(J)
   70 G(K)=G(K)+ZZ*A(K)
      DO 100 L=1,NTT
      DO 100 K=1,NTT
  100 AA(L,K)=AA(L,K)+A(L)*A(K)
      J=J+1
      IF(J.GT.NDT) GO TO 110
      GO TO 50
  110 CONTINUE
```

```
          ZMEAN=G(1)/NDT
          WRITE(6,163)
      163 FORMAT('1','** POLYNOMIAL MULTIPLE CURVILINEAR REGRESSION PROGRAM
         * **', ///1X,'BASIC STATISTICS FOR THIS RUN',//)
          WRITE(6,61) NDT,NF,L
       61 FORMAT('0','TOTAL # DATA POINTS= ',I3,//1X,'# OF FITS= ',I2,//1X,'
         *# OF TERMS IN HIGHEST DEGREE= ',I3,/)
          WRITE(6,62)(ND(LL ),LL=1,NF)
       62 FORMAT(1X,'EQUATIONS TO BE FITTED',16(I2,1X),//)
          DO 1000 MM=1,NF
          IER=1
          NDD=ND(MM)
          N1=ISX(NDD)
          DO111J=1,N1
          DO111I=1,N1
      111 BB(I,J)=AA(I,J)
          CALLGAUSZ(BB,N1,66,G,CCI,IDUM,IER)
          SUMR=0.
          SUMT=0.
          DO 130 J=1,NDT
          XX=X(J)
          YY=Y(J)
          ZP(J)=ZIP(CCI,XX,YY,NDD)
          R(J)=Z(J)-ZP(J)
          SUMR=SUMR + R(J)**2
      130 SUMT = SUMT + (ZMEAN-Z(J))**2
          EXPV=SUMT-SUMR
          COREL=SQRT(EXPV/SUMT)
          NDF=NDT-1
          TMSS=SUMT/NDF
          CDET=COREL**2
          NDFEX=ISX(NDD)-1
          NDFUN=NDT-NDFEX-1
          EMSS=EXPV/NDFEX
          UNMSS=SUMR/NDFUN
          FTEST=EMSS/UNMSS
          WRITE(6,132)NDD
      132 FORMAT(1X,'THIS IS A LEAST-SQUARES FIT OF THE',1X,I2,' DEGREE',//)
          WRITE(6,133)
      133 FORMAT(3X,'     X-VALUE     ',6X,'     Y-VALUE     ',5X,'     Z-VALUE     '
         *,5X,'Z PREDICTED',5X,'RESIDUALS',//)
          WRITE(6,140)(X(J),Y(J),Z(J),ZP(J),R(J),J=1,NDT)
      140 FORMAT(3X, F10.3, 9X, F10.3, 9X, F10.3, 8X, F10.3, 5X, F10.3)
          WRITE (6,150) NDD
      150 FORMAT('1', 'COEFFICIENTS FOR',1X, I2. 'DEGREE EQUATION',//)
          DO 160 J=1,N1
      160 NC(J)=J-1
          DO 165 J=1,N1
      165 WRITE(6,170) NC(J),CCI(J)
      170 FORMAT(1X,I3,1X,F25.15)
          IF(IIPUN.EQ.0) GO TO 181
          DO 175 J=1,N1
      175 WRITE(7,170) NC(J),CCI(J)
      181 WRITE(6,180)
      180 FORMAT('1','ANALYSIS OF VARIANCE MEASURES',///31X,'SUM',11X,'DEGR
         *EES',8X,'MEAN SUM',/28X,'OF SQUARES',6X,'OF FREEDOM',5X,'OF SQUARE
         *S',/)
          WRITE(6,171) SUMT,NDF,TMSS,EXPV,NDFEX,EMSS,SUMR,NDFUN,UNMSS
      171 FORMAT(9X,'TOTAL VARIATION: ',F13.4,8X,I3,7X,F13.4,//5X,'EXPLAINED
```

```
     * VARIATION: ',E13.4,8X,I3,7X,E13.4,//3X,'UNEXPLAINED VARIATION: ',
     *E13.4,8X,I3,7X,E13.4,////)
      WRITE(6,172) FTEST,CORFL,CDET
  172 FORMAT(3X,'F-RATIO: ',F10.5,//3X,'COEFFICIENT OF CORRELATION: ',F7
     *.5,//3X,'COEFFICIENT OF DETERMINATION: ',F7.5,///)
      GO TO 1000
  999 WRITE(6,991) NDD
  991 FORMAT(1X,'FIT OF THE ',I2,' DEGREE WAS CANCELLED DUE TO BAD INVER
     *SE OF S-MATRIX',//)
 1000 CONTINUE
      RETURN
      END
```

