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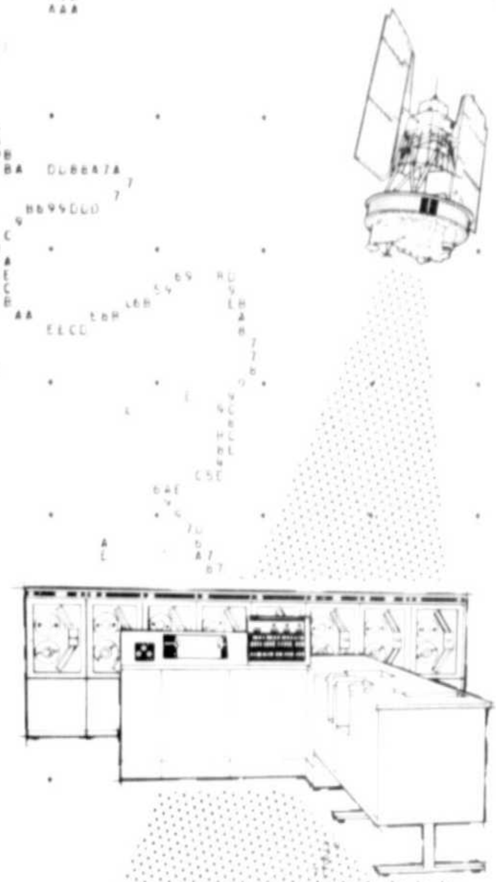
DETECTION AND MAPPING PACKAGE



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VOLUME 3: CONTROL NETWORK ESTABLISHMENT

(E77-10103) DETECTION AND MAPPING (DAM) PACKAGE. VOLUME 3: CONTROL NETWORK ESTABLISHMENT Final Report, Jan. - Jun. 1976 (Lockheed Electronics Co.) 50 p HC A03/MF A01 CSCL 08H G3/43

N77-18519

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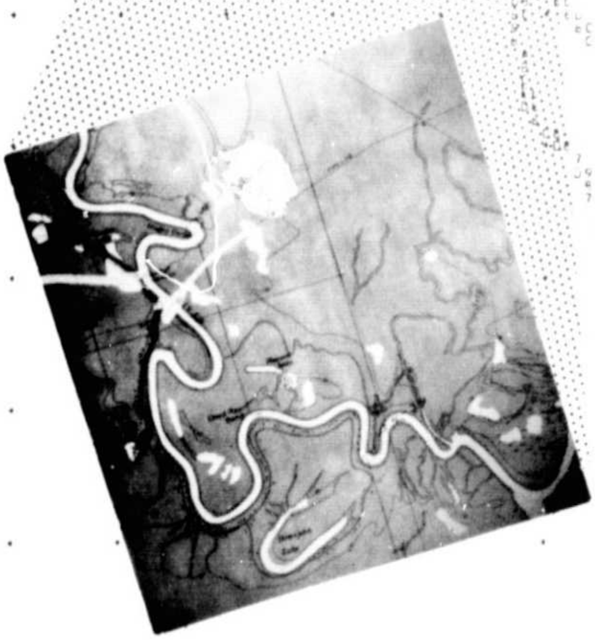

JUNE 1976

NASA

National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

JSC - 11379

DETECTION AND MAPPING PACKAGE

VOLUME 3: CONTROL NETWORK ESTABLISHMENT

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1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DETECTION AND MAPPING (DAM) PACKAGE Volume 3: Control Network Establishment		5. Report Date June 1976 6. Performing Organization Code
7. Author(s) Edward H. Schlosser		8. Performing Organization Report No. LEC-8663 10. Work Unit No.
9. Performing Organization Name and Address Lockheed Electronics Company, Inc. Aerospace Systems Division 16811 El Camino Real Houston, Texas 77058		11. Contract or Grant No. NAS 9-12200 13. Type of Report and Period Covered Final, Jan. – June 1976
12. Sponsoring Agency Name and Address A. W. Patteson Earth Observations Division Lyndon B. Johnson Space Center, Houston, Texas 77058		14. Sponsoring Agency Code
15. Supplementary Notes Software available from: COSMIC University of Georgia 112 Barrow Hall Athens, Georgia 30602		

16. Abstract

The DAM package is an integrated set of manual procedures, computer programs, and graphic devices designed for efficient production of precisely registered and formatted maps from digital Landsat multispectral scanner (MSS) data. The software can be readily implemented on any Univac 1100 series computer with standard peripheral equipment. This version of the software includes pre-defined spectral limits for use in classifying and mapping surface water.

17. Key Words (Suggested by Author(s))		18. Distribution Statement	
Computer programs, Earth resources, Earth satellites, land use, Landsat satellites, mapping, remote sensors, surface water, thematic mapping			
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161

JSC Form 1424 (Rev Nov 75) NASA — JSC

PREFACE

Multispectral scanners onboard NASA unmanned Landsat satellites provide an ideal source of current data for earth resources applications. The Detection And Mapping (DAM) package was originally developed at the Johnson Space Center for rapid conversion of the Landsat digital data into hydrographic maps matching standard topographic quadrangle series. Recent improvements in both the manual procedures and computer programs within the DAM package make it easier to use, faster, and more general purpose.

Documentation and software for the DAM package are available to all public and private agencies, in accordance with the NASA policy of encouraging maximum use of remote sensing technology.

Published documentation, of which this is volume 3, is comprised of the following volumes:

Volume 1: General Procedure

Volume 2: Software User Manual (in two parts)

Volume 3: Control Network Establishment

These volumes supersede the previous documentation published in 1973. Software releases prior to version 7602 cannot be used with the current documentation.

CONTENTS

FIGURES

ACRONYMS

CCT	computer-compatible tape
DAM	Detection And Mapping package
GMT	Greenwich mean time
JSC	Lyndon B. Johnson Space Center
MSS	Multispectral scanner
Pixel	picture element
RMS	root mean square
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

1. INTRODUCTION

The Landsat satellites circle the earth every 103 minutes in near-polar, sun-synchronous orbits. During each southbound (daylight) pass the multispectral scanner (MSS) onboard can produce a digital image of the earth's surface radiance in a continuous swath 185 kilometers (100 nautical miles) wide.

The MSS digital data are recorded in a dynamic, scanner-oriented, coordinate system. To allow mapping and direct correlation with information from other sources, MSS data must be transformed into a static, earth-oriented coordinate system. The approximate coefficients for such a transformation may be derived from system measurements of spacecraft orbit and attitude and of scanner geometry. Exact transformation coefficients must be computed from a network of control points for which both scanner-oriented and earth-oriented coordinates are known.

The remainder of this section describes the MSS data characteristics and the criteria for establishing a control network.

1.1 MSS CHARACTERISTICS

The MSS records spectral information in four channels covering the following wavelengths:

Channel	Spectral Band	Wavelength (micrometers)	
1	4	0.5 – 0.6	visible
2	5	0.6 – 0.7	
3	6	0.7 – 0.8	reflective infrared
4	7	0.8 – 1.1	

The MSS uses an oscillating mirror to scan perpendicular to the satellite's orbital path. The instrument's instantaneous field of view is sampled 3,240 times* during each active scan line and the analog detector signals for each of these picture elements (pixels) are digitized. Satellite motion provides along-track progression of the scan lines. Rotation of the earth under the satellite orbit results in progressive offset to the west of successive scan line coverage.

1.2 MSS DATA PRODUCTS

The continuous MSS coverage is transmitted back to the ground and segmented into scenes of 2,340 scan lines by 3,240 samples* (approximately 100 by 100 nautical miles on the ground) or 7,581,600 pixels. Each scene is then further processed into a number of data products available to the public. The two products which concern us in this volume are:

- System-Corrected Images. Each image covers an entire scene, except for 42 lines at the top and 42 lines at the bottom. The images are radiometrically calibrated and approximately corrected for scanner geometry, spacecraft altitude/attitude, and earth rotation based on satellite tracking and telemetry data. Figure 1 shows a typical system-corrected image of channel 4 (band 7). The ERTS-1 Data User's Handbook (reference 1) describes the various scales and formats available.
- "System-corrected" Computer-compatible Tape (CCT). Digital MSS data for each 100 by 100 nautical mile Landsat scene are divided into four 25-mile wide-strips (numbered 1 through 4 from left to right). The data are radiometrically calibrated, but not corrected for scanner geometry or orbital characteristics. The data for all four strips of the scene are then recorded on either 1, 2, or 4 reels of computer tape, depending on the file structure and recording density.

*This is an approximate number. The number of samples per scan line is constant within any individual scene, but may vary from scene to scene.

