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A NON-INTERACTIVE APPROACH TO LAND USE DETERMINATION

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ABSTRACT

In this paper, we report on an operational procedure for use by the Corps of Engineers to acquire land use information for hydrologic planning purposes. The operational constraints preclude the use of dedicated, interactive image processing facilities. The procedure, which is summarized in detail, combines manual interpretation techniques and the batch-mode computer analysis of Landsat digital data. An example of the application of the procedure to an urban watershed is described.

I. INTRODUCTION

The objective of our work is to develop operational procedures for the determination of land use to be employed by the Army Corps of Engineers to analyze urban watersheds across the United States. The operational methods are intended to be used by the district offices of the Corps of Engineers to generate land use computer files. These files are to be included in a spatially gridded geographic data structure, which provides the basis for an integrated data management and analysis study of urban watersheds.

The integrated data base is analyzed with the use of several computer models to assess the hydrologic, economic and environmental consequences of alternative land use patterns in combination with other physical characteristics of the watershed, such as soil class, erosion index, and topography. Land use information is the key factor in performing the analysis in that it is used as the primary indication of the watershed conditions and of its response to precipitation.

The acquisition of land use information by conventional methods such as manual classification using aerial photographs or ground surveys are often time consuming for large watersheds or inadequate, not providing accurate spatial information of land use. Remote sensing data can provide land use information accurately and in a timely fashion for hydrologic planning purposes. By proper use of high speed digital computers, highly accurate and point-by-point information of land use can be extracted from the remotely sensed data.

The final operational procedure is intended for use by the district offices of the Corps of Engineers, employing general purpose computers in the batch or time-shared modes. This precludes the use of dedicated and highly-interactive image processing systems such as the G.E. Image 100 or the Bendix M-DAS System. Thus, the procedure is to be designed for implementation on a general purpose computer in the batch mode, using only a line printer for output products, and having no image display hardware. A further objective has been to design a procedure which requires a small number of iterations. The developed procedure employs the use of standard techniques of manual interpretation of aerial photographs and topographic maps and the batch-mode analysis of Landsat digital data on a large, general-purpose computer. A preliminary description of this procedure has been published previously[1].

II. LAND USE CATEGORIES AND REMOTE SENSING FOR HYDROLOGIC APPLICATIONS

Since the land use pattern is an important factor in hydrologic, economic and environmental analysis, the development and use of a reasonable set of land use categories is quite important. Hardy and Anderson[2] have recommended a standard set of land use categories for use with remote sensing data. Ragan[3], in applications to water resources, has used a modified subset of land use categories* of Hardy and Anderson, and has shown that remote sensing data can provide land use information. The land use pattern was then used by Ragan to determine hydrologic parameters in urban hydrology.

The Hydrologic Engineering Center (HEC) of the Corps of Engineers has carried out a pilot study in the Trail Creek watershed near Athens, Georgia[4].

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*Land use categories used by Ragan in his work are: Forested area, highly impervious, grassed area, residential, streets and highways, bare land, streams, ponds or pools.

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This study has applications to economic and environmental analysis as well as to hydrology. Thus, the objectives and criteria which determine a set of land use categories in this study are different from what was used in previous work. Quoting the criteria applied by HEC to determine a rational set of land use categories:

" . The categories should be reasonably compatible with local and other agency land use classification schemes

. It must be reasonably possible to classify the land use within the study area by conventional or automated means

. The land use categories should allow rational, consistent determination of flood hazard, economic and environmental effects of land use change

. The land use categories should be compatible with those needed by certain available computer models

. The land use categories should provide a complete umbrella of classifications so that further breakdown of land use within each category would be possible if deemed necessary in future studies"

The different concerns in land use for each application are well expressed in another quotation from the HEC report:

"...from the hydrologic viewpoint, the concern in a land use sense is with moisture retention/precipitation excess and basin response characteristics which are related to impervious cover and land surface management measures. From the economic viewpoint the damage potential and disruption of community activities is a function of urban development in general and the size, density, and type of structures and contents. From the environmental viewpoint, the concern is mostly with the intensity of development and the potential for adverse impacts (such as pollution) that could derive therefrom."

