LANDSAT DIGITAL DATA BASE PREPARATION FOR THE PENNSYLVANIA DEFOLIATION APPLICATION PILOT TEST

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ABSTRACT

Landsat digital data are convenient and adaptable sources of data to incorporate as a base in a geographic information system. These data are readily convertible to various map projections and scales and provide the user/analyst with a format similar to that of an aerial photograph. Certain properties associated with the data, however, inhibit widespread use. The framing convention of the Landsat sensor does not lend itself well to imaging entire states or provinces at the required resolution cells. For large areas, digital Landsat data must be geometrically corrected to a standard map projection and then mosaicked.

A Landsat digital mosaic data base for the State of Pennsylvania was prepared for use in the development of an automated system to annually estimate the extent and severity of Gypsy Moth defoliation of hardwood forests. The techniques for detecting the defoliation and development of a Geographic Information System (GIS) to assess damage is being developed jointly by NASA/Goddard Space Flight Center and Pennsylvania State University using the JPL prepared mosaic base. JPL processing involved the use of ground control points from the Master Data Processor (MDP) for planimetric control, resampling of the Landsat data to 57 x 57 meter pixels, realignment to north, and reprojection to the Universal Transverse Mercator (UTM) projection in UTM zones 17 and 18. The completed mosaic for each UTM zone was subdivided into 1 degree of latitude by 2 degrees of longitude quadrangles for easy data handling.

Consideration is given to the issues of mapping standards, sensor and spacecraft platform characteristics, and their implication to geographic information systems operation. Methods for obtaining measures of accuracy for Landsat mosaics are reviewed.

1. INTRODUCTION

Since its introduction from Europe into Massachusetts in the late 1860's, the Gypsy Moth <u>Lymantria dispar</u> (L.), has repeatedly defoliated hundreds of thousands of acres of forest. The mature Gypsy Moth caterpiller is about 2 to 3 inches in length, and as many as 30,000 of these caterpillers can infest a single tree. Each caterpiller can consume up to ten small leaves a day.[1] Over the past ten years, the State of Pennsylvania has attributed the loss of

$32 million dollars worth of timber resources to this pest. The insect does not kill the tree immediately, but after prolonged infestations over several years the tree is destroyed. While the natural spread of the Gypsy Moth is slow, it can move rapidly because of its ability to hitchhike with people traveling through infested areas.

In order to plan appropriate pest management activites, resource managers must continually monitor the movements and damage caused by this insect. Over large geographic areas, conventional methods of surveillance such as field site visits and large-scale aerial photography are prohibitive to use because of cost and time. Alternative methods of assessment must be developed that are inexpensive, timely, and mesh well with current practices.

Developing new assessment methods for Gypsy Moth infestations is the goal of the Pennsylvania Defoliation Applications Pilot Test (APT), a joint study by Goddard Space Flight Center/NASA and Pennsylvania State University. These new methods being developed are to be transferred to the Pennsylvania Division of Forest Pest Management, Bureau of Forestry, for implementation to operational use.

The basic procedure is to utilize multi-date Landsat imagery to monitor the infestations.[2] An image is acquired for an area prior to infestation, and it is classified, using computer aided analysis techniques, to identify the extent of forest cover versus non-forest cover. After insect damage, a second image of the same area is obtained and it is digitally overlaid onto the forest cover map derived from the initial image. Forested areas exhibiting defoliation can then be identified and tabulated. Acreage counts and estimates can be generated and abatement procedures or strategies developed.

While Landsat is a convenient and relatively inexpensive source of data, certain properties associated with the data present problems. The framing convention of the Landsat sensor does not lend itself well to imaging entire states in a single scene. To increase the utility of the data, the Landsat frames must be geometrically corrected to a standard map projection and then mosaicked.

Goddard Space Flight Center, the lead center in this project, initiated a contract with Jet Propulsion Laboratory to prepare a Landsat digital mosaic of the State of Pennsylvania that will be used to address this problem. Three separate mosaics were prepared for the task: (1) an early date mosaic prior to defoliation; (2) the derived forest /non-forest cover map mosaic, and (3) a late date mosaic after defoliation.[3]

2. EARLY DATE MOSAIC

The Landsat data tapes used for the mosaic prior to defoliation were delivered to JPL by Goddard Space Flight Center. Goddard had originally ordered the scenes from EROS Data Center in order to proceed in a parallel effort with other aspects of the project. Table I depicts the Landsat frames used in this mosaic, and Figure 1 shows the individual footprint of each scene for the state.