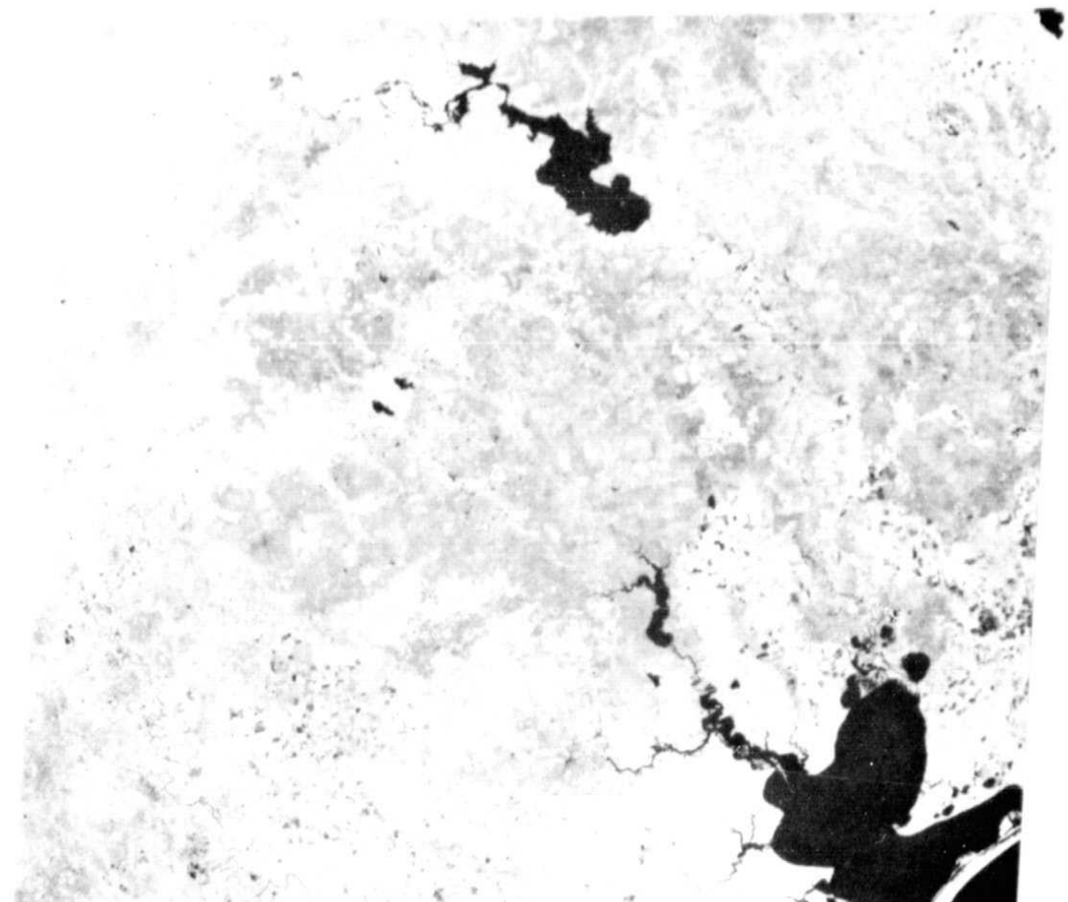


Figure 1. – Landsat System-Corrected Image (Reduced).

1.3 SCANNER-ORIENTED COORDINATES

Based on the conventions explained above and in reference 1, the following standardized notation will be used for identifying the scanner-oriented coordinates of a pixel:

(1) Scan lines are numbered from 1 to 2340, starting at the top of each scene.

(2) Samples are numbered from 1 to 3240 (approximately) starting at the left of each scene.

(3) Pixels are referenced by the coordinate pair (line-number, sample-number).

1.4 EARTH-ORIENTED COORDINATES

Earth-oriented coordinates of a control point may be in any of the following coordinate systems:

(1) Geodetic Latitude and Longitude in degrees or in degrees: minutes:seconds, to the nearest 0.001 degree.

(2) Universal Transverse Mercator (UTM) Easting and Northing in kilometers or in meters, to the nearest 10 meters. The zone number(s) must be specified.

1.5 CONTROL NETWORK CRITERIA

As explained previously, accurate positional measurements of a representative sampling of control points throughout each scene are needed to compute reliable transformation coefficients for that scene. This network of control points should meet the following criteria:

- The control points must be distributed uniformly within the scene.
- The features used for control must be stable over time.
- The point used for control must be well-definable, both on the scanner data display and on recent, reliable maps.

- Scanner-oriented coordinates of control points must be precisely measured.
- Earth-oriented coordinates (geographic or UTM) of control points must be precisely measured from recent, reliable maps.
- The control network must be internally consistent, as demonstrated by a mathematical adjustment yielding minimal residual errors.

Section 2 gives detailed procedures for laying out such a control network and section 3 gives detailed procedures for refining and validating the network.

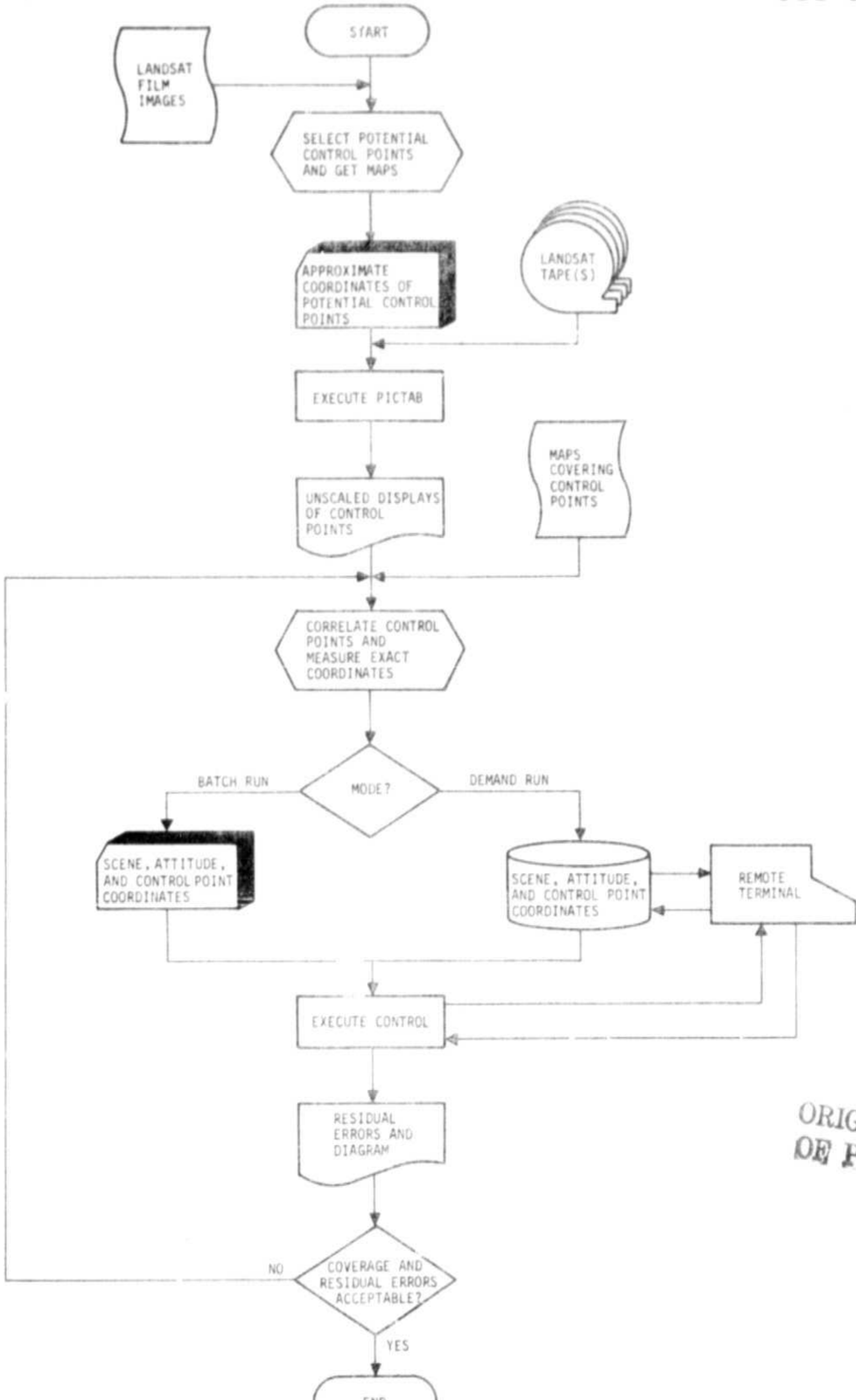


Figure 2. – Flow chart for control network establishment.

2. LAYING OUT THE CONTROL NETWORK

This section describes the initial phase of control network establishment, in which potential control points are selected and their approximate scanner-oriented coordinates determined.

Specific operations in this phase are:

(1) Outline area covered by Landsat scene on 1:1,000,000 scale map (preferably on Index to Topographic Map).

(2) Select network of potential control points for scene from the Landsat film image and corresponding Index to Topographic Maps.

(3) Measure approximate scanner-oriented coordinates of each potential control point from the Landsat film image.

Special materials required for this phase are:

(1) Positive transparencies of Landsat 9.5-inch system-corrected images (scale 1:1,000,000), channel 4 (band 7).

(2) USGS State Index to Topographic Maps (index is at scale of 1:1,000,000).

(3) Set of graphic devices listed in the appendix.

2.1 LOCATING LANDSAT COVERAGE

First, outline the area covered by the Landsat scene on a 1:1,000,000 scale map. Within the U.S.A., the appropriate USGS State Index to Topographic Maps is recommended for this purpose. The coverage outline may be readily transferred from a 9.5-inch system-corrected image, either by eye or by tracing directly onto the base map using a light table.* Once outlined, divide the area into four equal strips corresponding to the coverage of the four CCT's.

Next, position and tape a set of the ERTS-1 MSS scales (see figures 3 and 4) to the system-corrected image of channel 4 (band 7) as follows:

(1) Position the scale marked 18.6 CM = 3,240 SAMPLES (see figure 3) over the image, lining up the left edge (sample 0) with the left edge of the image, and the right edge (sample 3,240) with the right edge of the image, and tape to the image.

(2) Position the scale marked 18.1 CM = 2,256 LINES (see figure 4) on top, lining up line 42 with the top of the image and line 2,298 with the bottom of the image, and tape it.

The scales may not fit the image exactly due to the slight variations in image dimensions. If this is the case, try to achieve the best average fit. When positioned properly over the image, the scales will appear similar to figure 5. Note that they are not oriented at right angles, but match the angle made by the edges of the image.

The overlaid image will be used in selecting potential control points as described in the next part of this report, as well as in measuring the approximate control point coordinates (paragraph 2.3).

*In the event that the scene outline cannot be located precisely from the channel 4 (band 7) image, the channel 2 (band 5) image may be found more useful for this purpose.