In the specific application of the study to the Trail Creek Watershed in Georgia, HEC has adopted the set of land use categories shown in Table 1. These categories represent a compromise between the general criteria mentioned above and the technical requirements needed for applications to hydrology and economic and environmental studies. Note that, for the economic and environmental analysis, detailed land use information in urban areas is very important, while it is much less important for hydrologic analysis. The hydrologic models are much less sensitive to the land use distribution.

The desired land use classes listed in table 1 are not always within the resolution obtainable using Landsat data. The differentiation between commercial and industrial areas, and differentiation of the density of residential areas are difficult to accomplish. The obtainable discrimination of classes is strongly dependent on the quality of the available ground truth data, in the form of maps and aerial photographs. The time of acquisition, scale, and coverage of the watershed are critical factors in the accurate classification of land uses. The set of land use classes chosen for a particular watershed is dependent on these factors.

This work is sponsored by NASA and the Corps of Engineers as an ASVT (Application System Verification Test). Although well developed techniques are intended to be employed in a technology transfer project, we have found that a substantial number of new processing algorithms had to be developed as part of an integrated operational package. Several publications on details of these new algorithms have appeared or are in preparation. It is the intent of this paper to present a systematic view of the overall procedure and to discuss the salient points. In particular, we believe that our project is one of the first being completed which considers both the equipment constraints and the usability of remote sensing technology by non-specialists in an operational mode.

III. OUTLINE OF AN OPERATIONAL PROCEDURE

With the specific objectives and constraints stated above, we began an investigation of procedures based on the manual interpretation of aerial photographs and maps and the computer analysis of Landsat data, using a batch mode and a low degree of interaction.

We first considered the use of a supervised classification procedure, based on the maximum likelihood classifier[1]. We found this approach to be unsuitable, primarily due to difficulties in acquiring a suitable set of training areas in a non-interactive mode. In order to have a reliable estimate of statistics, the number of samples in the training areas for each class must be relatively large. In our application, it is difficult to find training areas of large size for some land use classes without looking outside of the watershed, or area of interest. Additionally, it is necessary to define and characterize a complete set of subclasses for each class, and to find training areas for each of these subclasses. For instance, brush fields and forests are categorized as natural vegatation, but they are likely to have distinctive spectral signatures and thus must be included in separate subclasses. This further complicates the problem of finding representative training areas. Furthermore, the determination of the exact outlines and coordinates of the training areas in the Landsat images is very difficult without the use of an interactive color image display system. These difficulties make a maximum likelihood classifier unattractive or impossible as an operational procedure with a minimum amount of interaction.

We then adopted the use of an unsupervised classification procedure, which does not require an a priori knowledge of land use categories nor the location of training areas, and thus is more suitable for our objectives and constraints. We have developed an operational procedure based on the two-pass application of a clustering algorithm. The algorithm used is a version of the ISOCLS program developed for NASA Johnson Space Center[5], which we have modified for our purposes.

The major steps, sources of data, and intermediate output products of the operational procedure are shown in block diagram or flow chart form in figure 1. The details of the steps are as follows:

A. DATA EXTRACTION, CORRECTION, AND CLUSTERING

The Landsat data covering the watershed must first be extracted from the computer-compatible tape (CCT) and then processed for radiometric and geometric corrections. The radiometric correction is applied to improve the classification results. The geometric correction is required for transforming the output products to the coordinate system of the spatially gridded geographic data structure.

Watershed Extraction. Using a 29.2 inch (scale 1:250,000) photographic print of band 5 of the selected Landsat frame, the coordinates of a rectangular area enclosing the watershed are determined. The largest watershed we have considered to date is 512x512 pixels. The watershed area is read from the Landsat CCT and reformatted to form the raw watershed data file.

Radiometric Correction. The Landsat digital data can be marred by striping errors due to variations in the response of the 6 radiometric sensors for each band. The statistics of the data itself are used to generate nonlinear memory-less equalization algorithms which are applied to the data to produce the radiometrically corrected watershed data file[6].