All processing performed at JPL utilized the Image Processing Laboratory (IPL). IPL hardware resources include an IBM 370/158 with 8 megabytes of memory, eight tape drives, and 3700 megabytes of on-line disk storage. The disk storage consists of CDC 3350 high speed disk drives. Image displays include a Ramtek display system that accomodates 6 bit black and white imagery up to 640 x 512 elements. The other system used consists of two COMTAL display units. A COMTAL 8003 system provides 512 x 512 element resolution for 8 bit color images and includes graphics planes and trackball cursors. A COMTAL 1024 system provides capability to display black and white images at a 1024 x 1024 element resolution.

The IPL also maintains a complete library of over 300 special purpose image processing applications programs. The system in use is the Video Image Communication and Retreival (VICAR) and the Image Based Information System (IBIS) developed at JPL.[4,5]. This system is available from COSMIC for a nominal charge.[6]

Table I.

PATH	ROW	SCENE IDENTIFICATION	LOCATION NAME	DATE
19	31	21267-15031	Titusville	July 12, 1978
19	32	21267-15034	Steubenville	July 12, 1978
18	31	2600-15094	Warren	September 13, 1976
18	32	2600-15100	Pittsburgh	September 13, 1976
17	31	30478-15123	Williamsport	June 26, 1979
17	32	30208-15141	Harrisburg	September 29, 1978
16	31	21660-15005	Scranton	August 9, 1979
16	32	2544-15001	Lebanon	July 19, 1976
15	31	30170-15020	Poughkeepsie	August 22, 1978
15	32	30098-15013	Trenton	June 11, 1978

2.1 Logging the Initial Scenes

The Landsat data were initially logged to be compatible with the VICAR format and system requirements. The logging consists of a series of separate steps depending upon the type of data ordered. Since February 1979, imagery processed by EROS is in band sequential format with major geometric corrections. If the data are processed prior to that date, the data are in band interleaved by pixel pairs with no geometric corrections performed. Typical of almost all applications involving this type of imagery, it was necessary to select acquisition dates spanning over a long period of time to obtain the most cloud free coverage possible. Hence, it was necessary to use both band sequential and band interleaved formats as basic data input for the task.

Imagery processed since February 1979 is fairly easy and inexpensive to log because no geometry changes are necessary, at least in the first phases of the mosaicking process. Extraneous engineering files are stripped off and a VICAR label attached to the image files to be used by subsequent VICAR modules. The uncorrected data, band interleaved by pixel pairs, require extended effort and expense to produce a data format suitable for the VICAR mosaicking process. Nominal geometric and rediometric corrections are made, in addition to dis-interleaving the image strips. Nominal corrections include removal of earth rotation induced skew, panorama effect, and mirror scan velocity profile (MSVP) compensation. The pixel size at this stage of the processing is the IFOV of 57 by 79 meters.

Every effort was made to obtain the clearest possible imagery during the growing season. There were a few problems with some individual scenes with respect to haze and overcast. The net effect of the haze is to reduce the variance in the scene while increasing the brightness. This poses particularly difficult problems when trying to match scenes radiometrically, and also when trying to extend multispectral signatures from one part of a scene to another part of the same scene.

2.2 Map Base

The Universal Transverse Mercator UTM Projection was chosen as the mapping base for the mosaic. It was decided to maintain a pixel size of 57 meters by 57 meters because of the IFOV sampling interval along the Landsat scan line. Selection of a 50 meter pixel size would have allowed the data to be selected from the UTM grid more conveniently, but would also have increased the amount of data to be processed while not increasing the information content.

The State of Pennsylvania covers about 6 degrees of longitude, large enough to encompass one UTM zone. Unfortunately, the state straddles a UTM zone boundary which bisects the state into a western and eastern zone, Zone 17, and Zone 18, respectively. To preserve map projection properties and to provide consistency with subsequent data sets to be registered to the Landsat mosaic data base, two separate mosaics were constructed, one for each zone. Coverage of the entire state with Landsat data can be met with ten scenes, but because of the two projection zones, six scenes were mosaicked for each zone, with the two central scenes contributing data to each zone. In effect, two six-frame mosaics were constructed for the task.