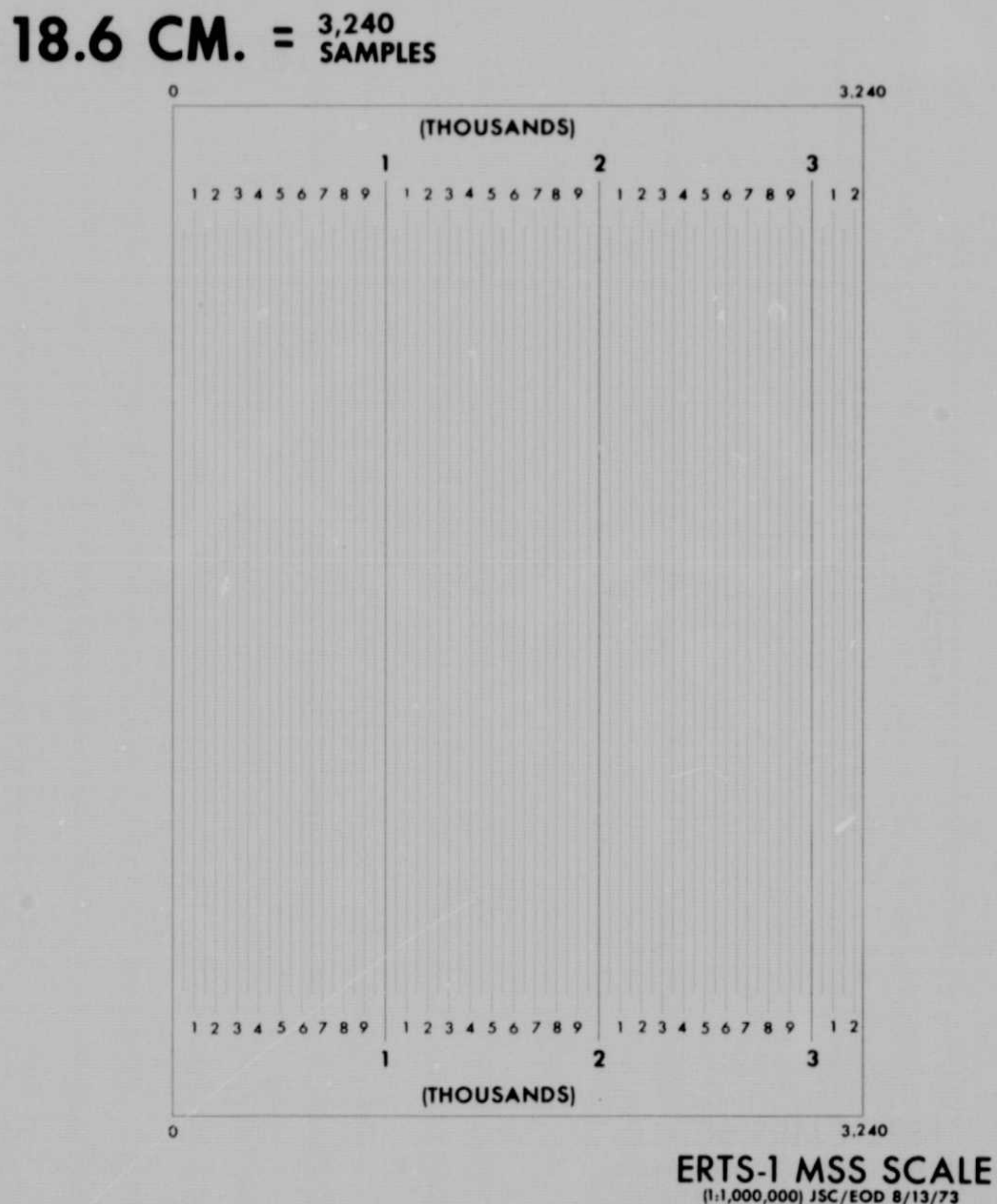
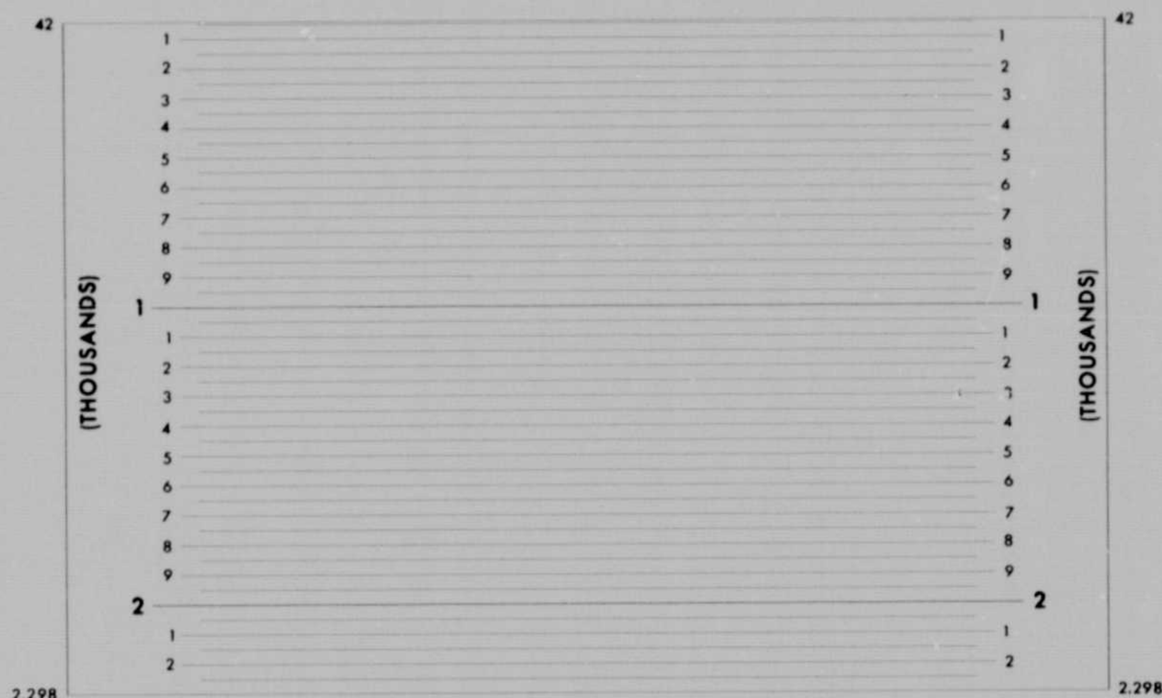


Figure 3. – Scale for 3,240 samples (reduced).

18.1 CM. = 2,256 LINES



ERTS-1 MSS SCALE

(1:1,000,000) NOTE: SCAN LINES 1-42 AND 2,299-2,340 ARE ON TAPES BUT NOT ON IMAGES. JSC/EOD 8/13/73

Figure 4. – Scale for 2,256 lines (reduced).

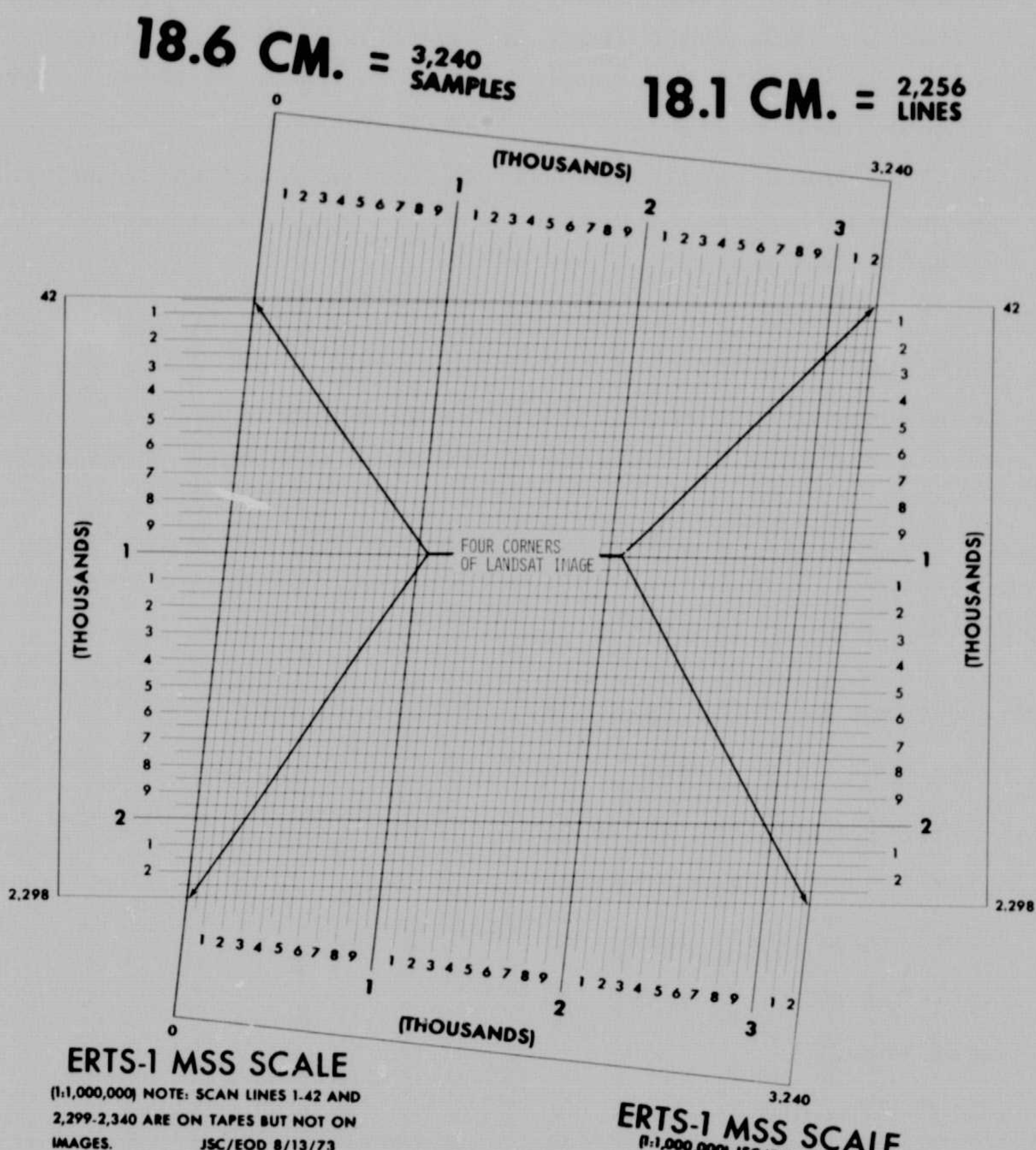


Figure 5. – Line and sample scales taped in position (reduced).