The first step in the correction of the data is the determination of 6 histograms for each of the spectral bands. From these histograms the mean and standard deviation at the output of the sensors is obtained. An example is shown in table 2 for the data from the Crow Creek watershed discussed in Section IV. Nonlinear equalization curves are generated to equalize all sensors such that all histograms are then identical.

Geometric Correction. The geometry of the Landsat-derived file must be corrected so that the final output products will be compatible with information acquired from maps. This is accomplished by applying a bivariate polynomial coordinate transformation to the data[7]. The coefficients of the transformation are obtained from a least square fit to sets of control points taken from the image and from the maps. Since the image control points cannot be acquired from an interactive display, we have developed a non-interactive technique[8]. In this technique, we apply an algorithm which enhances the roads and water bodies in the watershed and generates an alphanumeric printout which is used to locate the control points.

We have determined experimentally that it is necessary to acquire the locations of 25 to 35 control points to achieve a geometric correction having a root-mean-square error of one pixel. The resulting transformation is later applied to the output land use maps to make them compatible with USGS topographic maps based on the Universal Transverse Mercator (UTM) coordinate system.

Also, at this point in the procedure the coordinates of the boundary of the watershed are acquired from the USGS map. This boundary is later used to mask off the land use classifications for the region outside the watershed.

Clustering. The clustering program ISOCLS is applied to the corrected watershed data file to separate the data points into distinct groups or clusters, with the center of each cluster represented by its mean. ISOCLS is an iterative algorithm, performing two distinct phases on each iteration. In the first phase, existing clusters are split if they have a variance exceeding a user-specified value, combined if their intercluster distance is below a specified value, or deleted if they contain too few points. On the second phase, data points are assigned to the nearest cluster center, using a taxicab distance measure. Cluster means, covariances, and intercluster distances are then computed and another iteration is initiated. ISOCLS is used as a four-dimensional algorithm, operating on the four spectral bands of the Landsat data, so the computational requirements on each iteration are very heavy.

If the watershed data file is large, ISOCLS can be applied to a subsampled portion of the file, with 128x128 points being the optimal size. The ISOCLS input parameters are chosen such that the program iterates up to 20 times to partition the data into a maximum of 30 clusters, and to generate the file of cluster means. The average standard deviation of the generated clusters has been found to be in the range of 1.5 to 2.0.

B. INITIAL CLASS ASSIGNMENT

The land use class for each cluster is determined through a method of manual interpretation. This requires ground truth information in the form of maps and aerial photographs. The maps used are USGS 7 1/2 minute series standard topographic maps having a scale of 1:24,000. NASA color infrared aircraft photography is also employed. We have found that a photo scale of 1:50,000 is very good, 1:100,000 is marginal, and 1:125,000 is inadequate to identify land use classes.

Classification. The data points within the region of the watershed covered by the aerial photographs are assigned to clusters using the classification phase of ISOCLS. For small watersheds (less than 256x256 pixels), all points in the watershed data file are assigned to clusters. For a large watershed, it is convenient and sufficient to process a 256x256 pixel sub-area having the same coverage of the watershed as the aerial photographs. The cluster assignments are then printed as a set of cluster maps, with six clusters printed per map. On each cluster map, a unique label (printer symbol) is printed for each data point which has been assigned to one of the six clusters. Blanks are printed for data points assigned to other clusters. Printing the clustering results in this way reduces the clutter and makes interpretation of the results much easier.

Manual Interpretation. Land use classes are assigned to clusters by analyzing the regions of the cluster maps which have the same coverage of the watershed as the aerial photographs. Within these regions, the six largest contiguous sets of pixels from each cluster (spatial group) are identified on the cluster map. Large spatial groups distributed throughout the ground truth region have been found to provide the most information. Areas outside but near the watershed boundaries are used as long as they are of the same type of terrain as that within the watershed. A representative pixel is chosen for each spatial group and its location in UTM coordinates is determined from the Landsat CCT to UTM coefficients determined in section A above. The location of the representative pixel is marked on the appropriate USGS map. Using the map as a guide, this same point is located on an aerial photograph. An appropriate land use category is determined for each spatial group by a detailed examination of the immediate area surrounding the representative pixel on the aerial photograph and the USGS map. This process is repeated for all spatial groups of each cluster. If all spatial groups of a given cluster have the same class assignment, the cluster is assigned to a definite land use category. In general, this includes more than 30% of the clusters. A cluster having multiple class assignments is considered to be in conflict.

