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A COMPARATIVE INTERREGIONAL ANALYSIS OF SELECTED DATA FROM LANDSAT-1 AND EREP FOR THE INVENTORY AND MONITORING OF NATURAL ECOSYSTEMS

By Charles E. Poulton, Earth Satellite Corporation,
Berkeley, California

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ABSTRACT

The paper presents comparative statistics on the capability of LANDSAT-1 and three of the Skylab remote sensing systems (S-190A, S-190B, and S-192) for the recognition and inventory of analogous natural vegetations and landscape features that are important in resource allocation and management. Investigations were conducted in two analogous regions presenting vegetational zonation from salt desert to alpine conditions above timberline. The visual interpretation mode was emphasized in the investigation. An hierarchical legend system was used as the basic classification of all land surface features. Given adequate ground truth and a knowledge of what to expect ecologically within each region, it was possible to map and identify many features to the fourth hierarchical (first floristic) level in the classification system. Fourth level decisions were, however, strongly based on recognizing associated features and convergence of evidence. Identifications at second and third levels (physiognomic and structural criteria) were generally photo identifiable by knowledgeable interpreters. Comparative tests were run on image identifiability with the different sensor systems, and mapping and interpretation tests were made both in monocular and stereo interpretation with all systems except the S-192. Significant advantage was found in the use of stereo from space when image analysis is by visual or visual-machine-aided interactive systems. Some cost factors in mapping from space are identified. The various image types are compared and an operational system is postulated.

INTRODUCTION

The project we are reporting today had its origin with investigations which the author and his associates conducted starting with Gemini IV and Apollo VI and IX experimental earth resources photography. During these investigations work was begun on a uniform system for the inventory and monitoring of vegetational resources and natural environmental complexes by appropriate combinations of space, aircraft imagery, and ground work. The research was continued through the LANDSAT-1 experiment and into Skylab for the purpose of further development and refinement of the uniform system for interregional application and to make comparative tests of three of the sensor systems aboard Skylab.

Our working hypothesis has been that analogous vegetations and environmental complexes should have sufficiently analogous remote sensing signatures (at some appropriate level of classification) that they could be recognized widely throughout a region and, hopefully, in each of many regions from subject-image relationships worked out at a few representative locations. Given appropriate image quality control or radiometric fidelity, we have been able to accept this hypothesis as operationally feasible at various specified levels of classification in the hierarchical legend system we have been using to characterize the vegetation-landform systems that comprise the ecosystem units of the earth's land mass. Other work by Earth Satellite Corporation outside this project has also provided the opportunity successfully to apply the concepts on a global basis--on four continents.

Space technology now permits us to acquire both operationally useable photography and multispectral scanner data from space--the former with very good spatial resolution and the latter with very good radiometric fidelity. Such imagery is appropriate to a broad spectrum of natural resources applications. It has given us the particular capability:

1. To image and analyze vast areas of the globe in a very short period of time,

2. To obtain very broad synoptic coverage and thus to transcend boundaries of agency and ownership responsibility and even of political jurisdiction,

3. To view both multidate and multispectral scenes simultaneously in reaching interpretive decisions about earth resources, and

4. To put earth resources and their use in a vivid, pictorial perspective provided that regional, national, or global systems of identification and annotation are developed and used.

Historically man has evaluated and planned the development, use, and management of earth resources; first from the highly restrictive view provided by ground observation, then from the substantially improved perspective of conventional aerial photography, and most recently from the still broader perspective obtainable from an earth-orbiting spacecraft. Also, historically speaking, the earth resources themselves have been managed quite restrictively by a multiplicity of government and private interests and, particularly, in the United States with each having its own local or restricted regional point of view. Consideration of resource problems in the context of small-to-major watersheds is about as close as we have traditionally come to development of a broad synoptic view of problems and their interrelationships. In this context, it has neither been necessary to develop a unified procedure for the identification of earth resource features across broader regions, nor a truly national or global legend for their identification and annotation. Each agency, landowner, or river basin commission could achieve its stated objectives by developing its own techniques and legends, largely independent of the views and need for coordination with others. After all, the project boundary seemingly was the true limit of concern.

When, on the other hand, we consider the ever-increasing dependence of one region or nation on another for food, fodder, fiber, and minerals and also for environmental protection, this limit of concern broadens commensurately. It is in this context that remote sensing from an earth-orbiting spacecraft assumes its greatest potential significance. The synoptic view offered from such a platform makes it possible for a single unified legend system and identification method to be applied across all ownerships throughout a vast area and then to draw together what each responsible agency knows into a common, integrated data base--much of which can be pictorially portrayed on a space-derived image or mosaic. It becomes even more appropriate in this setting to take an ecological approach to resource inventory and environmental monitoring when relating each kind of resource area to its land use potential and management requirements. It has been my purpose through these almost 9 years of applications research to contribute to these kinds of goals and capabilities.

The specific objectives of the investigation now being reported are:

a. Further test and refine a uniform, hierarchical classification and legend system for the identification of natural vegetation and land surface characteristics from space and aircraft imagery,

b. Specify potentialities and limitations of the uniform legend concept for multistage, interregional, and potential global application and define the kinds of analogs that can and cannot be interpreted from the various types of space imagery,

c. Evaluate the contribution of stereo interpretation of space imagery to the accuracy of delineation and identification and for increasing the specificity of interpretable analogs,

d. Evaluate the effect of spatial resolution on interpretability, and

e. From comparative studies of stacked data over the same test sites, postulate an efficient multistage system for inventory and monitoring of natural ecosystems and man's impact upon them.

TEST REGIONS

To investigate problems implied by these objectives, we selected two widely separated test regions in the two major mountain chains of western North America (Figure 1)--the Colorado Plateau of southwestern Colorado and adjacent states and the Sierra-Lahontan of California and adjoining Nevada in the vicinity of Eastgate to Reno, Nevada and Lake Tahoe. The approximate local extent and shape of each test region is shown in Figure 2. Each of these test regions presents an analogous sequence of vegetational types from the salt desert to rocklands above timberline.

The Colorado Plateau Test Region

This test region includes vegetation zonation patterns highly similar to the Sierra-Lahontan with many vegetation analogs as well as a few vegetation types unique to its surrounding area (Figure 2). The zonation pattern within the Colorado Plateau Test Region is from the salt desert (Atriplex dominant) zone, through the sagebrush* or shrub steppe, pinyon-juniper, oakbrush, ponderosa pine, to aspen and spruce-fir, with some essentially alpine vegetation associated with the high mountain rocklands above timberline. A mixed coniferous type (Douglas fir, true fir, and ponderosa pine) occurs in the area, but it is generally restricted to northerly aspects in the intermediate and upper elevations of the ponderosa pine zone. The spruce-fir zone is well-defined immediately below timberline. The two regions are contrasted particularly in the high preponderance of the deciduous Gambel oakbrush type of the Colorado Plateau with very limited distribution of sclerophyllous shrub types, such as manzanita.