The mapping grid was configured so that the imagery would resampled to the selected scale of 57 meters and rotated north assuring the data scan lines would be aligned east-west relative to the mapping grid. The advantages of this technique are fairly straightforward. First, the data are displayed in a familiar fashion with north at the top, and second, map quadrangles can be extracted from the data base with a minimum of wasted storage space that results from rotation.

2.3 Planimetric Control

Planimetric control for remotely sensed imagery in a mosaicking context can be obtained in several ways. If the exposure or acquisition time of the scene is short enough, such as in a framing type sensor, calibration and control of the data using spacecraft emphemeris information is often sufficient. Since the scene acquisition time for the Landsat image is on the order of 27 seconds, and because it is a scanner type sensor, it is necessary to incorporate known geodetic points on the surface of the earth. Information obtained from the Control Point Library Building System (CPLBS) was used to provide planimetric control to each Landsat scene as each fits into the mosaic.[7]

The information from the CPLBS consists of a 32 pixel by 32 pixel image chip containing a geographic feature, e.g., a road intersection or river bend, as well as the latitude and longitude of the feature. Additional engineering data regarding the Landsat band and which satellite the image chip was taken from is also included. The accuracy of the point is generally within 20 meters. Figure 2 is an example of a chip file in image format for a path/row in Pennsylvania.

Image correlation is performed using the two dimensional Fast Fourier Transform (2D FFT) computational method to relate ground control points (GCP's) from the CPLBS with the associated locations in each Landsat scene.[8] To initiate the correlation procedure, three points are first identified in the Landsat scene that can also be found on a map. This process is usually done on an interactive display system with the line/sample coordinates found using a trackball cursor. The latitude and longitude of that point is read directly from the map. The three points are used to determine an affine surface that is used as an estimator of where the 2D FFT correlation routine is to search in the image to match a particular GCP. While the affine fit does not give the true location within a pixel (or several pixels), it does provide the search algorithm with a reasonable window in which to search. As good correlations are obtained, the surface is refined so that less searching is required as the algorithm proceeds through the GCP file.

There are several problems associated with using a pre-established ground control point file for image registration. First and foremost, the file has to be built, a large effort that has been expended by NASA and IBM. The file also has to be continuously updated because of changes in the ground scenes and the varying conditions of the imagery. A particularly difficult problem in the Pennsylvania mosaic registration and control effort was trying to correlate the GCP's with Landsat scenes that were acquired over several seasons. The ground reflectance changes that occur from season to season impair the correlation performance. As an example, a stream course feature in a GCP may be highly recognizable in a particular season, but when examining the scene it is being correlated with, the stream may be silted and the surrounding land cover blends in with the stream creating a low variance, and hence a low information content image. This makes it difficult to correlate all the GCP's selected for that particular path/row. At most, 18 of the 25 GCP's for each path/row were correlated for the Pennsylvania mosaic. One alternative to this problem is to include the GCP's from neighboring paths/rows for the correlation process, however, this was not done due to time constraints.

Successful use of the CPLBS is also dependent upon the geographic locale of the scenes to be planimetrically controlled. In humid continental and humid subtropical climates, atmospheric moisture contributes to haze in the object scene. The deciduous forests, characteristic of these climates, provide a fairly dynamic land cover association posing difficulties in correlating single date GCP's. Experience in constructing Landsat mosaics of the western United States has shown that arid environments produce the most consistent and haze-free imagery, as well as static imagery in terms of overall ground cover. This considerably minimizes problems of poor correlations due to land cover change.

Our experience with digital mosaicking has shown the CPLBS files of ground control points considerably reduce analyst efforts in compiling the ground control point file for the mosaicking process. In addition, the CPLBS files provide a consistent source of LAT/LONG type data whereas 'manually' selected GCP's are subject to numerous errors, due in part to the tedious nature of selecting the points as well as analyst fatigue.