Typical spatial clusters contain 6 to 40 data points for situations in which very few data points are assigned to a cluster, it may be very difficult to identify the six desired spatial groups. The KL plot described below can often be used to help with determining the class assignment for these small clusters.

KL Plot. As an aid in resolving the conflicts in cluster to class assignments, the cluster means are plotted in a transformed feature space. The first two transformed components (associated with the two largest eigenvalues) of the Karhunen-Loève (KL) transformation of the cluster means are plotted, resulting in a two-dimensional representation of the means. The clusters having definite class assignments are labelled, and all clusters having definite class assignments are consolidated (circled on the K-L plot). In general, the clusters assigned to the same class will be adjacent to one another. The consolidated class boundaries are then used to check the classification procedure for inconsistencies, for example: (a) clusters from one class should not be surrounded by clusters of another class, and (b) clusters in conflict in general include class assignments of neighboring classes. A cluster which is distant from other clusters should be given a definite class assignment, as additional clarification of its assignment generally will not be gained from submitting such clusters to reclustering, described below.

C. RECLUSTERING AND INTERMEDIATE CLASS ASSIGNMENT

The clustering program is applied a second time, this time operating on the pixels in the watershed data which were members of the clusters in conflict. The purpose of the reclustering is to more finely partition the data in the difficult areas to allow unequivocal class assignments to be made.

Clustering. ISOCLS is applied to the corrected watershed data file, excluding those data points assigned to clusters having definite class assignments. The input parameters are chosen such that the program iterates up to 15 times to partition the data points from conflicting clusters into a maximum of 30 additional clusters.

Classification. Using the cluster means from the reclustering step above and the means of the clusters which were given definite class assignments in the initial clustering step, the data points within the region of the watershed covered by the aerial photographs are again assigned to clusters using the classification phase of ISOCLS. These cluster assignments are then printed as a set of cluster maps.

Manual Interpretation. The new clusters produced by reclustering are assigned to land use classes using the same manual interpretation procedure described in section B above.

D. RESOLVING CONFLICTS AND FINAL CLASS ASSIGNMENTS

KL Plot. To resolve conflicts in the cluster to class assignments, a KL plot of the new set of cluster means is prepared. Consolidated class boundaries are again used to check the class assignments. This time, the results of the manual interpretation of the spatial clusters and the KL plot are used to choose the best final class assignment possible, even in cases where there may be some conflicts.

Classification. Using the final set of cluster means, all of the points within the watershed data file are assigned to clusters using the classification phase of ISOCLS. Using the final cluster to class assignments, a land use map is printed in the original Landsat coordinate system. The watershed boundary coordinates, acquired in the geometric correction step described in section A are used to mask out the land use classifications for the region outside the watershed.

Geometric Correction. Using the geometric transformation which was generated in section A above, the land use map is transformed using nearest neighbor resampling to the UTM coordinate system. Accounting for printer symbol spacing, a map-compatible display of land use is printed.

Editing. Using the land use map as a USGS map overlay, the land use assignments within the watershed can be checked. Where discrepancies exist between the computer product and the results of manual interpretation for extraneous or isolated misclassified points, an editing program can be used to change the assignments.

We are currently considering a modification in the procedure wherein the two sets of cluster maps produced are geometrically transformed and resampled so that they can be used as overlays on the USGS maps. This simplifies the manual interpretation, but it will be necessary to study the effects of the error introduced by resampling before adopting this modification.