The area has important geologic and mineral significance but in these respects is strongly contrasted to the Sierra-Lahontan. There are rather extensive areas of irrigated agriculture heavily oriented to livestock ranching. Forestry, mining, recreation, and wildlife are important in the region. This test area includes parts of two Indian reservations and large amounts of Bureau of Land Management and federal Forest Service land.

The Sierra-Lahontan Test Region

Direct analogs with the Colorado Plateau Test Region occur here. They are found in the salt desert zone, the sagebrush or shrub zone, the pinyon-juniper zone, and also in the Jeffrey pine zone, which is analogous with the ponderosa pine zone of the Colorado Plateau. In the Sierra-Lahontan Test Region, the spruce-fir zone is not distinctive as in southwestern Colorado. The spruce-fir of the latter test area is ecologically but not floristically analogous to the mountain hemlock types below timberline in the

*For scientific names of important species see the Table of Analogs, Appendix A.

Sierra-Lahontan Test Region. One might expect the signatures of these two types, however, to be similar. In the latter area, the sclerophyllous shrub type predominates in most of the forest openings, and Gambel oakbrush is entirely absent. Deciduous oak trees are, however, present in the Jeffrey pine zone. This is in floristic contrast with the common occurrence of Gambel oak in the understory of ponderosa pine forests in the Colorado Plateau Test Region. In spite of the floristic contrast, these two types are ecologically analogous and one might expect their signatures to be similar in the two regions. The mixed conifer type (more extensive in this region) is essentially analogous with the north-aspect, mixed conifer types of the Colorado Plateau. An idealized picture of the vegetational zonation pattern in the two regions is shown in Figure 3.

There is an Indian reservation in the Sierra-Lahontan Test Region with similar preponderance of other federal land. The patterns of agriculture and crop types are highly similar with livestock production being a significant part of the local economy. Wildlife and recreation are also very important in this region. Aspen types occur but are much more restricted than in Colorado. The two regions are strongly contrasting geologically but, in spite of this, good vegetational analogs do occur.

IMAGE AVAILABILITY

For the quantitative work under this project we settled on relatively small areas near Cortez, Colorado and Pyramid Lake, Nevada, where, in spite of the interminable problems of clouds, mission scheduling, and performance, and high-flight support acquisition we did in fact have useable examples of all image types available superimposed over an identical area in each region. The available imagery that we were able to use in the experiments (exclusive of the high-flight that was used primarily for ground truth confirmation on identifications and experimental mapping) is summarized in Table I. The only serious problem arose when choices were made in favor of the all-important data superimposition (stacking) requirement. Interregional variation in photographic quality for the S-190A and S-190B systems as well as the high-flight photography made direct experimental testing of interregional interpretability with the photographic data impossible. In addition, a large part of the Sierra-Lahontan imagery lay outside our area of maximum ground truth although it had been covered by over-flight aircraft observations in some detail and by two limited ground truth missions. Considering this problem, all of our experimental mapping was limited to the Colorado Plateau Test Region, where the data stack also covered an area of high ground truth density. Formal photo interpretation tests were possible in both regions as individual experiments.

A PRACTICAL SETTING FOR EVALUATION

As we approach the question of the extent to which and how remote sensing imagery from space can be incorporated into the practical solution of natural ecosystem problems, it is important to recall to mind the relationships between scale and resolution in the resource use and management decision process. Each problem and level of administrative-management has its own general scale requirements for decision making. When we say resolution in this case, we mean both spatial and spectral, because there is a strong trade-off between the two which usually, in the practical context, has to be compromised. We can rarely have the best of both worlds, since for some solutions spatial resolution holds the key while in other cases spectral resolution makes the greater contribution. The question can be disposed of by saying that it would be the grossest error to place emphasis only on one or the other.

What one can derive from remotely sensed data is strongly and directly dependent upon the practical problem to be solved. There are levels of problems just as there are levels of scale and refinements in resolution. These interrelationships are recalled to mind by Figure 4. In the complete management context, scales of 1:250,000 and smaller are superior for many problems in policy and broad planning. On the other extreme in practical resource management, especially in rangeland resources and forestry, sample point imagery at scales as large as 1:1,000 to 1:600, are often required if the contribution of remote sensing to efficient management is to be maximized.

Thus, we are addressing the question, "What is the role of space and high-flight imagery in this total process?" We are not at all concerned with the question, "Can or will space and high-flight imagery from presently available systems replace conventional aerial photography?" The most effective operational system is a combined one. For specific problems it may or may not require a space component.

METHODS

Ground Truth Activities

Ground truth consisted of:

a. Vegetational and soil resource maps provided by cooperating federal agencies in the respective regions.

b. Ground observations made by EarthSat scientists at or near the time of overpass.

c. Supplemental notes and observations, particularly on vegetation phenology (seasonal development), by agency cooperators.

d. Low level aerial photography, vertical and oblique, flown by EarthSat staff at or near the time of key seasonal overpasses by Skylab.

e. High-flight photography provided by NASA.

The legend categories to fourth and fifth level were used directly for field and air-check documentation. All of our ground truth data were plotted on 1:250,000 topographic sheets by numbered keys to facilitate relating them to each of the space imagery (Figure 5). Each of these locations was then transferred to a LANDSAT-1 1:250,000 enlargement with each datum point identified by legend symbol. Most of our critical mapping and interpretation experiments were done on 1:250,000 enlargements of the space image although some work was done on the duplicate 9x9 transparencies provided by NASA.

Image Interpretation Testing

Three separate interpretation tests were run using students from the remote sensing classes at the University of California, Berkeley. Groups of interpreters were selected on the basis of performance in the first-year course. None had had significant prior experience in photo interpretation. For each of the tests, ten students were assigned to two major groups consisting of five interpreters each. In the first test these groups evaluated the imagery by making a total set of 2400 decisions on each of eight image types. The image types evaluated were from the Colorado Plateau only and consisted of the eight types shown in Table II. In the first test imagery at the appropriate scale of 1:110,000 was used. In the second test, similarly constituted but different groups of interpreters evaluated imagery from both regions with all images enlarged to the common scale of 1:250,000. In this test five examples of each tester analog were evaluated for each image type (Table II) to give a total of 250 decisions per image type in the two regions combined.

In both of these tests, training examples of each tester analog were identified on the imagery. Remaining examples were located and randomly numbered. The interpreters were given five minutes to study the training sets on each image type and 30 seconds each to identify each member of the numbered test set. These data were analyzed by Tukey's method of pairwise comparison and by the conventional commission-omission error analysis. In a third image interpretability experiment with the first of the above interpreters, ten individuals repeated the test by the interpretation of LANDSAT-1 in side-lap stereo. Subjective evaluations of interpretability were also made by highly experienced interpreters.