```
      FUNCTION ZIP(C,AX,AY,NDD)
      DIMENSION C(100)
      REAL*8 C,X,Y
      X=AX
      Y=AY
      Z=C(1)+C(2)*X+C(3)*Y
      IF(NDD.EQ.1) GO TO 10
      Z=Z+C(4)*X**2+C(5)*X*Y+C(6)*Y**2
      IF(NDD.EQ.2) GO TO 10
      Z=Z+C(7)*X**3+C(8)*X**2*Y+C(9)*X*Y**2+C(10)*Y**3
      IF(NDD.EQ.3) GO TO 10
      Z=Z+C(11)*X**4+C(12)*X**3*Y+C(13)*X**2*Y**2+C(14)*X*Y**3+C(15)*Y**
     *4
      IF(NDD.EQ.4) GO TO 10
      Z=Z+C(16)*X**5+C(17)*X**4*Y+C(18)*X**3*Y**2+C(19)*X**2*Y**3+C(20)*
     *X*Y**4+C(21)*Y**5
      IF(NDD.EQ.5) GO TO 10
      Z=Z+C(22)*X**6+C(23)*X**5*Y+C(24)*X**4*Y**2+C(25)*X**3*Y**3+C(26)*
     *X**2*Y**4+C(27)*X*Y**5+C(28)*Y**6
      IF(NDD.EQ.6) GO TO 10
      Z=Z+C(29)*X**7+C(30)*X**6*Y+C(31)*X**5*Y**2+C(32)*X**4*Y**3+C(33)*
     *X**3*Y**4+C(34)*X**2*Y**5+C(35)*X*Y**6+C(36)*Y**7
      IF(NDD.EQ.7) GO TO 10
      Z=Z+C(37)*X**8+C(38)*X**7*Y+C(39)*X**6*Y**2+C(40)*X**5*Y**3+C(41)*
     *X**4*Y**4+C(42)*X**3*Y**5+C(43)*X**2*Y**6+C(44)*X*Y**7+C(45)*Y**8
      IF(NDD.EQ.8) GO TO 10
      Z=Z+C(46)*X**9+C(47)*X**8*Y+C(48)*X**7*Y**2+C(49)*X**6*Y**3+C(50)*
     *X**5*Y**4+C(51)*X**4*Y**5+C(52)*X**3*Y**6+C(53)*X**2*Y**7+C(54)*X*
     *Y**8+C(55)*Y**9
      IF(NDD.EQ.9) GO TO 10
      Z=Z+C(56)*X**10+C(57)*X**9*Y+C(58)*X**8*Y**2+C(59)*X**7*Y**3+C(60)
     **X**6*Y**4+C(61)*X**5*Y**5+C(62)*X**4*Y**6+C(63)*X**3*Y**7+C(64)*X
     ***2*Y**8+C(65)*X*Y**9+C(66)*Y**10
   10 ZIP=Z
      RETURN
      END
```

```
      SUBROUTINE BORDER(NBR,NBC,NEWOBS,XMIN,XMAX,YMIN,YMAX,NCOLS)
      DIMENSION X(200),Y(200)
      DIMENSION NC(200),NR(200),NCC(1000),NRR(1000)
      DIMENSION NBR(1000),NBC(1000),MAP(130)
      DIMENSION ID(20)
      LOGICAL*1 LAST
      K=1
  110 READ(5,111) X(K),Y(K),LAST
  111 FORMAT(2F10.2,59X,L1)
      IF(LAST) GO TO 120
      K=K+1
      GO TO 110
  120 NOBS=K
C        DUPLICATE LAST BORDER POINT
      X(NOBS+1)=X(1)
      Y(NOBS+1)=Y(1)
      NOBS1=NOBS+1
C        CONVERSION TO ROW AND COLOMN
C        SCALING
      RX=XMAX-XMIN
      RY=YMAX-YMIN
      XLP=.8
      YNY=RY/RX*NCOLS*XLP+.5
      NY=YNY
      XI=RX/(NCOLS-1)
      YI=RY/(YNY-1)
C        CONVERT TO ROW AND COLUMN
      DO 250 I=1,NOBS1
      NC(I)=(X(I)-XMIN)/XI+1.5
  250 NR(I)=(Y(I)-YMIN)/YI+1.5
C        ROW INTERPOLATION
      L=0
      DO 1000 J=1,NOBS
      K2=J+1
C        CHECK FOR DIFFERENCE BETWEEEN ROWS
      NDIF=NR(K2)-NR(J)
      NADIF=IABS(NDIF)
      L=L+1
      NRR(L)=NR(J)
      NCC(L)=NC(J)
      IF(NADIF.LE.1) GO TO 1000
      DIF=NADIF
      COLD=NC(K2)-NC(J)
      COLI=COLD/DIF
      NT=NADIF-1
      DO 400 KL=1,NT
      KK=KL
      IF(NDIF.LT.0) KK=-KK
      L=L+1
      NRR(L)=NR(J)+KK
      XINT=NC(J)+COLI*KL+.5
  400 NCC(L)=XINT
 1000 CONTINUE
      NEWOBS=L
      L=0
      I1=0
      I2=1
 1100 NTOT=0
 1200 I1=I1+1
```