IV. EXPERIMENTAL RESULTS

In developing the operational procedure, we have studied six different urban watersheds ranging from a few to tens of square miles located in five states: California, Georgia, Iowa, Pennsylvania, and Texas. We have implemented programs used in the procedure on the CDC 7600 computer at the Lawrence Berkeley Laboratory which is used on a remote link by HEC. A hydrologic engineer from HEC has been trained in the use of the procedure, and has performed the studies of two watersheds.

The procedure has been recently applied to the Crow Creek watershed near Davenport Iowa, a tributary to the Mississippi River having a drainage area of 21.2 square kilometers (8.2 square miles). The ground truth for this study included a July 1977 aerial photo mosaic having a scale of one inch to one thousand feet which was provided by the Rock Island District of the Corps of Engineers. This data had previously been acquired for a Flood Plain Information study, so the NASA aircraft photography was not used. The USGS topographic maps covering the watershed had been photorevised in 1970 and 1975. The Landsat frame used was a May 18, 1976 scene (scene ID 82482155855). The extracted watershed data file was 300x235 pixels, or 70500 data points.

In the initial clustering step, every other column and every other row of the data (150x118 pixels) was processed. Twenty-six clusters were generated and sixteen of these, representing 12000 data points or 68% of the data, were given definite class assignments. The KL plot for the initial clustering step is shown in figure 2. Note that the clusters assigned to the same class are generally adjacent to one another, particularly in the case of the six clusters in the center of the plot which were assigned to agriculture. From our experience with several watersheds, this is a very typical distribution of consolidated class boundaries on the KL plot.

In the reclustering step, the entire watershed data file was processed, excluding those data points which had previously been assigned to clusters having definite class assignments. Nine additional clusters were generated, for a total of thirty-five clusters. The KL plot for the reclustering step is shown in figure 3, and several important observations can be made by comparing this plot with the KL plot from the initial clustering step. Cluster 23, which was initially in conflict, has split into four clusters, numbered 23, 28, 33, and 34 in figure 3. The two clusters (23 and 28) which moved toward cluster 24 which was previously assigned to industrial/commercial can now by themselves be assigned to industrial/commercial and two clusters (33 and 34) can now be assigned to agriculture. Cluster 26 split into two clusters: 26, which is now classified as a trailer park (residential), and 27, which is now assigned to agriculture. Similarly, cluster 18 split into 3 clusters (18, 30, and 35), each of which is now given a separate class assignment. Clusters 1 and 14 probably should not have been submitted to reclustering since they were distant from other clusters in the initial KL plot. This is confirmed in the reclustering KL plot, as cluster 14 did not move or split. Cluster 1 did split, but both of the new clusters (1 and 27) are classified as industrial/commercial. Cluster 1 contains only 44 data points, or 0.25% of the total number of points.

The final set of land use classes includes: natural vegetation, developed open space, residential, agricultural, commercial/industrial, pasture, and water bodies. The following comments are pertinent:

(a) The density of residential areas is very difficult to determine from the Landsat data. More work on fairly large urban areas is needed to determine whether the residential density can be differentiated.

(b) The differentiation between industrial and commercial classes may not be accurately determined with our procedure.

(c) The assignment of clusters to the four vegetative classes (natural vegetation, developed open space, agricultural, and pasture) is often an ambiguous problem. In some cases, very detailed classifications can be made. For example, clusters 13 and 21 from Crow Creek were found to be forest woods. However, for other clusters it was difficult to decide which vegetation class was appropriate.

V. DISCUSSION

We have developed a detailed operational procedure for the determination of land use which is based upon standard techniques of manual interpretation of aircraft photographs and maps and the analysis of Landsat data using the batch mode of a general purpose computer with a low degree of interaction and no image display hardware. All of the details of the procedure have been worked out, and the procedure is now being tested by the Hydrologic Engineering Center of the Army Corps of Engineers.

While our initial charter was to employ existing methodologies, we have found it necessary to develop new algorithms and approaches to several problems. In order to correct for the variations of the response of the Landsat radiometric sensors, we have developed a nonlinear equalization algorithm. We have successfully performed a geometric correction on the Landsat data to produce map-compatible output products without the use of an interactive image display. This has been accomplished by enhancing and printing maps of curvilinear features and then acquiring the necessary control points from the maps. This procedure has proven successful, but more work is needed to refine the technique and to analyze the errors involved.