Mapping Experiments

All mapping experiments were performed on 1:250,000 enlargements of the color imagery. In addition, the full 13 seconds of S-192 color composited data were mapped at the scale of the imagery as provided by NASA in five-inch film format (approximately 1:737,000).

A set of mapping criteria and guidelines were prepared and all imagery types were mapped according to these guidelines by a single interpreter to avoid variation in method since the primary purpose was to evaluate the various types of imagery. After doing the mapping in monocular examination, each area was additionally evaluated in stereo and notes were taken on the amount of line changes and number of identifications corrected as a result of the better perception of elevational and land-form relationships.

As the mapping was done, the interpreter assigned each boundary delineation a "certainty of delineation" and an "identifiability" rating according to the criteria in Tables III and IV, respectively. These data were then summarized by image type and evaluated for indications of the superiority of image type.

These results were compared among image types as an assessment of possible benefits from the use of stereo from space and also to determine if there were differences among image types with and without the stereo contribution to the interpretation process.

The same test area was mapped and each analog identified from RC-8, color infrared high-flight photography. On this the legend units were positively identifiable and except for the problem of generalizing the mapping to somewhat correspond to the intensity used on the space imagery, type delineation was very accurate. These maps were then compared as regards the kinds and nature of analogous features within each mapping unit on the five kinds of space imagery evaluated in the second test (Table II). As an additional check for the southern part of the test area, mapping was compared with vegetation and soils maps prepared by the Bureau of Indian Affairs and some Forest Service type maps provided spot checks in other areas.

In addition, 16 relief conditions were identified and measured from 1:250,000 topographic sheets. These points were located on each image type and evaluated as to the clarity with which they could be perceived in stereo examination. These results were summarized to compare image types and to establish the relief thresholds discernible with each type of imagery. The stereoscopic comparison was made at both the 1:250,000 scale and the 9x9-inch NASA product duplicate scale of approximately 1:737,000. In all cases transparency materials were used--for interpretation testing and mapping experiments.

Finally, based on our accumulated experience, the above evaluations, and the operational use of space imagery in the EarthSat applications program, a flow diagram was developed for a suggested operational system to analyze landscapes by appropriate combinations or alternatives of space imagery and aircraft photography.

Classification and Legend System

Since the first involvement of the author with space imagery in 1966, he and his associates have been evolving an hierarchical legend system under a consistent set of discriminative criteria. The system is especially suited to multistage remote sensing application and is decimal numerical for computer compatibility.[1] This effort has stabilized into a format and set of classification categories that is published elsewhere and has enjoyed widespread practical application in comprehensive ecological analysis of earth resources and land use studies.[2,3]

From the standpoint of plant ecology, vegetation and soil resource management, a classification and characterization of the form of the land surface is extremely important to both the student of landscapes and resource ecology and to the resource manager. For many years in the author's research at Oregon State University and in projects involving his graduate students, they have used a three-component system for landscape characterization. The components are: macrorelief, landform, and microrelief.

Macrorelief refers to the largest categories of classification of major relief change within the landscape system being described. Landform refers to the specific form of the landscape as a secondary level characterization. The classes we have devised to this date are consistent with and accommodate the major landform features recognized by geomorphologists within the two broad categories of fluvial and desert erosional characteristics or provinces. They also accommodate equally well the concept of features of negative and positive relief, i.e., high features and depressional features.

After trying repeatedly to use the technical landform classifications of the geomorphologists, we have gone back to a set of classes, with some modification and improvement, similar to the ones the author started to use in the early 1950s while conducting vegetation-soil relationships studies in forested and rangeland environments. While these classes may cause the professional geomorphologist some pain, they do have the distinct advantage of being especially relevant to and capable of depicting the kinds of landform features that are most relevant to plant ecology and soil development and to the practical use, development, and management of earth resources.

The microrelief classes define the contour of local landscapes, features of very low relief. For example, they express the micro-contour of a single mountain slope, small undissected mesa, or valley bottom.

Most of the classes or categories have been previously described and illustrated in various of NASA reports and other publications where they do not make use of common terms described in the geomorphological literature. Thus in the interest of time and space, descriptions of the classes are not included herewith. It is sufficient for the purposes of this paper to merely indicate the format of the system (Figure 6). The legend for all analogs evaluated in this project and for the characterization of the land surface is presented in Appendix A. The one new development that came out of this project was an improvement and refinement in the macrorelief and landform classes over that presented in 1972 (2). The major change involved bringing all classes under the same decimal numeric system and revising the landform classes to more logically accommodate the land surface features that are ecologically significant in vegetation and soil development and in land use and resource management decisions (Figure 7).

RESULTS AND DISCUSSION

Quantitative Comparison of Image Types for Interpretability

The purpose of these quantitative tests was to determine which of five image types were superior for ocular identification of natural vegetation analogs in the two test regions. The analogs used in the test are shown in Table V. An "Other Vegetation Types" class was included so that a variety of unknown image types could be interjected into the testing to create possible confusion with the subject analogs and thus provide a better assessment of true interpretability.

In conducting the test, the students were given a brief discussion of the common vegetational zonation patterns in the two regions and the various analog types were described so they would have some feeling of familiarity with the subject areas. In the familiarization discussion, no mention was made of image characteristics associated with the vegetation analogs.

The image set for the Colorado Plateau test region represented green season phenological development in the lower and middle altitudes, and pre-emergence dormant season at the very highest altitudes. The full-development, green condition prevailed generally below 9,000 feet elevation and pre-emergence dormant season essentially above 9,000 feet, except for evergreen species. The Sierra-Lahontan test area represented the dormant season condition below approximately 6,000 to 7,000 feet, and green mature vegetation conditions above approximately 7,000 feet. These particular dates in each of the two regions were selected because they were the only dates on which we accumulated useable, essentially cloud-free imagery for all image types over the same area. A much more desirable test would have been achieved had it been possible to use both green and dry season imagery for both of the analogous regions.

Interpretation Test One.-

Statistical Analysis: On the basis of Tukey's method of pairwise comparison, the image types compared in Test One can be ranked in order as shown in Table VI. From this table it is seen that the two best image types are S-190A color infrared and LANDSAT-1 color composite. S-190B color ranks third, thus its higher resolution on color film did not compensate for the color infrared spectral qualities. It is interesting also that black-and-white infrared imagery ranked close alongside S-190B color in this test with the suggestion that both black-and-white types (LANDSAT-1 and S-190A) may be more accurately interpretable for the point identification of vegetation analogs than S-190A color. The red band imagery was poorest of all.

It is informative to consider the image types that resulted in the fewest commission errors for each vegetation analog in this more comprehensive single-region test. These results are presented in Table VII.

The importance of high resolution in the S-190B color is evident in its superiority for identification of the sedge meadow analog. Sedge meadows are narrow stringer types in this region. They rarely occur except in narrow valley bottoms and around the edge of small lakes. Such features can only be seen and correctly interpreted on S-190B.