The ground control points correlated with the Landsat scenes used for the mosaic give each scene its position and projection in the global mapping output grid. If each scene was corrected and inserted into the grid with only the GCP's as control, overall planimetric accuracy would be acceptable, but in all likelihood the edges between the neighboring frames would not match perfectly. To remedy this situation, a series of edge matching points are correlated in all overlapping areas of all scenes used. These points are then mapped (controlled) by the GCP's. The net effect of these additional points is to eliminate any side-to-side or top-to-bottom mismatch between scenes.

Information in the overlap area regarding brightness is also obtained and used to radiometrically correct the imagery at the same time that geometry changes are made. Difficulties in matching neighboring scenes radiometrically were experienced during the processing. With haze problems and the varying dates of the imagery, it was possible with existing software to match the brightness (but not variance) of average areas. However, with variance differences not resolved, marked divisions between scenes occur.

The early date mosaic was completed in two stages. Separate control point files and mapping were used for UTM zone 17 and UTM zone 18. The resultant 'halves' of the mosaic for the state were each 6500 lines by 8500 samples. All four Landsat bands were corrected. The Landsat mosaics for each band, and zone, once completed, were segmented into standard map quadrangles. Figure 3 shows the quadrangles within the state. Most quadrangles were one degree of latitude by two degrees of longitude, except for the border quads in the western part of the state. Typical size of an output quadrangle is 3100 lines by 3100 samples. Figure 4 is an example of a $1^{o} \times 2^{o}$ quadrangle while Figure 5 depicts the zone 17 mosaic.

3. FOREST/NON-FOREST MOSAIC

In a parallel effort, Goddard Space Flight Center personnel applied multispectral classification techniques to the unprocessed Landsat scenes that were used as input for the early date mosaic. One file of data depicting forest and non-forest land cover was derived and sent to JPL to be registered with the mosaic data base. Since the classification was derived from the 'raw' unlogged data, logging was performed using nearest neighbor interpolation to make the nominal geometric adjustments and then geometrically corrected a second time with nearest neighbor interpolation using the control points produced for the early date mosaic. These data were then mosaicked and segmented into the 1 degree by 2 degree quadrangles.

4. LATE DATE MOSAIC - POST DEFOLIATION

Requirements for this task stipulated that once the base mosaicking was completed for the entire state, the technology to update the mosaic on a yearly basis be transferred to the State of Pennsylvania. The VICAR/IBIS software system was obtained from COSMIC[6] by the Office of Remote Sensing of Earth Resources (ORSER) at Pennsylvania State University. In early 1982 the system was installed and tested. Additional program modules needed to produce update mosaics were also delivered, installed, and tested. Once the system was running, a test mosaic was attempted with several goals in mind. First, it was necessary to initiate the ORSER staff in the functions and operation of the VICAR system with regard to mosaicking applications. Second, the Penn State computer system was exercised with VICAR to isolate problems peculiar to the facility. Finally, a prototype procedure for actually creating update mosaics had to be generated and an application case performed.

The late date mosaic, as was the early date mosaic, had to be generated in two sections, one section for each UTM zone in the state. In order to ease scheduling difficulties and to provide Penn State ORSER staff with mosaicking experience, a parallel effort was undertaken with the update mosaic for UTM zone 17 being generated at JPL and the update mosaic for UTM zone 18 generated at ORSER.

The Landsat scenes used in the zone 17 update mosaic were, fortunately, in the EDIPS format, easing pre-processing efforts. Table II depicts the scenes used in the update mosaic. Since the second date imgery is registered to the early date mosaic, the resultant products are identical to the original mosaic, except for ground cover changes. The update mosaic's dimensions are the same as the early date mosaic, 6500 lines by 8500 samples, and it is also segmented into the requisite quadrangles.

5. ACCURACY

The accuracy of Landsat digital mosaics has been evaluated to some degree by several sources, including Goddard and Purdue University.[9] Edge-to-edge matching is the most visible error in mosaics. Edge errors tend to encourage scrutiny and degrade the aesthetic and planimetric qualities of the final product.