2.2 SELECTING POTENTIAL CONTROL POINTS

All potential control points must lie in areas covered by USGS map quadrangles of either the 7.5- or 15-minute series, as determined from the USGS State Index to Topographic Maps.* Areas covered by 7.5-minute quadrangles are preferable to those covered by 15-minute quadrangles for the following reasons:

(1) The 7.5-minute quadrangles are closer in scale to computer-generated displays of control points, and thus easier to visually correlate.

(2) The 7.5-minute quadrangles are generally more recent and more reliable.

(3) Geographic or UTM coordinates can be measured more easily and more accurately from the larger-scale 7.5-minute quadrangles.

Select the network of potential control points for each scene using features associated with water bodies visible on the system-corrected image of channel 4 (band 7) (figure 1).

Some features which may provide good control are:

- sharp bend in a stream
- intersection of two streams
- major bridge across a stream
- identifiable small lake
- small island in a larger lake
- small strait

*Many parts of the world are not covered by either 7.5-minute or 15-minute quadrangle maps. However, the procedure described in this manual can be used with other maps; i.e., county highway maps. The largest scale and most accurate maps should be used.

Shoreline features in relatively flat terrain should not be used for control since they usually fluctuate with changes in water level.

Six well-distributed control points are required for each scene when more than one of the four CCT's is being processed. At least one of these points must be near each corner of the scene and one near the center. In addition, each of the four CCT strips must contain at least one of these points. In figure 6, control points 1, 2, 3, 4, 5, and 6 provide an acceptable minimum network for the scene.

When processing only one CCT strip of a scene, a minimum network for the CCT strip may be obtained with a total of only five points within the strip (one at each corner and one in the center). In figure 6, control points 5, 6, 7, 8, and 9 provide an acceptable minimum network for CCT strip number 4.

Increasing the number of control points for each scene above 6 will generally increase the accuracy of mapping, provided the points are evenly distributed.

More potential control points should be selected than will be required, since several may prove to be invalid or unusable. A good rule of thumb is to select two potential control points for each valid control point desired.

After selection of the potential control points, the next step is to measure their approximate coordinates using the ERTS-1 MSS scales overlaid on the 9.5-inch image.

2.3 MEASURING APPROXIMATE CONTROL POINT COORDINATES

Estimate the scanner-oriented coordinates of potential control points using the ERTS-1 MSS scales previously taped over the

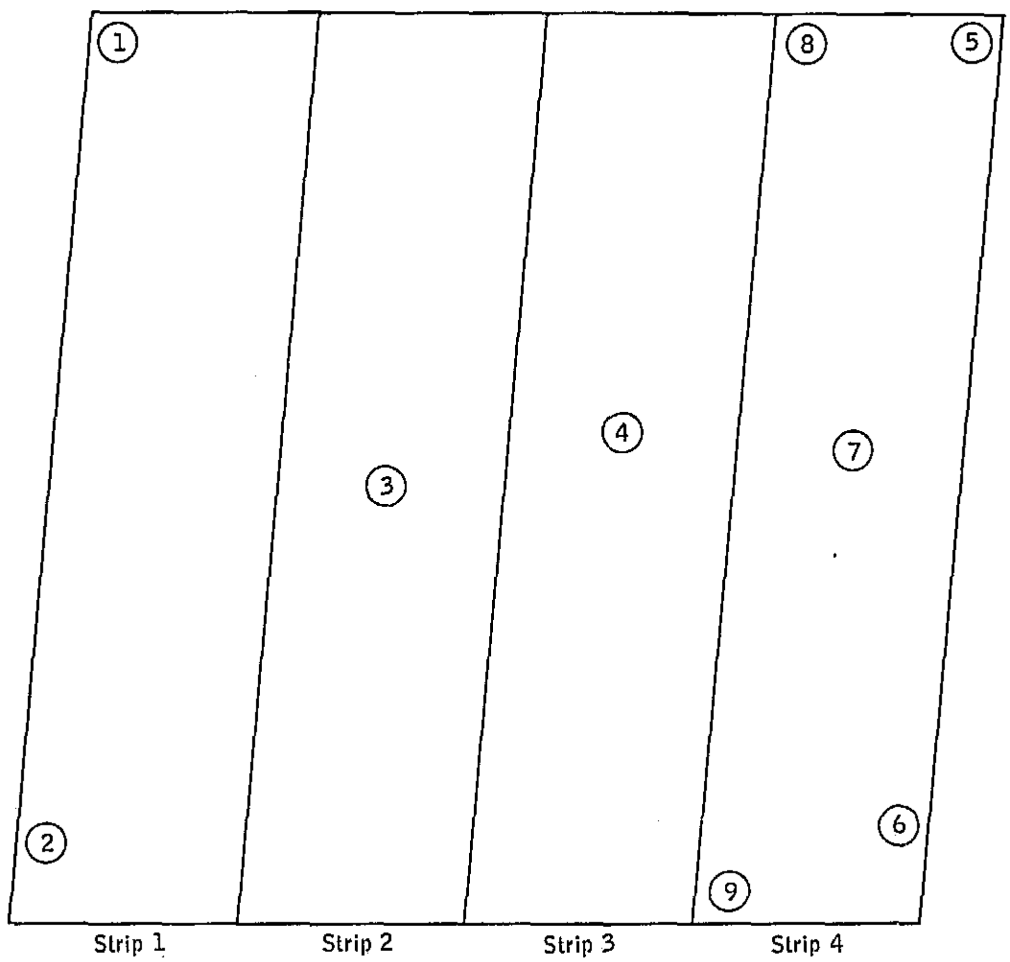


Figure 6. — Typical minimum control network. Points 1-6 provide a minimum network for the entire scene. If only strip 4 is to be processed, points 5-9 provide a minimum network for this strip.

9.5-inch system-corrected image as discussed in paragraph 2.1. For example, the picture element (pixel) in the lower right-hand corner of the image is located at line number 2298 and at sample number 3240. Following the Landsat convention of giving line number before sample number, we identify the scanner-oriented coordinates of this pixel as 2298, 3240.

Scanner-oriented coordinates should be interpolated to the nearest five or 10 lines and samples. The error in these estimated coordinates will generally be less than 80 lines and 50 samples.

The following information for each potential control point should be recorded on a list or map:

- control point number
- approximate scanner-oriented coordinates
- quadrangle name and map series

After completion of the above, the potential control points are subjected to additional processing and tests before the control point network is considered to be established. These are described in the next section of this report.

3. EVALUATING THE CONTROL NETWORK

This section describes the final phase of control network establishment, in which the potential control points which were selected and measured in section 2 are refined and validated and their exact coordinates are determined.

The specific operations in this phase are to:

(1) produce a computer-generated display for each potential control point.

(2) visually correlate the computer-generated display of each control point with its representation on a map.

(3) measure exact scanner-oriented and earth-oriented coordinates of each control point.

(4) adjust the control network, evaluate residual errors, and make necessary corrections.

The special materials required for this phase are listed below:

(1) List or map produced in the initial phase giving approximate scanner-oriented coordinates for all potential control points.

(2) Landsat system-corrected MSS tapes.

(3) USGS State Index to Topographic Maps (or equivalent).

(4) USGS 7.5- or 15-minute quadrangle (or equivalent) for each potential control point.

(5) Supply of blank Control Point Worksheets.

(6) Set of graphic devices listed in the appendix.

3.1 DISPLAYING POTENTIAL CONTROL POINTS

Each Landsat pixel represents an area of approximately 1.7 acres on the surface of the earth. The pixels with MSS channel 4 (band 7) radiance values between 0 and 4 generally fall entirely over fresh, clear water bodies. Pixels with somewhat higher radiance values in channel 4 (band 7) typically fall over turbid water, over wetlands, or partly over water and partly over land. A display of pixels with channel 4 (band 7) radiance values from 0 to approximately 14 will include most major lakes and streams, which is useful for selecting control points, but may also contain some features of questionable usefulness.

Displays of all potential control points should be generated with the PICTAB program (see volume 2). When executing the program in batch mode the window displayed for each potential control point should include "buffers" of at least 80 lines and 50 samples around its estimated coordinates, to allow for errors in the estimate. A demand terminal user may achieve the same result by generating several displays with various spacings and origins. Regardless of mode, the following rules apply:

(1) Always start with displays of channel 4 (band 7) radiances between 0 and 14.

(2) Always use displays with line and sample spacing of 1 for exact correlation and control point measurement.

The computer-generated displays of the potential control points are next compared visually with topographic quadrangle maps of the areas containing the points to determine which points are suitable for inclusion in the control point network.

3.2 VISUAL CORRELATION OF CONTROL POINTS

The user should compare the channel 4 (band 7) computer-generated display of each potential control point with its representation on a USGS 7.5- or 15-minute quadrangle map to verify that:

(1) The feature used for control has not changed between the date it was mapped and the date of the Landsat overpass.

(2) The control point itself is well defined on both the computer-generated display and the map.

This comparison is most easily performed (for maps at the scale of USGS 7.5-minute quadrangle sheets) by overlaying the computer-generated display and the quadrangle map on a light table. Once they have been shifted and rotated to bring the control point into coincidence, a pointed instrument may be used to simultaneously prick the location on both. (This marked location should be exactly in the center of a print character on the display.)

All control points should be correlated, marked, and labelled. Inconclusive and incorrect points should be discarded.

The network of potential control points which have been validated should now be examined. These valid control points should be distributed evenly throughout the scene, with a minimum of one point near each of the four corners, and one point near the center (in addition, each strip must contain at least one point). If these conditions are not met, additional control points must be selected and validated.

Figures 7 through 11 illustrate some of the situations which may arise in evaluating potential control points. The computer-generated displays in these figures were produced from CCT's for the following two Landsat scenes:

- E-1132-16535, strip 3, December 2, 1972, covering the Howard County, Texas, vicinity.
- E-1073-16244, strip 3, October 4, 1972, covering the Houston, Texas, vicinity.

Each figure contains seven reduced computer-generated displays at the upper right, identified as T=9 through T=15. The "T" refers to the maximum channel 4 (band 7) radiance value displayed. A bold arrow indicates the minimum channel 4 (band 7) radiance value displayed at full size on the left side of the figure. Channel 4 (band 7) radiance values in these full-size displays are symbolized as follows:

Channel 4 Radiance	Display Symbol
0-9	0-9
10	A
11	B
12	C
13	D
14	E
15	F

The lower right side of each figure contains the part of a USGS quadrangle map corresponding to the area covered in the computer-generated display. Note that the area covered is "skewed" due to the effects to earth rotation.