With the general inferiority of black-and-white broad band imagery for visual interpretation one might wonder why S-190A black-and-white infrared was among the best image types for aspen, spruce-fir, and the "other natural vegetation" categories. With the test imagery taken in the summer green season, aspen would be very highly reflective, thus producing unusually light tones in sharp contrast to the spruce-fir which occurs largely in juxtaposition with aspen and would image as a very dark tone on black-and-white infrared. Thus whenever the sharp edge of black on white was observed on the S-190A black-and-white infrared at high elevations, the logical conclusion would be to identify aspen for the light tones and spruce-fir for the dark tones.

The "other natural vegetation" category was probably interpreted well on S-190B color because we tended to select small contrasting vegetation analogs for the "others" category. It is important also to note that color infrared was superior for five vegetation analogs whereas color was superior only for three analogs. One should recognize, however, that in one instance (S-190B) the opportunity did not exist to compare both color and color infrared from this high resolution system. It is quite likely that the CIR would also have been superior over color film in the S-190B system. In summary, these results indicate the general superiority of color infrared remote sensing products for all natural vegetation interpretations.

Commission-omission error analysis: The results of the more comprehensive Test One are also summarized from a conventional omission-commission error analysis in Table VIII. If one looks first at the percent correct for the eight image types, it is apparent that both LANDSAT-1 color reconstitution and S-190A CIR meet frequently acceptable standards of accuracy, particularly the latter. LANDSAT-1 black-and-white Band 7, S-190A black-and-white infrared, and S-190B color gave essentially the same results; and next to the color infrared renditions, S-190A color and S-190A black-and-white red band were poorest in terms of point identification accuracy.

If one looks at the percent commission error category, comparisons can be made more explicitly (Table IX). This difference matrix shows LANDSAT-1 4, 5, 7 color reconstitution superior to 3 out of 7 other image types. It was better than LANDSAT-1, Band 5, and S-190A color and black-and-white red band. S-190A color infrared was not different but with a non-significant suggestion that it might hold a slight edge over LANDSAT-1 4, 5, 7 reconstitutions. However, this hypothesized advantage would be overridden by the image quality control problems (poor radiometric fidelity) of the S-190A camera system. In our experiment the planned interregional comparisons were impossible because of this problem.

The S-190A color infrared was superior to LANDSAT-1 Band 7 only at a low probability (P=0.90); but it was highly superior to S-190A color. The S-190B color was superior to S-190A color (P=0.95) but also inferior to S-190A color infrared (P=0.90). In all comparisons the black-and-white red or Band 5 was outstandingly poor, with commission errors of 48.7 and 53.5 percent.

Interpretation Test Two.-

Statistical Analysis: Based on experiments performed under this contract in only the Colorado Plateau region during the spring of 1974, we decided that substantially fewer than 2,400 interpretation decisions would provide acceptable results[4]. Both cost factors of employing experimental interpreters and especially the time required to process larger amounts of data, led us to compromise on five interpreters and four tester analogs on the five image types in two regions for these additional comparisons of LANDSAT-1 and Skylab data.

The basic data derived from Test Two are displayed in Table X. These data were first analyzed by a one-way analysis of variance which showed highly significant differences in the Group I Sierra-Lahontan data and significant differences in Group II Sierra-Lahontan data. The accuracy obtainable with the image types in the Colorado Plateau region were not significantly different, although Group II approached significance. Careful study revealed that there was a tendency for variation among interpreters and in image quality to obscure meaningful differences.when all the data were grouped. Using between-region differences in correct identifications with a given image type as an index of regional variation in image quality, or the effect of seasonal difference between regions, the interpretability of LANDSAT-1 data was different between the two regions at a probability far in excess of 0.99. Similarly, Group II interpreted both S-190A color and S-190B color imagery differently between the two regions at a probability far in excess of 0.99. Only S-190A CIR imagery was interpreted with the same accuracy by both groups in both regions.

The results for Group I and II in the Sierra-Lahontan region and the combined groups for the Colorado Plateau region were then tested for significant differences among all image type comparisons. These data are summarized in matrix Tables XI, XII, and XIII. This analysis shows that, at varying levels of probability (all in excess of P=0.90) the interpretability of LANDSAT-1 data was higher than all other types in the Sierra-Lahontan. Also at varying levels of P=0.90, S-190A color infrared was superior to S-190A color, S-190B color, and S-192, except one instance of a group interaction in the test. Group II gave highly significant superiority to S-190A color infrared over S-190A color, but Group I did not show a difference between these two image types. No other comparisons gave significant results. This suggests that the radiometric qualities of color infrared are more important in contributing to accuracy of interpretation than is the high resolution of the S-190B system. The same can be said with respect to the LANDSAT-1 color infrared rendition, in spite of its lower resolution, as compared to both of the Skylab camera systems.

It is somewhat surprising that S-190B color did not rate higher in this test. A possible explanation is that, for point identification of image types (where mapping decisions are not involved) the higher resolution of both the S-190B and S-190A color is unimportant. It is likely that had we used color infrared film in the S-190B camera, its interpretability score would have been substantially higher (see section on mapping experiments where S-190B color and S-190A color were both found superior to LANDSAT-1 and S-190A color infrared imagery).

In the Colorado Plateau area, LANDSAT-1 color reconstitution proved inferior to both S-190B color and S-190A color at a highly significant level. S-190B color was superior to S-192 at P=0.90. No other differences approached significance in the Colorado Plateau test. The reason for poor performance in the Colorado Plateau region may be the season of imagery used. For the low elevation arid types, it was peak green. Differentiations between sagebrush and salt desert were somewhat difficult and images were particularly variable because of soil type variation. At the intermediate elevations oakbrush was in full leaf and tended to override associated juniper and ponderosa pine when the latter were in open stands. At the high elevations, vegetation was still dormant so that poor discriminations were provided between aspen and meadow types and between oakbrush and aspen stands where the former fingered up into the higher elevations.

Commission-omission error analysis: A standard commission-omission error comparison was also performed on the Test Two data (Table XIV). The Sierra-Lahontan study (those most consistently significant in comparisons among image types) gave essentially the same results as the more comprehensive Test One, insofar as color imagery is concerned.

From the Colorado Plateau test area, LANDSAT-1 data ranked poorest of all on the basis of "total percent correct" and interpretations and commission errors, although differences were small and few of them significant. The best results were obtained for this region with S-190B color, both on the basis of total correct and the number of commission errors; although in these instances we are talking about apparent differences, none of which would be found significant at reasonable probability levels. On the basis of commission errors, a suggested ranking of S-190B best and LANDSAT-1 with S-192 poorest is suggested by the Colorado Plateau data; and LANDSAT-1 best with S-190A color, S-190B color, and S-192 poorest in the Sierra-Lahontan region (Table XIV).