Table II

PATH	ROW	SCENE IDENTIFICATION	LOCATION NAME	DATE
19	31	22311-15214	Titusville	May 24, 1981
19	32	22311-15220	Steubenville	May 24, 1981
18	31	22400-15142	Warren	August 18, 1981
18	32	22400-15144	Pittsburgh	August 18, 1981
17	31	22381-15084	Williamsport	July 30, 1981
17	32	22381-15090	Harrisburg	July 30, 1981

Overall, scene-to-scene mismatch in the Pennsylvania mosaic is minimal. What does exist is difficult to assess primarily because imagery of different dates was used to produce the mosaic. Those few areas that did exhibit some degree of mismatch were on the order of one to three pixels, but only for very short stretches (100 pixels). In addition, mismatch areas generally fell outside the Pennsylvania state border and did not adversely impact the project.

5.1 Planimetric Accuracy

From a cartographic viewpoint, the evaluation of map accuracy represents a difficult procedure. Accuracy is interpreted from map specifications and standards, but several interpretations of the standards is possible depending upon the method used. The gray areas of interpretation must be acknowledged so that the relatively narrow standards are not applied inappropriately, that is, so they do not reflect the intent or spirit of the specifications.

For continuity, the United States National Map Accuracy Standard (NMAS) were applied in a limited way to evaluate the planimetric qualities of the mosaic. These standards are:

> For maps of the scale of the scale of 1:20,000 and smaller, not more than 10 percent of the points tested shall be in error greater than 1/50 inch. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well defined points are those that are easily visible such as the following: monuments or markers, such as bench marks, property boundary monuments; intersections of roads, railroads, etc.; Features not identifiable on the ground within close limits are not to be considered as test points within the limits quoted, even though their positions may be scaled closely upon the map. In this class would come timber lines, soil boundaries, vegetation associations, etc.[10]

The root mean square error (RMSE) for identifiable points in a series of 7-1/2 minute quadrangles was calculated. Verification points were located in 19 quads within a 1^o x 2^o quadrangle in the state. There are over 800 7-1/2-minute quads in Pennsylvania making it expensive to sample each one. For several of these quadrangles, the actual GCP's for the CPLBS were obtained, providing some measure of control. In gathering the data to calculate the RMSE, the goodness of the actual GCP's were examined and found to be excellent per specifications for the CPLBS. Line/sample values for a given point in the mosaic were located 'after the fact' on an interactive display unit with a trackball cursor and then recorded. The calculated position of that point per the UTM mapping projection grid was compared against the located point and the deltas (X,Y) noted. The RMSE was calculated by the following formulae for all points checked:

$$RMS_{LINE(Y)} = \sqrt{\frac{Y_i^2}{n}} \; ; \qquad (1)$$

$$RMS_{SAMPLE(X)} = \sqrt{\frac{X_i^2}{n}} \; ; \qquad (2)$$

$$D = \sqrt{RMS_Y^2 + RMX_X^2} \; . \qquad (3)$$

Results of these calculations are given in Table 3.

Table 3.

	ROOT MEAN SQUARE ERROR (RMSE)	
	PIXELS	METERS
Delta Line	1.13	64.41
Delta Sample	3.49	198.93
Delta D	3.67	209.19

The total number of points used in the verification was 19, one point for each 7-1/2 minute quadrangle. The distribution for these points was narrow; all fell within a 1^o x 2^o quadrangle. While in the process of the initial verification it was noted that certain areas of the mosaic had geometric stability problems, while others did not. Our efforts were concentrated on the problem areas.

The acceptable error for maps of the 1:250,000 scale class is 127 meters in the X and Y directions. While the line errors are well within this limit, the sample errors are not, and of course neither are the derived D values. These particular errors have been attributed to the Mirror Scan Velocity Profile (MSVP) of the multispectral scanner. Formulas used in the nominal corrections of the data were obtained from the published public record. The formulas are determined by instrument bench tests during system pre-flight checks. It is possible that fatigue and wear in the scanner system caused the MSVP to change, and if so, the correcting formula would change similarly. The MSVP can be compensated for during the mosaicking process but it requires an extremely dense network of GCP's, especially within the peaks and troughs of the profile. Contributing factors that inhibit proper correction are the inability to obtain sufficient correlation of GCP's because of changes in land cover, lack of actual identifiable features, and atmospheric conditions.