Please turn to the next page.

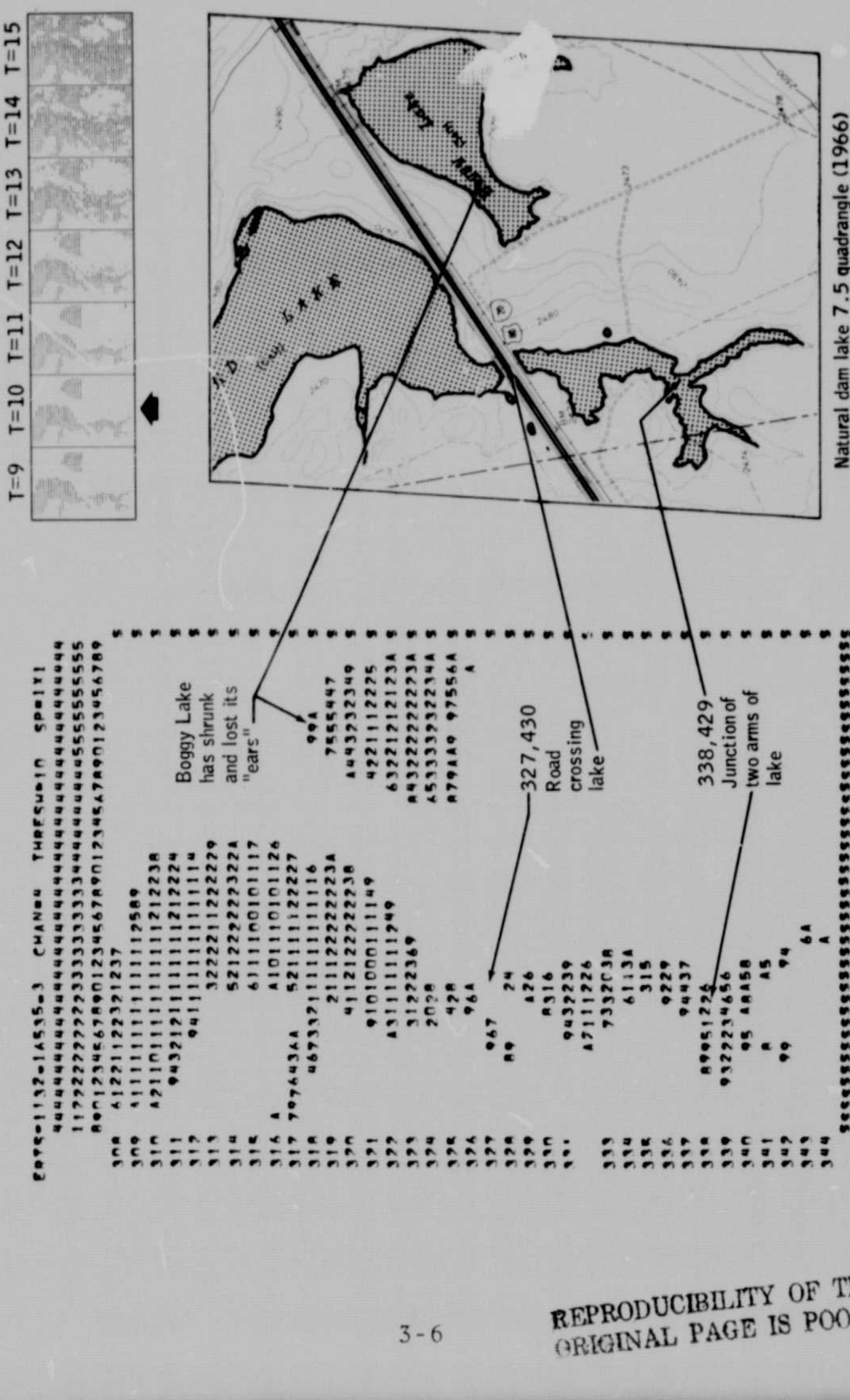


Figure 7. - Control point evaluation (1 of 5).

Figure 7. — Computer-generated display clearly pinpoints pixel (327,430) as the point where U.S. 80 and a railroad cross Red Lake on an embankment. No additional control points are required on this map sheet since control should be evenly distributed throughout the entire scene. However, this example also illustrates several other considerations in evaluating control points. Although the arms at the southern end of Red Lake are several pixels wide, their centers may be clearly traced by following the lowest channel 4 (band 7) radiance values — pixels with higher radiance values are generally perimeter pixels containing mixtures of land and water. This allows us to pinpoint another valid control point, the intersection of these arms at pixel (338,429). Boggy Lake illustrates the dangers of choosing shoreline features for control. This lake has apparently shrunk and lost its "ears". Less drop in water level might have shifted the positions of these "ears" without noticeably changing their shapes. Also note that channel 4 (band 7) radiance values of 0 to 10 are displayed.

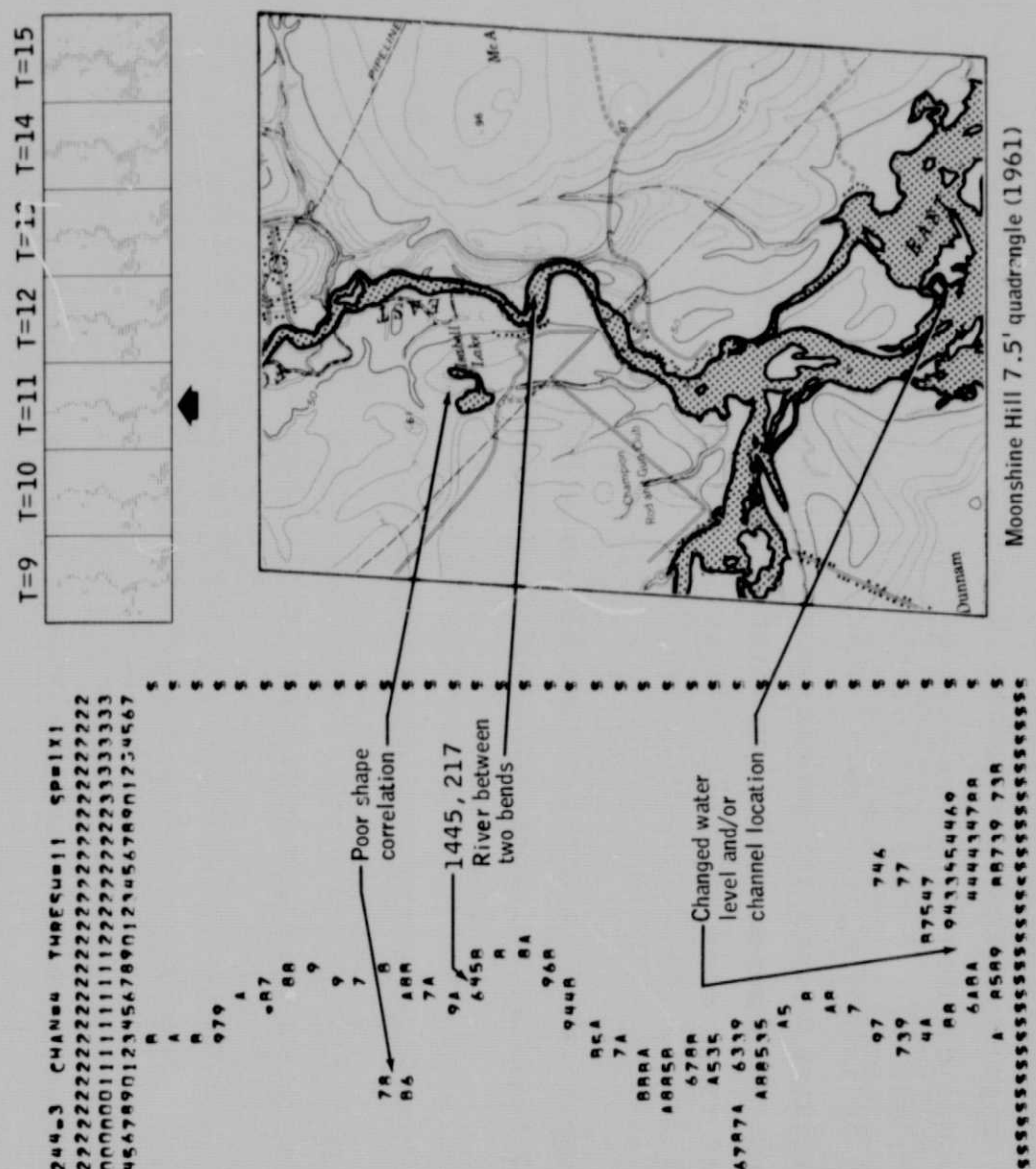


Figure 8. - Control point evaluation (2 of 5).

Figure 8. — Pixel (1445,217) is a good control point. It has a relatively low channel 4 (band 7) radiance value of 4, and its two neighbors are almost as low. Together the three correspond to the wide section of the river between two sharp bends. There are no other good control points on this display. It is uncertain whether bends in the upper part of the river have changed between the map date and the date of the Landsat overpass. Also note that the shapes shown for Isabell Lake on the map and on the computer-generated display do not agree, and cannot be made to agree by varying the range of channel 4 (band 7) radiance values displayed. Finally, considerable changes in water level and/or channel location between the computer-generated display and the map are evident.