If these data were combined for all groups and regions, the combined magnitude of error and compensating differences resulted in essential non-significance. Only S-190A color infrared and LANDSAT-1 color reconstitutions were significantly better than S-192 (P=0.99 and 0.95, respectively). A more specific explanation may be that some of the images, particularly LANDSAT-1, were far superior for the Sierra-Lahontan than for the Colorado Plateau. In the Colorado Plateau the LANDSAT-1 image was uniformly red to pink for many vegetation types, whereas they were strongly contrasting in Sierra-Lahontan. The same can be said of the S-190A color infrared, although the problem was not as bad as with LANDSAT-1 data in the Colorado Plateau.

These results further support a practical guideline that our accumulated experience has suggested--namely, the best season for imaging natural vegetation with color infrared is as the vegetation types of interest are moving into the dry or mature season. The interpretability of many types of natural vegetation is nearly always low during the peak green season.

In making these statements one must not minimize the importance of the multidate imaging capability of the LANDSAT-1 system. Both for full visual and machine-aided, interactive interpretation of space imagery, the multidate component is the only way some identifications can be made with reliability (Figure 8 and 9).

The most specific statement that can be made from this series of comparisons is that LANDSAT-1 and S-190A color infrared are the superior image types when the capability of interpreters to correctly identify point images is the criterion for judgment, and that LANDSAT-1 over S-190A color infrared seems to be favored. As support imagery the S-190B shows some points of advantage; and, had we the opportunity to test S-190B color infrared, it might well have been higher in the scale assuming adequate photo quality control and consistency. In addition, the black-and-white infrared showed advantages in selected discriminations and thus should be considered in a support role for visual interpretation.

It should also be recognized that S-192 is really a finer-tuned multispectral system than LANDSAT-1 and it is unfair to compare it in photographic mode. We were asked specifically to include the 1, 7, 9 color reconstitutions in our visual interpretation testing. For lack of funds and time after receipt of S-192 tapes, we were unable to include it in the digital analysis format where it might well have performed superiorly if our parallel experience with LANDSAT-1 digital data can be taken as an indication of what to expect.

In considering these results as well as in designing new and further experiments, it is important to recognize that only point identification, not mapping, of natural vegetation analogs was tested in the previous experiments. This is only half of the mapping job. Delineation capability must also be assessed. The final "proof of the pudding" is, however, in identification because there are workable alternatives for minimizing problems of delineation.

Kinds of commission errors.- In a combination of data from Tests One and Two, we considered the interpretability of specific analogs in terms of the kinds of confusion involved in the commission error categories. We established a threshold level of two commission errors per ten decisions on a single vegetation analog category as the possible confusion level above which special training and care would be required or justified to minimize commission errors in interpretation. There is a significant analog-image type interaction. Thus the best image type is a function of the subject of interest (Table VII).

The next table (Table XV) summarizes the problem analogs based on the above-mentioned threshold concept. For this summary and analysis the results of Tests One and Two were combined and the combined results presented in Table XV. Observe that

341.1, pinyon-juniper; 341.2, ponderosa/Jeffrey pine; 347, mountain brush or chaparral; and 315, meadows are the problem analogs on which training and care of interpretation should concentrate.

Mapping Experiments

Mapping experiments are most difficult to conduct because any map is a generalization of reality and to a large degree the result is subject to the individual interpretation of mapper who must decide:

1. How to resolve gradients and intricate patterns with the legend system,

2. How to compromise these same patterns with a mapping intensity or level of generalization appropriate to the purposes for which the map is being made, and

3. When to ignore certain features as unimportant inclusions.

Except in the case of pure, distinct types that clearly exceed the minimum "intensity of delineation" standards, it is rare that any two experienced individuals will produce exactly the same map. If they correctly identify the subjects delineated within each boundary and reasonably assess the proportions of each within that boundary, their differences in delineation are inconsequential--who is to say which map is correct and which is in error. If these decisions by the interpreter are accurate (identification and proportion of area), the data tabulation for all interpreters will add up to the same set of statistics regarding the kinds and amounts of features being mapped.

In the Sierra-Lahontan region we found it necessary to use widely diverse areas to get a representation of the necessary analogs while we could achieve this in a single transect of approximately 1,761 square kilometers in the Colorado Plateau region. All mapping experiments and comparisons were done in the latter region for this reason.

A set of mapping guidelines was followed in delineation and annotation (Appendix B1). As each delineation was made its components were tallied on a standard form (Appendix B2) along with time expended notations. Delineation was done on the combined basis of vegetation and land surface features so that identification provided both components of the legend. The key results of all this work are presented in the tables and discussion that follow.

Image types discernible on each kind of image.- One of our first experiments was to determine the number of kinds of images that could be discerned on each image type without regard to identification of the subjects represented. Such a test is meaningful and valid on the assumption that if one can discern a difference and thus delineate a subject area, there are many ways by which it can be accuaretely identified to provide useful information.

To make this comparison, an identical area of approximately 21-square inches was laid out on each image type. From this population, six one-square-inch samples were drawn. To provide direct comparability, the same six locations were used for each image type. Two experienced interpreters examined each square-inch sample and independently decided on the number of image classes that could be discerned within the designated sample area. They first did the "easy to discern" determination, compared results and discussed differences to agree on the number that their collective experience indicated could be repeatedly detected without problems of incomplete boundary location and consistency of recognition. This number was entered as the first observation for the square-inch sample area. They then repeated the process to decide on the total number of image classes that could possibly be discerned in the same sample area by considering subtle differences in density, color, or image texture. Notes were compared and a single decision again reached on the maximum number that could be practically interpreted in an operational setting; i.e., entire boundary definable and reasonable expectation that interpreters, working under the same set of mapping intensity guidelines, would be able to recognize each image type.

The average number of classes discerned in the six square-inch sample areas is tabulated in descending order by film type in Table XVI.

These data enable a comparison of color versus black-and-white; for the "easy discernability" class color defined, 38 percent more kinds of images than black-and-white and 50 percent more for the "total possible" class. In this case note that S-190A color infrared and S-190B color were superior and that S-190A black-and-white red band was third even though in the identification testing this image type was either poorest or next to poorest image type. LANDSAT-1 color reconstitution was fourth; and while the infrared black-and-white images proved out well in the identification tests, they were rated on the bottom in terms of discriminating power.

Comparative results of mapping.- The comparative results of mapping provide a guide to the better image types in two ways: First, from information relevant to the amount of extractable information; and second, on the basis of costs of deriving the information. Table XVII summarizes the data relevant to these questions for each image type when mapped at the constant scale of 1:250,000.