Our two pass application of clustering results in a very fine partition in regions where this is required, without involving the expense of the typical alternative, which is to finely partition the entire data set. The use of plots of the cluster means in a transformed feature space is a significant aid in resolving conflicts in class assignments. Finally, the capability of editing isolated misclassified points in the map-compatible output product leads to improved classification results.

There are three elements of the procedure which need some improvement. The principal problem is with the clustering program ISOCLS, which is very cumbersome and costly to apply in our situation. We are currently working on a new algorithm for unsupervised classification. Secondly, the geometric correction technique, which has been shown to be effective, is still rather cumbersome to perform. It is possible that the new geometrically corrected Landsat products produced by the EROS Data Center digital image processing system[9] will solve these problems. We are currently pursuing this alternative. Finally, we cannot determine at this time the upper limit of the areal extent of the watershed which can be handled by this procedure. This is why we have confined ourselves to a maximum size image of 512x512 pixels, and even at this size we may have problems. This topic also may require more work.

ACKNOWLEDGMENT

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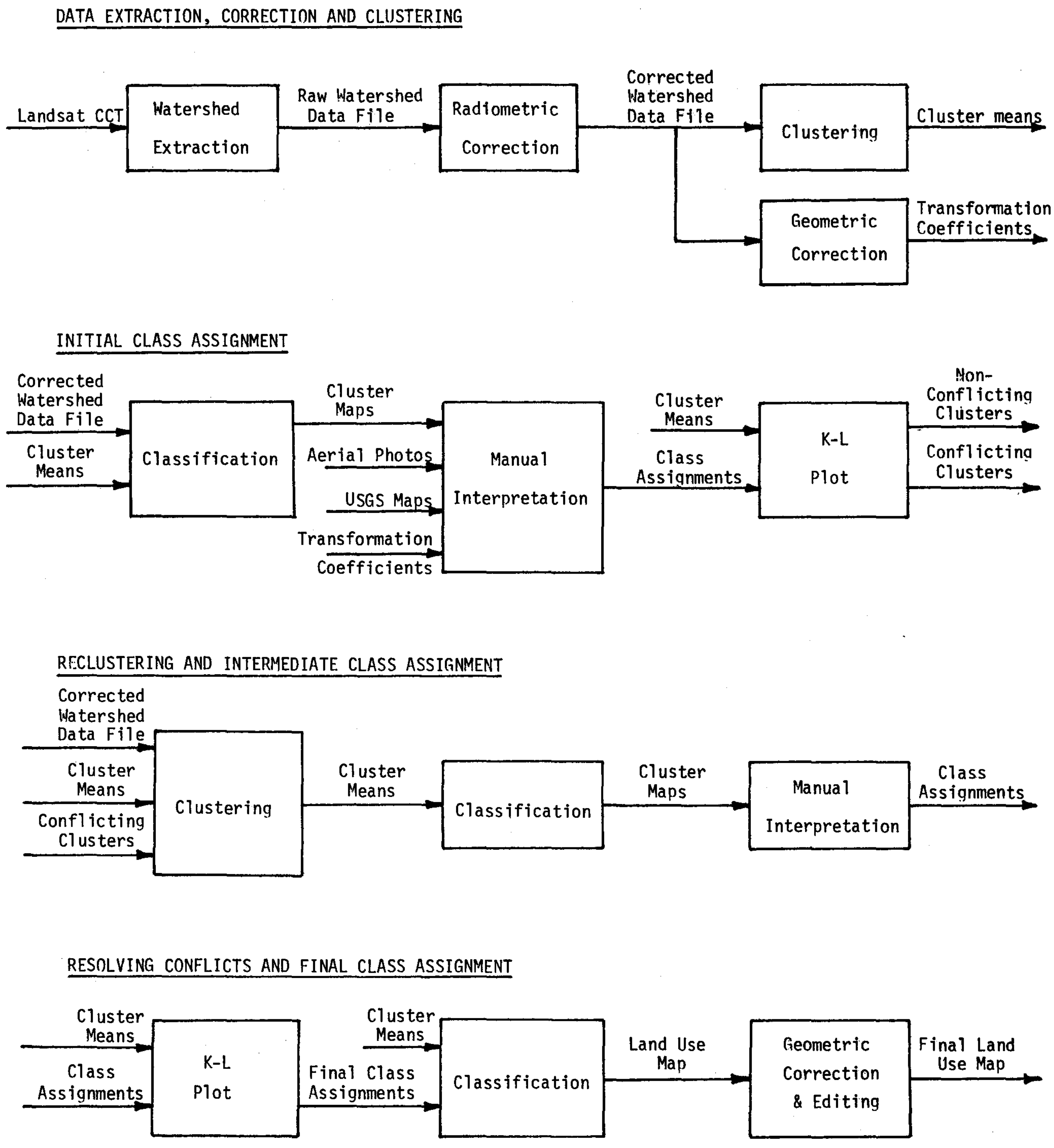