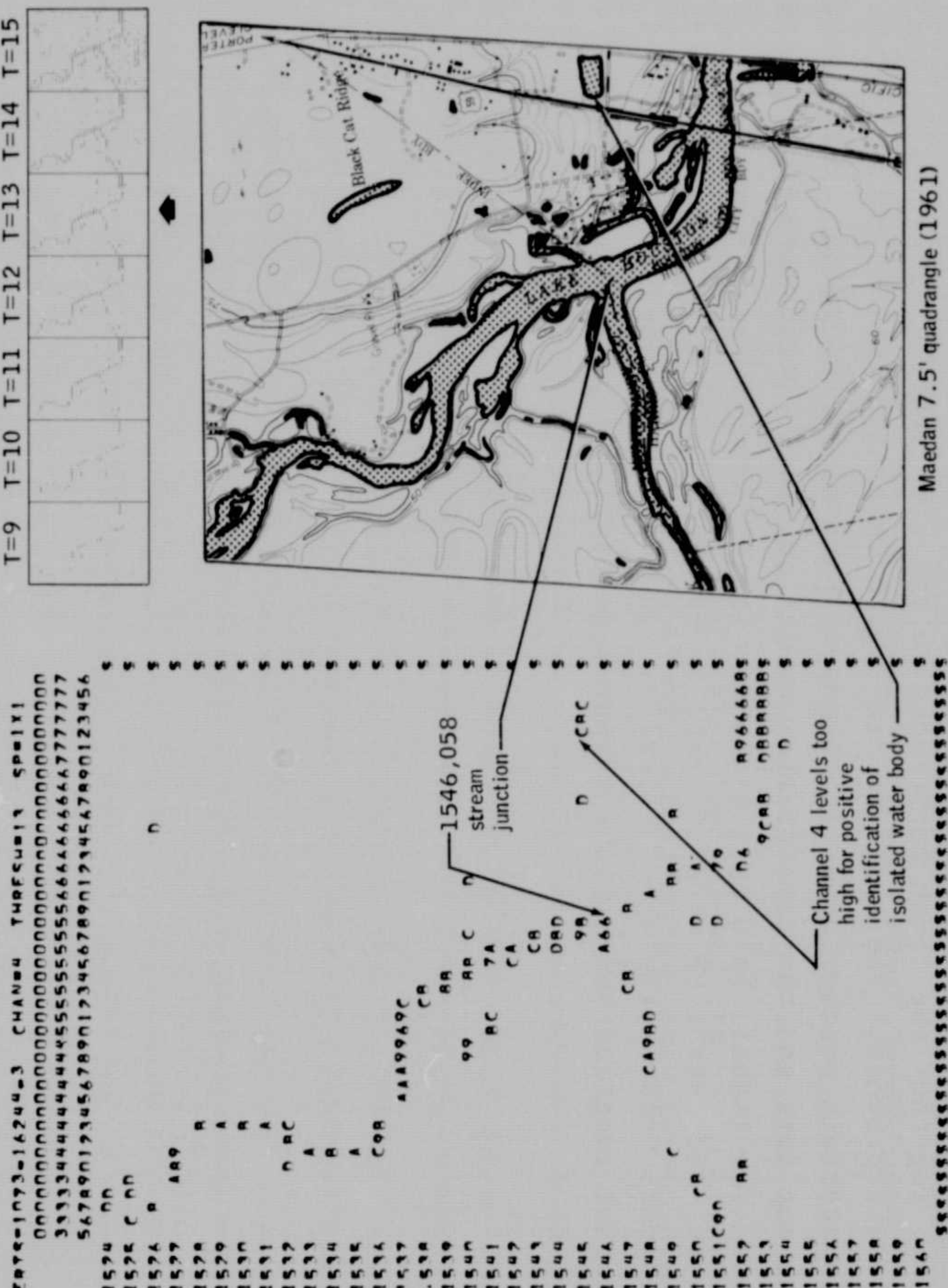


Figure 9. - Control point evaluation (3 of 5).

Figure 9. — The stream junction at pixel (1546,058) is a good control point, with the relatively low channel 4 (band 7) radiance value of 6. Note, however, that a maximum channel 4 (band 7) radiance value of 13 is required to display enough of the smaller stream at the left to validate its junction point with the main stream. This is reasonable since the left stream is fairly narrow, resulting in these pixels representing a mixture of water and land. Moreover, its computer-generated display does agree in shape with the map and does contain some scattered pixels with channel 4 (band 7) radiance values as low as 9. On the other hand, the small, regularly-shaped water body in the right center of the map is of questionable value as a control point. It lies in flat terrain and is probably man-made and subject to change both in location and area. It appears to be correlated with a group of three pixels similarly located on the computer-generated display. However, the channel 4 (band 7) radiance values of these isolated pixels are too high (11 and 12) for positive identification of this feature. The rule here should be: "When in doubt, throw it out!" Finally, note that the lake just to the left of Black Cat Ridge does not appear on any of the computer-generated displays, regardless of which channel 4 (band 7) radiance values are displayed.

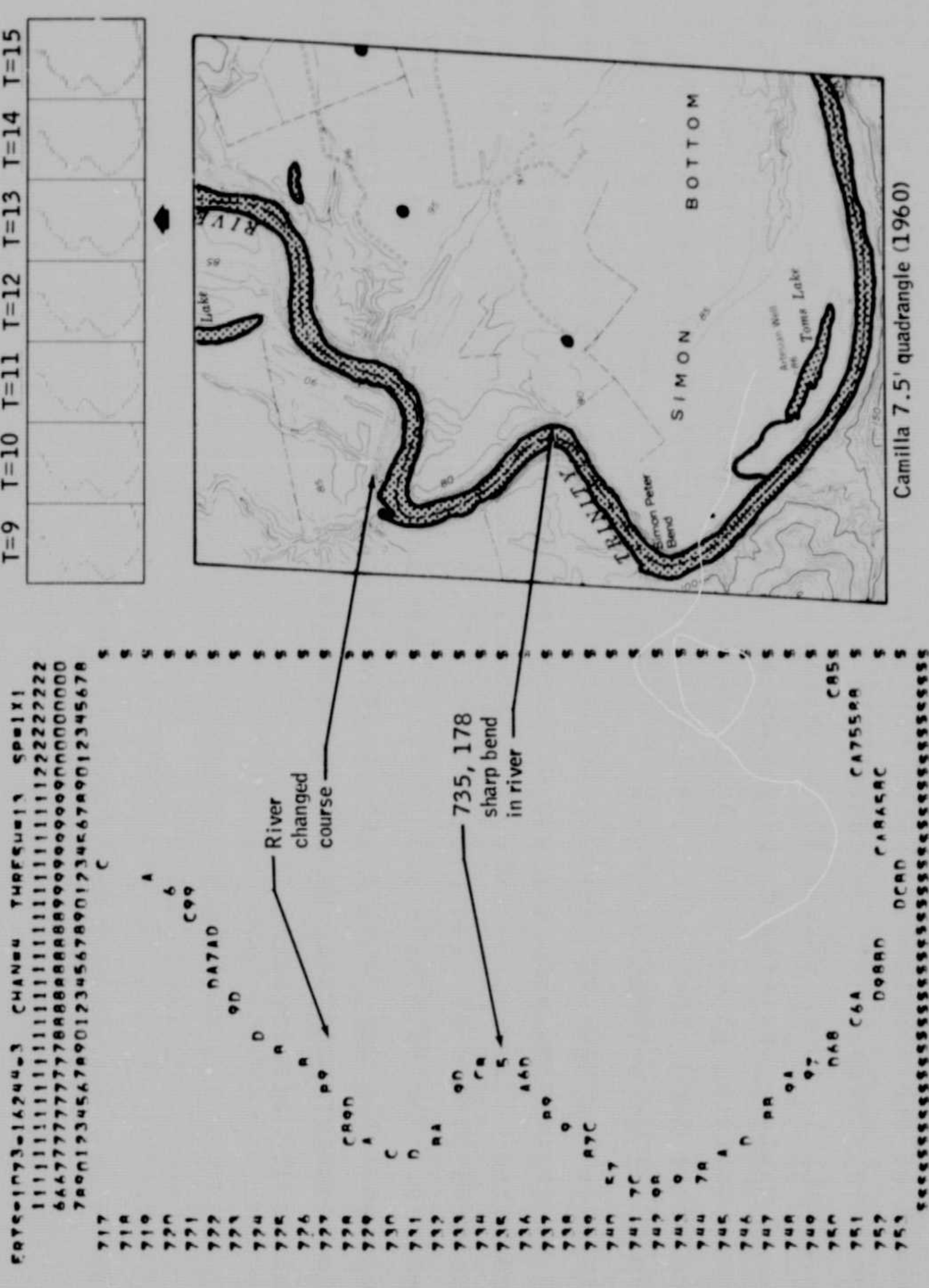


Figure 10. - Control point evaluation (4 of 5).

Figure 10. – The sharp bend in the river at pixel (735,178) is a good control point. The sharp bend just above it on the map would have been a good control point – if it still existed. This illustrates a common problem associated with the use of water features for control – those points which are well-defined often tend to be the least stable over time. Also note that the lakes at the top and bottom of the map do not appear in any of the computer-generated displays, even when displaying pixels with channel 4 (band 7) radiance values as high as 15.