Note first that LANDSAT-1 provided the highest percentage of "pure types," but this may be due to the higher level of generalization inherent in the poorer resolution of the image used and season of acquisition. The other image types are essentially the same as regards this indication of mapping intensity. The highest percentage of 3-way complexes mapped was from the highest resolution image types, S-190B color and S-190A color infrared. In the former case the percentage was high (14 percent) because of resolution of the system. In the second case it was high (13 percent) because of the increased detectability of certain types resulting from the infrared band and the false color product. The other high percentage of 3-way complexes was mapped on the Uncompahgre Plateau example of the S-192 color data. Here the reason was due to our mapping this example from 1:79,000 scale material and the fact that this image was particularly good in terms of vegetation type resolution. We were able to see and identify far more kinds of vegetation than could be mapped at such a small scale.

The average boundary scores favored S-190A color and S-190B color with S-192 color averaging lowest. The number of delineations per 2,000 square kilometers is also an index of information content when mapping is done under the same standards. This tends to place S-190B color at the top, S-190A color and color infrared intermediate, and LANDSAT-1 and S-192 at the bottom in that order.

Cost factors are, of course, a function of the number of delineation and identification decisions that have to be made and how easily they can be arrived at. When imagery is poor, and of its nature generalizes the ground features, costs tend to be low but cost per unit of information may be high. Similarly, S-190B color looks very expensive in man-hours and S-190A color infrared more expensive than LANDSAT-1. If, however, one ratios the cost to information on the assumption that number of delineations per 2,000 square kilometers is an index of information content, the image types line up as follows:

Image Type	Ratio
S-190B color	0.50
S-190A color infrared	0.42
LANDSAT-1	0.43
S-192 color	0.30
S-190A color	0.30

There are, of course, other criteria of benefit and value. Without considerably more work it is difficult to determine which system the cost benefit really favors--except to recall that the two intermediate cost systems (S-190A color infrared and LANDSAT-1 4, 5, 7 color) were nearly always on top in accuracy of identification. These two systems also came out top and intermediate, respectively, in the discriminating power study (Table XVI). These facts would strongly tend to throw the cost benefit in their favor because of the higher reliability of the information derived--since the proof is in reliability of information, not delineation density.

Accuracy of identification in mapping.- It was our original intention to use the high-flight RC-8 color infrared photography as a standard for judging the accuracy of both mapping and identification by the space imaging systems. This did not prove too successful because of the difficulty of deciding how best to generalize between the aircraft and the space systems and because we did not encounter enough examples of some types within the test belt of superimposed imagery to provide a sufficient sample size. However, for one second order, one third order, and four fourth order analogs, we were able to make a reasonably good comparison. This comparison for two strongly contrasting image types, S-190B color and LANDSAT-1 is presented in Table XVIII. In both cases we expected the accuracy at second and third level to be higher than at fourth level. This was true only for the S-190B color, not for LANDSAT-1. For all but the 320 (shrub/scrub) class, accuracy levels are quite acceptable, being lowest for 341 (coniferous forest). The 320 class was low because this is one of the most difficult classes in this particular region to discriminate. There was a strong tendency to confuse 320 with some of the 341 types. This may also be what pulled down the 341 accuracy. More importantly, these results show that space imagery can be interpreted to fourth level in some instances if the interpreter knows what to expect in the area. Had the area allowed a comparison of 324 (salt desert), 325 (shrub steppe), and 327 (macrophyllous shrub), it is our hypothesis from other interpretation work in the project that satisfactory results would have been obtained--especially had it been possible to incorporate multidate imagery and to evaluate the areas in stereo.

Stereo Interpretation from Space Imagery

Since our first successful experience with the stereoscopic interpretation of Apollo VI photography over southern Arizona, this author and many of his associates have been proponents for the use of stereoscopic interpretation of space imagery whenever possible. Upon our request, most of our Skylab imagery was taken with 60 percent forward lap, and we had done side lap stereo interpretation of LANDSAT-1 data in the early phases of that experiment. Routinely in our operational project work, we make use of the side lap area between orbits as a starting point in visual image interpretation of LANDSAT-1 data.

Our first experiment in stereoscopic interpretation was conducted with inexperienced students in connection with Identification Test One. In this experiment, ten of the interpreters were given a stereoscopic identification test of point data in the Colorado Plateau Test Region as a repeat of the monoscopic test they had taken some weeks earlier. The long delay was intended to compensate for any familiarity bias in the second stereoscopic test. S-190A color infrared images were used for the test. The working materials were enlarged to the point that the images would be at approximately the same scale when viewed under a magnifying stereoscope as the monoscopic images when viewed without magnification.

The following overall results were recorded for the ten interpreters: monoscopic interpretation, 82.7 percent; stereoscopic interpretation, 77.3 percent. The two sets of data were not significantly different when subjected to a paired "t" test (P=0.99). Two reasons are offered in explanation: (a) although the students had unimpaired stereo vision, none had had significant exp ience with stereoscopic interpretation; and (b) more importantly, none of the students were experienced in relating vegetation to its physical setting--they just did not know what to expect. The illustrated introduction to the natural vegetation was apparently inadequate to prepare them for interpretation of the stereoscopic model.

To assess whether the results of a trained interpreter might be better than those of the student group, one of the investigators took the same test. This individual had had extensive stereoscopic viewing experience and understood the relationships between vegetational zonation, landform, and elevation. His results are summarized below:

Category	Number of Correct Responses (maximum = 10) Monoscopic	Stereoscopic
J - Pinyon-juniper	6	10
P - Ponderosa pine	8	10
W - Carex meadows	9	7
A - Aspen	7	10
S - Spruce-fir	5	7
X - Other vegetation types	5	7

Pronounced improvement in identification accuracy was noted for all categories but one. This category--sedge meadow (W)--always occurs in very small units and was sometimes difficult to see clearly on the stereo model. This limited comparison highlights the important role to be played by a trained interpreter when extracting image information from a complex landscape. Knowledge of the ecological relationships present in that landscape is essential to accurate interpretation. Under these circumstances, it was our hypothesis that stereoscopic interpretation will produce markedly improved results over monoscopic interpretation.

In connection with the more comprehensive mapping experiments, we set about to test this hypothesis.

Stereoscopic evaluation of ground resolution.- Each image type was viewed at two scales for this test. Four kinds of a natural resolution target were evaluated for clarity (++ = very clear or obvious; + = evident; - = not evident). These were converted into a numerical score as shown in Table XIX. The S-190A color and S-190B color were best and the only place where stereoscopy gave an advantage was in some of the linears.

Stereoscopic perception of relief change.- We next set about to determine what magnitude of relief differences a person with good stereo perception could actually see as a three-dimensional model with each kind of space imagery. Side lap stereo was used for LANDSAT-1. All of the features listed in Table XX were scored by the same method as the ground resolution targets and numerical scores were computed in the same way. This showed S-190B color superior to other systems. On S-190A color and the S-190B one could see relief differences as slight as 200 feet. The perception of relief was a function of the rate of change but even in relatively level to rolling macrorelief, one could see a true stereo model down to a threshold of 200 to 225 feet per mile. This perception capability is highly important and of great value in identification of vegetation analogs through relationship to landform, slope, and position on slope. While conducting this test it was evident that under certain conditions monoscopic viewing could give a depressional perspective when in fact one was looking at strongly hilly macrorelief. Such misconceptions of landform did lead to identification errors of substantial magnitude--for example, erroneously calling deciduous aspen and mountain meadows sagebrush steppe and salt desert vegetation types when viewed monocularly.