6. CLOSING COMMENTS

Landsat digital mosaicking is an extremely complex and tedious process because of the nature of the data. If Landsat type multispectral data were available in quantity from a framing type sensor, several problems, particulary those relating to geometry, would be minimized. The reality is that because Landsat data are as plentiful as they are, efforts must be directed to increase their utilization in a wide range of applications. Large regional applications pose particular problems of continuity and data organization whenever the study area exceeds the dimensions of the Landsat framing convention. Mosaicking is one solution to a major part of the problem.

Clearly, differences of opinion relative to 'wants' and 'needs' of accuracy will readily surface. Concurrently, an educational process is also occurring as mosaickers learn more about the 'wants' and 'needs' of the user community, and users learn more about the realities of mapping standards. The ability to locate a specific point in a rural area that lacks valid recognizable points to within 200-300 meters (4-6 pixels) is a vast improvement over non-cartographically based imagery. However, every effort should be made to improve geometric stability and performance of digital imagery such as Landsat mosaics.

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   Computer Center
   112 Barrow Hall
   University of Georgia
   Athens, Georgia
   Telephone: (404) 542-3265

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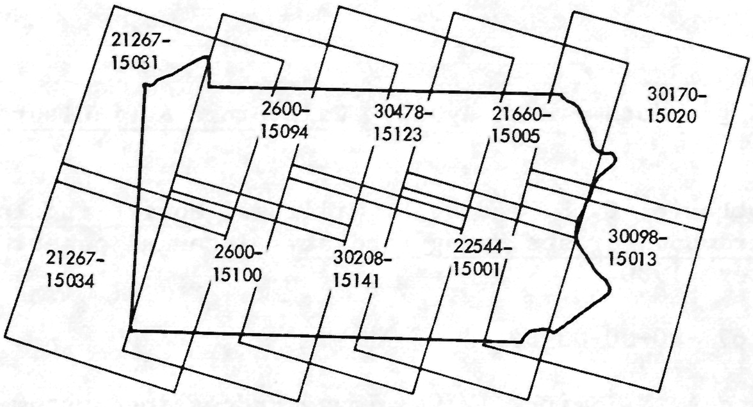

Figure 1. Landsat Frames Footprints - This illustration shows the individual footprints of each scene used for the Pennsylvania Mosaic, both UTM zones.