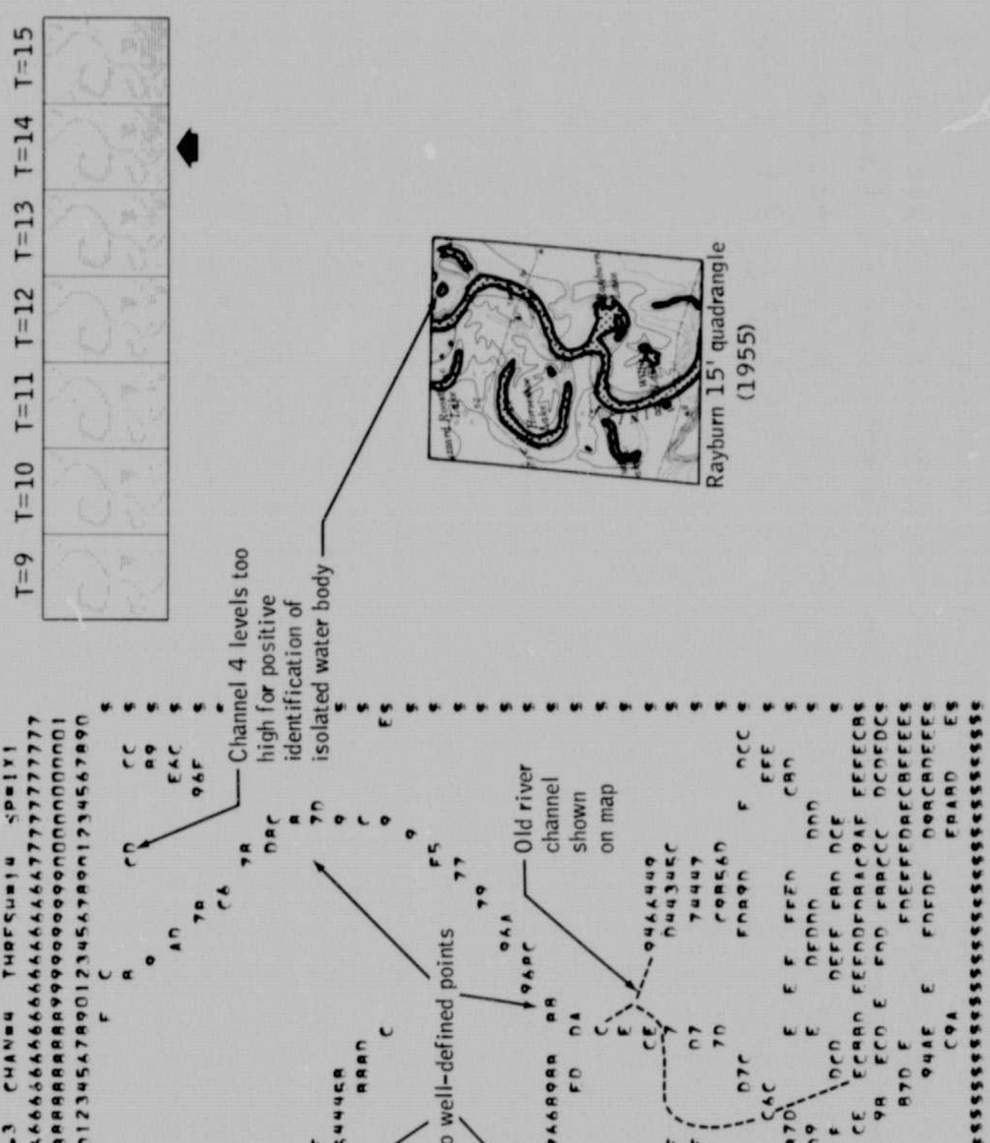


Figure 11. - Control point evaluation (5 of 5).

Figure 11. — This figure illustrates several problems: First, the map is from a 15-minute series quadrangle, at a scale of 1:62,500. This smaller scale makes visual comparison with the computer-generated display more difficult. Next, the river has changed course completely in the vicinity of Rayburn Lake since the map was compiled in 1955. Also, water bodies on the map which appear not to have changed do not contain any well-defined points. The one possible exception is the small lake at the top of the map just to the right of the river. This lake appears to correspond to a pair of pixels on the computer-generated display. Again, however, the channel 4 (band 7) radiance values of these isolated pixels are too high (12 and 13) for positive identification of this feature.

After completing visual correlation of the potential control points as shown on computer-generated displays and topographic maps, the next step is to measure the exact earth-oriented and scanner-oriented coordinates of the points which satisfy the criteria set forth above. These exact coordinates, together with attitude (pitch and roll) data from the computer-generated displays, serve as input to computer program CONTROL for mathematical adjustment of the control point network (part 3.4 below and volume 2).

3.3 MEASURING EXACT CONTROL POINT COORDINATES

Exact scanner-oriented coordinates and geographic or UTM coordinates must be measured for all valid control points. A Control Point Worksheet (figure 12) should be used to record the measured coordinates for all control points. A partially completed worksheet is shown in figure 13. Note that latitude and longitude are entered in degrees to the nearest 0.0001°. Also note that the worksheet contains a table to facilitate conversion of 2.5-minute parallels and meridians from degrees/minutes/seconds to decimal equivalents in degrees. These conversions are required when using the geographic nomoscales explained later in the paragraph. Scanner-oriented coordinates should be entered on the worksheet to the nearest line number and nearest sample number. Every valid control point should be plainly marked and numbered on both the computer-generated display and the USGS quadrangle map and described briefly on the worksheet.

Each display generated by PICTAB contains line scales at the left and sample scales at both the top and the bottom. In addition, the displays usually contain internal tick marks every 10 lines and samples. By creasing or cutting the display just above the bottom sample scale, this scale can be positioned on a control point and used (in conjunction with the line scale) to read off its exact scanner coordinates.

Min/Sec	Degrees	Min/Sec	Degrees	Min/Sec	Degrees
00'00"	.0000	20'00"	.3333	40'00"	.6667
02'30"	.0417	22'30"	.3750	42'30"	.7083
05'00"	.0833	25'00"	.4167	45'00"	.7500
07'30"	.1250	27'30"	.4583	47'30"	.7917
10'00"	.1667	30'00"	.5000	50'00"	.8333
12'30"	.2083	32'30"	.5417	52'30"	.8750
15'00"	.2500	35'00"	.5833	55'00"	.9167
17'30"	.2917	37'30"	.6250	57'30"	.9583

GEOGRAPHIC CONTROL POINT WORKSHEET

ERTS SCENE ______________

CCT STRIP NUMBER ______________

PITCH __________ ROLL __________

CODED BY: __________ DATE __________

CONTROL POINT	(1) NUMBER							
	(2) FEATURE							
	(3) USGS QUADRANGLE							
LATITUDE NORTH	(4) 2.5' PARALLEL SOUTH OF POINT (degree/min/sec)							
	(5) 2.5' PARALLEL SOUTH OF POINT (degrees)							
	(6) LATITUDE INCREMENT TO POINT (degrees)*							
	(7) TOTAL LATITUDE OF POINT ((5)+(6)) (deg)							
LONGITUDE WEST	(8) 2.5' MERIDIAN EAST OF POINT (deg/min/sec)							
	(9) 2.5' MERIDIAN EAST OF POINT (degrees)							
	(10) LONGITUDE INCREMENT TO POINT (degrees)*							
	(11) TOTAL LONGITUDE OF POINT ((9)+(10)) (deg)							
SCANNER COORD.	(12) LINE							
	(13) SAMPLE							

* from NOMOSCALE

Figure 12. – Blank geographic control point worksheet.

Min/Sec	Degrees	Min/Sec	Degrees	Min/Sec	Degrees
00'00"	.0000	20'00"	.3333	40'00"	.6667
02'30"	.0417	22'30"	.3750	42'30"	.7083
05'00"	.0833	25'00"	.4167	45'00"	.7500
07'30"	.1250	27'30"	.4583	47'30"	.7917
10'00"	.1667	30'00"	.5000	50'00"	.8333
12'30"	.2083	32'30"	.5417	52'30"	.8750
15'00"	.2500	35'00"	.5833	55'00"	.9167
17'30"	.2917	37'30"	.6250	57'30"	.9583

GEOGRAPHIC

CONTROL POINT WORKSHEET

ERTS SCENE 1073-16244 (4 Oct 72)

CCT STRIP NUMBER 3 (3240 samples)

PITCH +0.27 ROLL -0.55

CODED BY: EAS DATE 5/3/76

CONTROL POINT	① NUMBER	8	9					
	② FEATURE	RIVER BET. 2 BENDS	STREAM JUNCTION					
	③ USGS QUADRANGLE	MOONSHINE HILL 7.5'	MAEDAN 7.5'					
LATITUDE NORTH	④ 2.5' PARALLEL SOUTH OF POINT (degree min sec)	30°05'00"	30°00'00"					
	⑤ 2.5' PARALLEL SOUTH OF POINT (degrees)	30.0833	30.0000					
	⑥ LATITUDE INCREMENT TO POINT (degrees)*	.0050	.0321					
	⑦ TOTAL LATITUDE OF POINT (⑤+⑥) (deg)	30.0883	30.0321					
LONGITUDE WEST	⑧ 2.5' MERIDIAN EAST OF POINT (deg min sec)	95°07'30"	95°15'00"					
	⑨ 2.5' MERIDIAN EAST OF POINT (degrees)	95.1250	95.2500					
	⑩ LONGITUDE INCREMENT TO POINT (degrees)*	.0247	.0131					
	⑪ TOTAL LONGITUDE OF POINT (⑨+⑩) (deg)	95.1497	95.2631					
SCANNER COORD.	⑫ LINE	1445	1546					
	⑬ SAMPLE	1837	1678					

* from NOMOSCALE

Figure 13. – Partially completed geographic control point worksheet.

Exact UTM coordinates can be measured from the quadrangle maps with either a metric scale or a special coordinate template, by first constructing the grid lines to the left and below the control point (using blue ticks in the map margin as a guide) and then measuring the incremental distances from these grid lines.

Exact geographic coordinates can be measured from the USGS 7.5- and 15-minute quadrangle maps using a set of geographic nomoscales (see figures 15 and 16). These nomoscales can be used to measure latitude and longitude anywhere in the western hemisphere between latitudes 23° North and 55° North.* Detailed instructions for the calibration and use of the nomoscales are contained on the scales. Figure 17 illustrates the calibration of a nomoscale and figure 18 illustrates the use of a nomoscale to measure geographic coordinates.

The exact scanner-oriented and earth-oriented coordinates for all potential control points accepted as meeting the criteria in paragraph 3.2 above are measured and entered on the Control Point Worksheets. The network of individually valid control points must now be adjusted mathematically and any residual errors determined by use of the CONTROL program as discussed below.

3.4 RESIDUAL ERRORS IN CONTROL POINT ADJUSTMENT

The CONTROL program (see volume 2) corrects the network of control points for attitude and then uses a least-squares procedure to develop a set of transformation coefficients between earth-oriented coordinates and scanner-oriented coordinates which gives the best fit. This program then compares each control point's measured scanner-oriented coordinates with the scanner-oriented coordinates computed from the transformation coefficients.

*These latitudes cover only the 48 conterminous states. The nomoscales must be redesigned for use in other latitudes or hemispheres.

Figure 14. — (Reserved for future use).