Figure 1. Operational Procedure Flow Chart

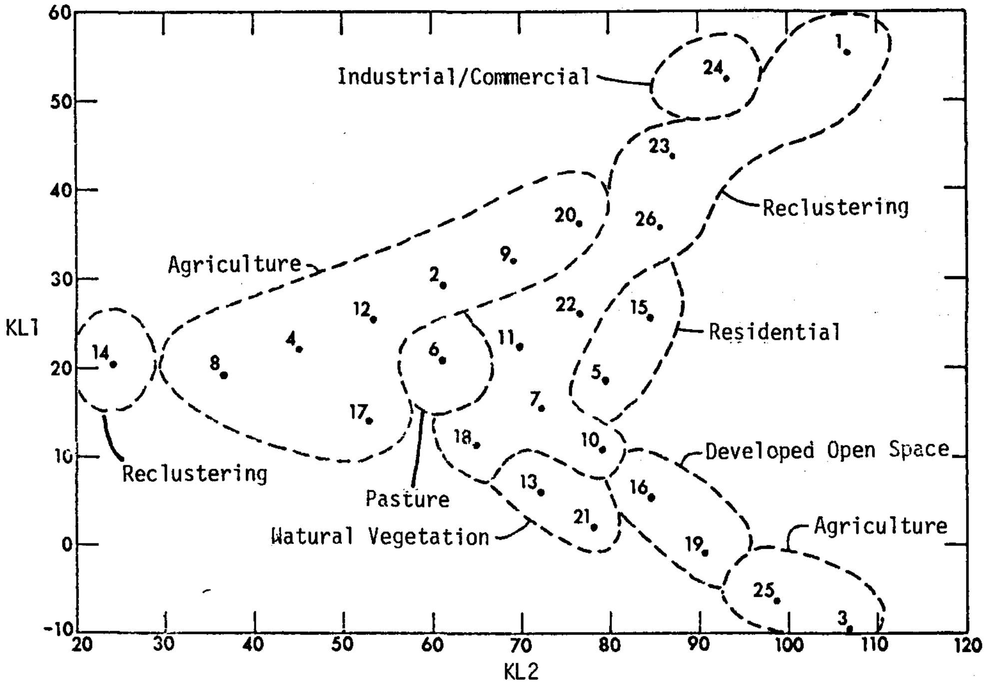

Figure 2. Initial K-L Plot

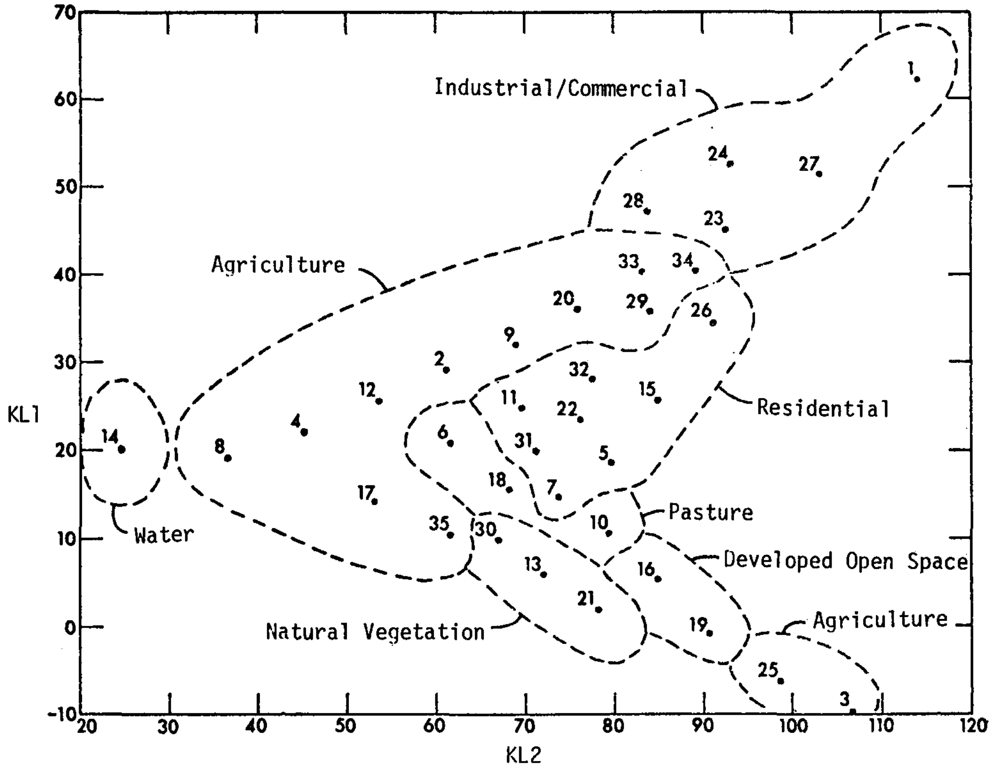

Figure 3. Reclustering K-L Plot

Table 1. HEC Land Use Categories, Trail Creek Watershed

1. NATURAL VEGETATION

   Heavy weeds, brush, scrub areas, forest woods

2. DEVELOPED OPEN SPACE

   Lawns, parks, golf courses, cemeteries

3. LOW DENSITY RESIDENTIAL

   Single Family: 1 unit per 1/2 to 3 acres; average 1 unit per 1-1/2 acres. Areal Breakdown: 5% structures; 10% pavement; 50% lawns; 37% vegetation. Proportion developed = 60%

4. MEDIUM DENSITY RESIDENTIAL

   Single Family: typical subdivision lots; 1 unit per 1/5 to 1/2 acres; average 1 unit per 1/3 acre. Areal Breakdown; 10% structure, 15% pavement, 45% lawns, 30% vegetation. Proportion developed = 70%

5. HIGH DENSITY RESIDENTIAL

   Multi-Family: row houses, apartments, townhouses, etc., structures on less than 1/5 acre lots; average 1 unit per 1/8 per acre. Areal Breakdown: 25% structures; 15% pavement; 35% lawns; 25% vegetation. Proportion developed = 100%

6. AGRICULTURAL

   Cultivated land, row crops, small grain, etc.

7. INDUSTRIAL

   Industrial centers and parks, light and heavy industry. Average 1 plant per 8 acres. Areal Breakdown: 20% pavement, 50% structures, 30% open space. Proportion developed = 100%

8. COMMERCIAL

   Shopping centers and "strip" commercial areas. Average 3 structures per acre. Areal Breakdown: Structures 30%, lawns 5%, vegetation 10%, pavement 55%. Proportion developed = 80%

9. PASTURE

   Livestock grazing areas, ranges, meadows, agriculture open areas, abandoned crop land

10. WATER BODIES

   Lakes, large ponds, major streams, rivers

Table 2. Band 4 Sensor Statistics, Crow Creek Watershed.

Sensor No.	1	2	3	4	5	6
Mean	19.8	20.2	20.1	20.4	20.9	20.5
Standard Deviation	3.13	3.14	3.18	3.23	3.05	3.35