```
      I2=I2+1
      NTOT=NTOT+1
      IF(I2.GT.NEWOBS) GO TO 1250
      IF(NRR(I2).EQ.NRR(I1)) GO TO 1200
 1250 N1=I2-NTOT
      N2=I1
C        CHECK FOR LOCAL TWO POINT MIN OR MAX
      NS1=N1-1
      IF(NS1.LT.1) NS1=NEWOBS
      NS2=N2+1
      IF(NTOT.EQ.1) GO TO 1450
      IF((NRR(NS1).LT.NRR(N1).AND.NRR(NS2).LT.NRR(N2)).OR.(NRR(NS1).GT.N
     *RR(N1).AND.NRR(NS2).GT.NRR(N2))) GO TO 1300
C        ASSUME TWO PINTS OR MORE ARE INFLECTION POINTS
      L=L+1
      NBR(L)=NRR(N1)
      NBC(L)=(NCC(N1)+NCC(N2))/2
      GO TO 1460
 1300 L=L+1
      NBR(L)=NRR(N1)
      NBC(L)=NCC(N1)
      L=L+1
      NBR(L)=NRR(N2)
      NBC(L)=NCC(N2)
C        CHECK FOR ONE POINT MIN OR MAX-DUPLICATE POINT
      GO TO 1460
 1450  N=1
      IF((NRR(NS1).LT.NRR(N2).AND.NRR(NS2).LT.NRR(N2)).OR.(NRR(NS1).GT.N
     *RR(N2).AND.NRR(NS2).GT.NRR(N2))) N=2
      DO 3000 KK=1,N
      L=L+1
      NBR(L)=NRR(N2)
 3000 NBC(L)=NCC(N2)
 1460 IF(N2.LT.NEWOBS) GO TO 1100
      NEWOBS=L
C        ORDER THE NBR ARRAY IN ASCENDING ORDER-PRESERVE THE NBC ARRAY
      DO 4000 I=1,NEWOBS
      NINC=999999
      DO 3900 J=1,NEWOBS
      IF(NBR(J).LE.NINC) GO TO 3700
      GO TO 3900
 3700 NINC=NBR(J)
      JX=J
 3900 CONTINUE
      NRR(I)=NBR(JX)
      NCC(I)=NBC(JX)
      NBR(JX)=999999
 4000 CONTINUE
C        ORDER THE NCC ARRAY IN ASCENDING ORDER-PRESERVE THE NRR ARRAY
      I1=0
      I2=1
 4100 NTOT=0
 4200 I1=I1+1
      I2=I2+1
      NTOT=NTOT+1
      IF(I2.GT.NEWOBS) GO TO 4250
      IF(NRR(I2).EQ.NRR(I1)) GO TO 4200
 4250 N1=I2-NTOT
      N2=I1
```

```
      DO 4500 I=N1,N2
      NCI=999999
      DO 4400 J=N1,N2
      IF(NCC(J).LF.NCI) GO TO 4300
      GO TO 4400
 4300 NCI=NCC(J)
      JX=J
 4400 CONTINUE
      NBR(I)=NRR(JX)
      NBC(I)=NCC(JX)
      NCC(JX)=999999
 4500 CONTINUE
      IF(N2.LT.NEWOBS) GO TO 4100
      RETURN
      END
```