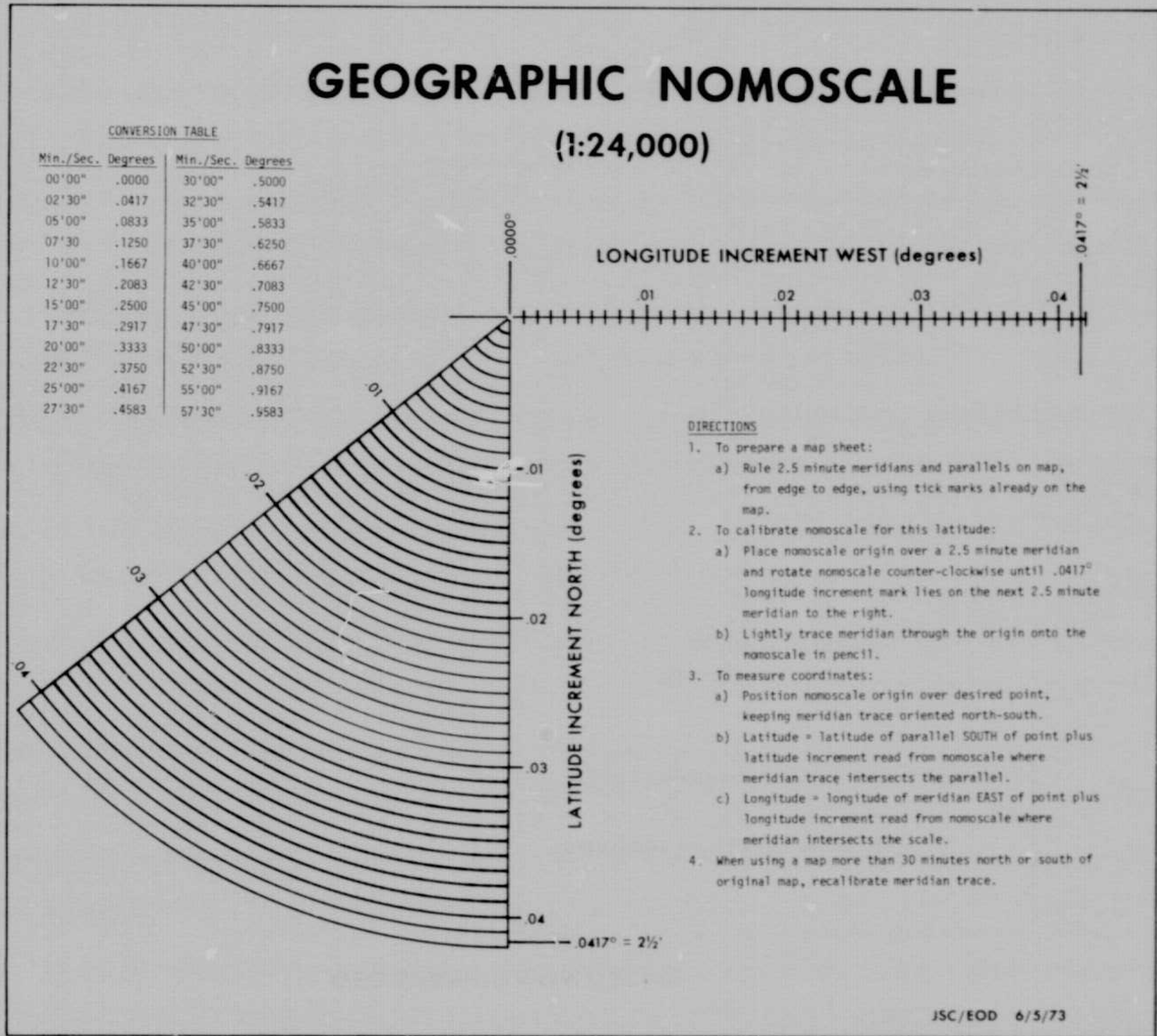


Figure 15. – 1:24,000 geographic nomoscale (reduced).

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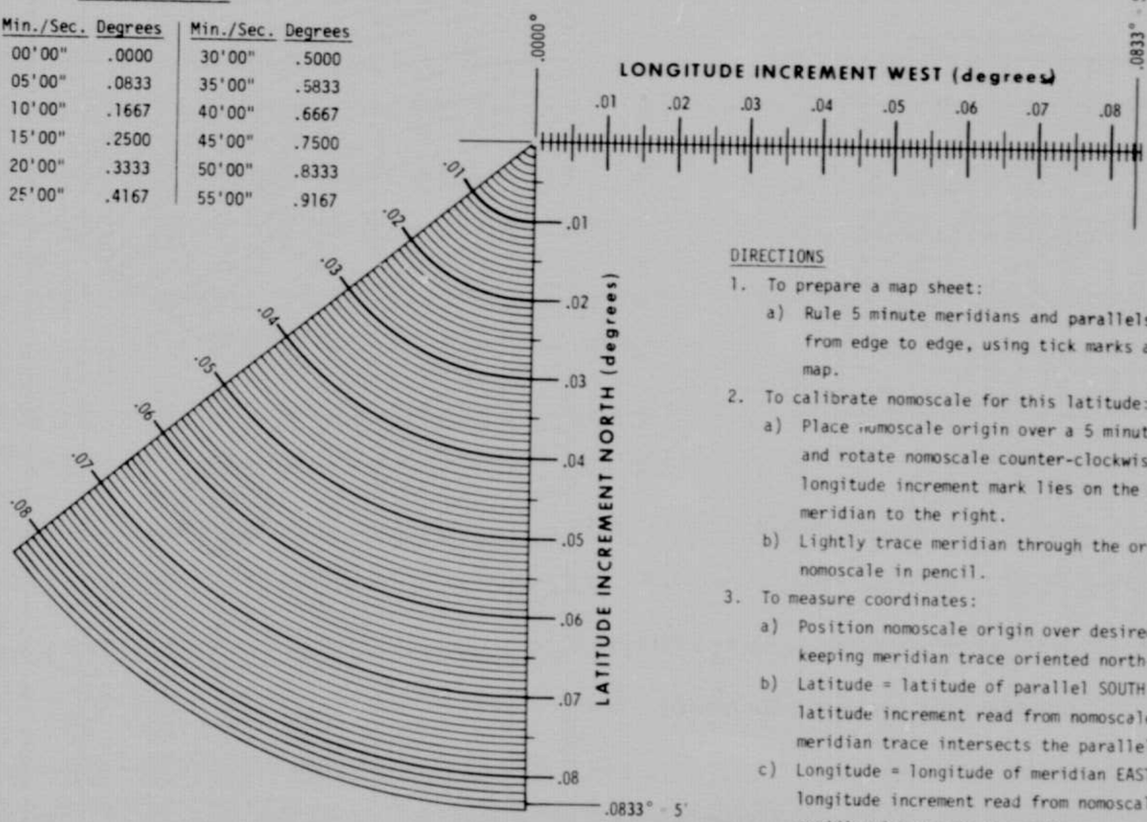
GEOGRAPHIC NOMOSCALE
(1:62,500)

CONVERSION TABLE

Min./Sec.	Degrees	Min./Sec.	Degrees
00'00"	.0000	30'00"	.5000
05'00"	.0833	35'00"	.5833
10'00"	.1667	40'00"	.6667
15'00"	.2500	45'00"	.7500
20'00"	.3333	50'00"	.8333
25'00"	.4167	55'00"	.9167



DIRECTIONS

1. To prepare a map sheet:
   a) Rule 5 minute meridians and parallels on map, from edge to edge, using tick marks already on the map.
2. To calibrate nomoscale for this latitude:
   a) Place nomoscale origin over a 5 minute meridian and rotate nomoscale counter-clockwise until .0833° longitude increment mark lies on the next 5 minute meridian to the right.
   b) Lightly trace meridian through the origin onto the nomoscale in pencil.
3. To measure coordinates:
   a) Position nomoscale origin over desired point, keeping meridian trace oriented north-south.
   b) Latitude = latitude of parallel SOUTH of point plus latitude increment read from nomoscale where meridian trace intersects the parallel.
   c) Longitude = longitude of meridian EAST of point plus longitude increment read from nomoscale where meridian intersects the scale.
4. When using a map more than 30 minutes north or south of original map, recalibrate meridian trace.

JSC/EOD 7/2/73

Figure 16. – 1:62,500 geographic nomoscale (reduced).

Residual errors between measured scanner-oriented coordinates and computed scanner-oriented coordinates are printed to indicate how well the control points have been correlated and measured.

Residual errors should meet the following criteria:

- Every individual control point must have a residual error less than 250 meters.
- The entire control network must have a root mean square (RMS) error less than 125 meters.

In addition, the network should meet the following overall criteria:

- The network must cover more than 50% of the scene.
- The network centroid should be within 20 kilometers of the scene center.
- Control points should be evenly distributed (not "bunched up").

When the network contains a large number of control points (approximately 12 or more) evenly distributed in both lines and samples, an error in coordinates for a single control point should result in a larger residual error for that control point than for any other and therefore, that control point should be reevaluated or discarded. With fewer or poorly distributed control points, the point with the largest residual error may not necessarily be the control point whose coordinates are in error, and, therefore, all control points should be reevaluated.

In any case, if the preceding criteria are not met, the offending control point(s) must be corrected or replaced and the network adjusted again.

Once individual and RMS errors meet the criteria, the control network has been validated for use in producing precisely registered maps from Landsat MSS digital data.

Figure 17. – Calibration of nomoscale.

Figure 18. - Use of nomoscale.

4. REFERENCES

1. NASA Goddard Space Flight Center, "Earth Resources Technology Satellite: Data User's Handbook," 1972.

2. Gr[illegible]eal, G. E.; Hall, F. G.; Moore, B. H.; and Schlosser, E. H.: "ERTS-1 Data in Support of the National Program of Inspection of Dams." Third Earth Resources Technology Satellite-1 Symposium, Vol. 1, Section A, 1973.

APPENDIX A

GRAPHIC DEVICES

APPENDIX A

GRAPHIC DEVICES

- ERTS-1 MSS Scale (18.1 CM = 2,256 lines)
- ERTS-1 MSS Scale (18.6 CM = 3,240 samples)
- Geographic Nomoscale (1:24,000)
- Geographic Nomoscale (1:62,500)