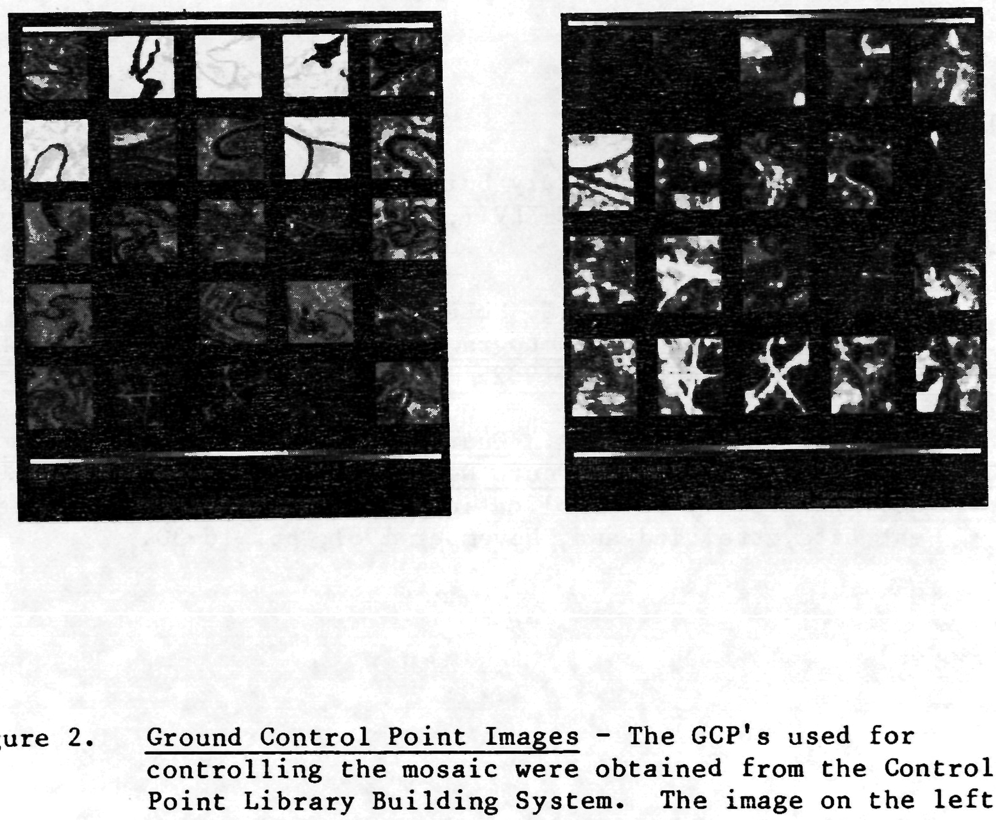

Figure 2. Ground Control Point Images - The GCP's used for controlling the mosaic were obtained from the Control Point Library Building System. The image on the left is the display of the actual CPLBS points, while the display on the right shows the matches in the Landsat scene as a result of the correlation process.

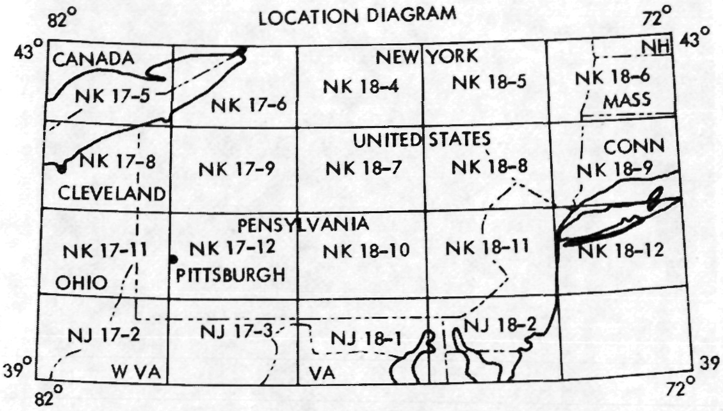

Figure 3. <u>Quadrangles</u> - This location diagram shows the quadrangles used within the State of Pennsylvania.

Figure 4. <u>1 Degree x 2 Degree Quadrangle</u> - Shown here is the Scranton Quadrangle which corresponds to the AMS map series (1:250,000) NK18-8. Landsat Band 5 (red) is displayed.

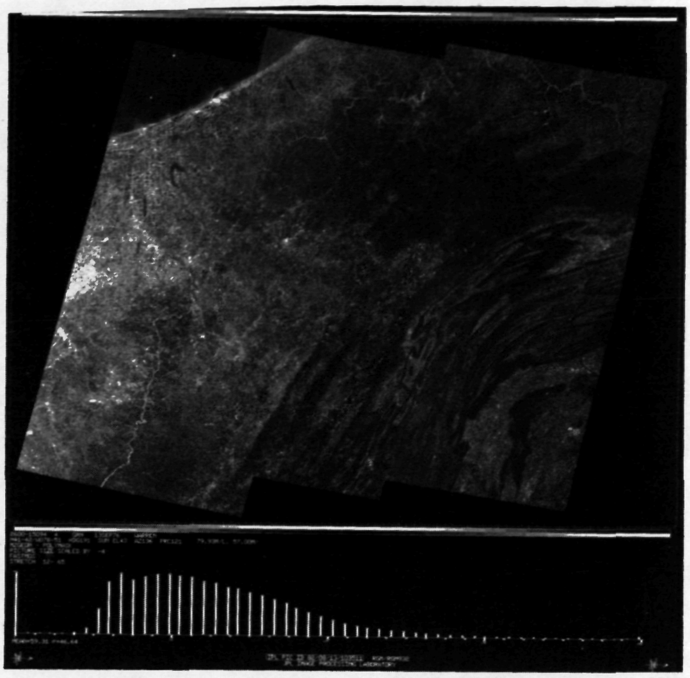

Figure 5. <u>UTM Zone 17 Mosaic</u> - This image depicts the UTM zone 17 Landsat Mosaic for Pennsylvania. Landsat Band 4 (green) is shown here. The image in size is 6500 lines by 8500 samples per line.