Stereoscopic improvement of identification decisions.- By reassessing monocular mapping and identifications of both vegetation and landform features in the same 1,761 square kilometer area of each imagery type except S-192, we were able to make a good assessment of the benefits from stereo interpretation. Table XXI shows the amount of delineation and identification change made by stereo examination at a scale of 1:250,000. This table suggests that there are important differences among imagery types as regards the benefit from stereo viewing. More changes in boundary were made with LANDSAT-1 and S-190A color than with the other imagery types. Many of these boundary changes were of substantial areal significance. Most of them were made either in areas of undulating to slightly hilly macrorelief or in areas where the image characteristics gave the impression of gentle relief when in fact the subject was strongly hilly to mountainous. This is particularly helpful in the case of isolated buttes and small mountain systems. Also in the gentler relief areas one can relate a vegetation change to a break in relief when such is impossible in mono viewing. The changes in identifications were substantial for S-190B color.

The low contribution of stereo to S-190A color infrared is probably due to the poor resolution characteristics of the particular image used in this experiment. The large number of changes in landform classification with the S-190B color when viewed in stereo is most likely due to its higher resolution and the fact that by viewing in the stereo model, more of the features of relief can be seen and more of the vegetation pattern explained.

We next looked at the exact nature of the changes in identification resulting from stereoscopic viewing. These comparisons are shown in Table XXII. Part of the change in the 2.3 class was the result of calling the lands more flat in mono interpretation and to the changes in the hilly and mountainous classes. Changes were made from hilly to mountainous. A stereo classification into mountainous of some of the lands formerly considered in class 2.3 accounted for some of the large differences between mono and stereo identification. Some of the mountainous relief difference could not be judged by monocular interpretation.

Much of the change in 130, rockland, resulted from being better able to perceive mountainous rocklands in stereo. The perception of lowland flatlands contributed to some of the change into 310, herbland, classifications. Most of the change in 327, macrophyllous shrub, and 341, coniferous forest, resulted from being better able to define the true 327 areas in stereo since they are higher plateau and hill land related. There was a tendency to overestimate 327 where it occurred adjacent to 341 and particularly to underrate the latter where stands were open. Some of these errors were corrected by landform relationship in stereo viewing. While one could not see individual conifer trees, the 341.3, mixed conifer, class could be much more accurately identified in stereo because of the strong relationship to steep slopes, valleys, and high hill and mountain positions that this type occupies.

While more in-depth studies by larger numbers of experienced interpreters could refine and improve upon measurements of value from stereo, we feel that these results are sufficient to stimulate more serious consideration in use of stereoscopic interpretation of space imagery where natural vegetation and soil conditions are the main points of concern.

AN OPERATIONAL SYSTEM FOR EARTH RESOURCE ASSESSMENT

One of the author's goals from the beginning of his involvement in the Earth Resources Space Applications Program has been to devise or suggest an effective operational system for amalgamation of space and aircraft remote sensors into an efficient and cost-effective operational system for inventory, analysis, and monitoring of earth resources and land use. While some may feel we haven't yet arrived, the facts are that, since early in the LANDSAT-1 program, Earth Satellite Corporation has been using space and aircraft image · in combination and alone when appropriate, to service the needs of clients on three continents and in all disciplines in a cost-effective way. The following flow diagrams and discussion do not necessarily reflect the unified opinion of the company. It is the author's expectation, however, that high agreement in principle and on the general concept will prevail throughout the remote sensing community. Most disagreement among those of us with substantial experience in space systems applications would probably be in the area of details and adaptation of this kind of general pattern to specific cases. At least the author is willing to take full responsibility for the commendable qualities and deficiencies of the following ideas with the hope that this presentation will stimulate criticism and a focusing of energy on the true problems of a cost-effective, operational space and aircraft system so that the benefits of space technology can more effectively serve the needs of mankind.

A highly generalized flow diagram is presented in Figure 10. The details represented by each of its blocks are then expanded in Figures 10a, 10b, 10c, and 10d.

The generalized flow diagram of Figure 10 is essentially self-explanatory, but a few points may require clarification. A ground truth mission is scheduled deliberately relatively early in the flow chart. In practice ground truth missions come into the system at many points. It is better to emphasize their role by inclusion in the direct flow-line rather than to de-emphasize such an important component by placing it in a multi-focused peripheral loop. The first ground truth mission, in a reconnaissance mode, may actually have to be performed as a part of the background work in some projects. It can be a part of any subsequent stage through "refined interpretation."

This generalized flow diagram emphasizes another important concept--namely, that the first-cut interpretation is done most effectively by knowledgeable and experienced interpreters. This is in contrast to the viewpoint of some who feel that "because of the magnitude of data in wide-area synoptic coverage, the first interpretations must be by machine." Accumulating experience and demonstrated ability to do these first-cut interpretations rapidly, efficiently, and adequately by visual interpretation leads this author strongly to challenge the wisdom and particularly the cost effectiveness of doing these first-cuts by computer analysis.

Finally, in the generalized treatment, the role of "feedback" deserves some special attention. Almost without exception in the operational mode, feedback may start at any stage beyond the initial stratification to bring about refinements, to improve adaptation to the specific problem situation, and to enhance performance. Feedback is, of course, particularly important when one reaches the monitoring component of the "decision and action" block. Now let us look within these blocks at some important details and alternatives.

Some of the major components of background work are specified in the expanded flow diagram of Figure 10a. The various functions in this unit should be self-evident but disregarding or side-stepping of important components in this stage sometimes jeopardizes successful application of the system.

The block representing those factors of design, classification, intensity, and repeatability also includes the idea of adopting the legend system. Following are the main advantages of the legend system we have devised and perfected by diligent modification and testing plus sessions to seminar and critique the legend by people actively involved in practical operational use of the system. It has gone through numerous revisions and extensive field verification. The legend has evolved into its present form demonstrating its practical usefulness for application to space and high-flight image analysis after having a rigorous and critical development process. The main advantages of the system are:

1. It is based on divisive logic that is consistent with a growing understanding of earth resources and upon consistent criteria for differentiation by visual stimuli among classes at each hierarchical level.

2. It accommodates in a single coherent system the natural vegetation, vegetation modified by intent with a permanent management goal, barren lands, all water resources, as well as those land-uses that have permanently altered the nature of the earth's surface, i.e., urban, industrial, transportation, and utility distribution, and extractive industries.

3. By being ecologically rather than urban-industrially orientated, it characterizes the landscape features on a natural basis that is free of land-use bias.

4. The system thus provides a superior basis for treating the multiple land-uses so common in the "wildlands" situation such as the case where the same piece of land is used for forestry, range, watershed, wildlife, and recreation. To knowledgeable resource ecologists, these potentialities for use are often self-evident in the description that the legend system gives of specific landscapes.

5. It is numerical and thus highly computer compatible.

6. It is conceived on a consistent logic through the fourth, fifth, and even to the sixth hierarchical level.

7. It allows easy and consistent agglomeration from the finest to the most generalized category.

The initial stratification stage (Figure 10b) is largely determined by the nature of the problem being attacked and the information needs being met through remote sensing. For problems where a regional perspective is needed or a land-use interrelationship picture is to be portrayed, space imagery is often ideal. For some problems however, the initial small-scale, stratification stage may best be performed on high-flight aerial photography. In the initial stratification stage it is also important to emphasize the need to do ground truth and over-flight missions with imagery in hand.

Especially when working with space imagery the first two intensity levels of stratification should consider the appropriateness of an ecological province (or subregion) breakdown followed by a second-order stratification into land systems after the technique that is widely used in Australia. Following this, the third-order stage is delineation into appropriate levels of an hierarchical legend system similar to the one we have devised and proven through extensive use. For some projects this latter will represent the first order of stratification.

One of the most important features or concepts of space and high-flight image application is exemplified in the "prioritized areas" function of the initial stratification stage. By the application of these techniques, one quickly defines the areas of no concern so that all energy at an early point is focused on those important landscapes that are truly relevant to the problems at hand. This feature is a great saver of dollars and both scientific and managerial manpower.

In the second subsampling stage (Figure 10c) one moves to larger scale and/or finer resolution, and machine-aided, interactive interpretation becomes appropriate if not essential for maximum effectiveness of the system.

Strong emphasis should be placed on "support system selection and staging." At this point, the results of research similar to those reported here become paramount in making the proper choices among operational support systems. The author's own accumulated experience to this point strongly suggests that, if space imagery is appropriate as the initial stratification stage, the LANDSAT MSS system is ideal for such applications. Supporting this system then, in the second subsampling stage, one has at least four highly viable options. Remember that this stage follows the prioritizing of areas of concern. Within these areas then, the options become first, digital analysis of MSS data similar to LANDSAT-1 or possibly, with de-bugging and refinement, systems like the S-192. A second option which we in Earth Satellite Corporation are beginning to use extensively is the special enhancement and reprocessing of LANDSAT-1 data from the magnetic tapes to produce an improved photographic product at scales from 1:400,000 to 1:100,000. These images can be somewhat "tuned" to the needs of second-level analysis in areas of critical concern. A third option is use of special space systems such as the Skylab S-190B where higher resolution is needed because of the nature of problems being addressed.

A little-used option with high potential is visually interpreting stereo imagery from space, and still another option employs multidate or multi-season imagery. This requirement is another strong point in favor of an un-manned system such as LANDSAT-1 as the basic earth resource monitoring system. When one considers the practical problems encountered in getting a desired set of multidate imagery, superimposed over a clearly defined pair of interregional test sites, the advantages of a continuous running or programmable sun synchronous system can be easily demonstrated. While, for natural vegetation applications, nine-day frequency of repeat coverage will rarely if ever be needed, there were many times during our LANDSAT-1 and Skylab experiments when a nine-day repeat cycle would have given us imagery we critically needed. Slippage of nine days around a critical stage of plant development can usually be tolerated, 18 days often not.

Finally, but certainly not of least importance, conventional aerial photography in a multistage mode will always have a role to play in any comprehensive earth resources inventory and monitoring system that has as one of its goals contribution to resource management The scale and spatial resolution of systems used under this option are highly dependent on the kinds of problems addressed. For example, if the solution of rangeland resources problems is approached with the intent of fully capitalizing on remote sensing capability, certain components of the problem require imagery at larger scales of 1:1,000 or 1:600 and with stereo overlap. These needs can hardly be met from presently available,civil applications space technology. At the present time it is the author's feeling that, while digital analysis of LANDSAT MSS data can be effectively done at a quasi scale of approximately 1:24,000 looking at 0.4 hectare units of land, this multispectral system cannot meet all of the requirements for assessing many natural vegetation management and soils stability problems.

Having selected the appropriate support systems and designed a multistage approach compatible with the problem situation, refined interpretation moves ahead to produce both certain and uncertain inventory decisions. A ground truth mission comes back into the loop as the uncertainties are removed or reduced to a tolerable level.

The product development block (Figure 10d) is an integral part of the remote sensing application package in the context of map preparation, derivation of statistical sets of necessary data and the interpretations that give the data and maps relevance to the problems to be solved. These actions lead to reports and recommendations that carefully address the problem. This ensures that the real "proof of the pudding" can be realized in a rational decision and action program--one that is effectively monitored to fine tune and adjust the program and ensure complete success in problem solving.

To the question, "Is such an operational program feasible?" we merely respond that Earth Satellite Corporation is now using LANDSAT-1 data, and in some cases Skylab imagery, together as appropriate with aerial photography for solving real problems. Such applications have taken place in the United States and on at least two continents other than North America. Many of the ideas embodied in the above flow diagram have been field tested in these kinds of operational projects. In this writer's opinion, space-born remote sensing systems have already been proven operational. A significant number of projects are now moving ahead in developing nations and other where the resource base is not well understood with a speed and at a cost that could not be approached--in some cases not even considered--if we lacked the option of doing the first-phase analysis by the interpretation of space imagery.

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Table I.- Types and Dates of Imagery Used in the Two Test Regions

System/Film	Date	Area
LANDSAT-1 CIR	May 18, 1973	Colorado Plateau
S-190A/CIR	June 5, 1973	Colorado Plateau
S-190A/Color	June 5, 1973	Colorado Plateau
S-190B/Color	June 5, 1973	Colorado Plateau
S-192 (1,7,9) Color	Aug. 4, 1973	Colorado Plateau
LANDSAT-1 CIR	July 25, 1973	Sierra-Lahontan
S-190A/CIR	Aug. 11, 1973	Sierra-Lahontan
S-190A/Color	Aug. 11, 1973	Sierra-Lahontan
S-190B/Color	Aug. 11, 1973	Sierra-Lahontan
S-192 (1,7,9) Color	July 25, 1973	Sierra-Lahontan

TABLE II.- THE IMAGE TYPES EVALUATED IN THE FIRST AND SECOND SERIES OF INTERPRETATION TESTS

First Test	Second Test
LANDSAT-1 Color Composite Band 5 B/W Band 7 B/W	LANDSAT-1 Color Composite
SKYLAB, S-190A Color Infrared Color Red Band B/W Infrared Band B/W	SKYLAB S-190A Color Infrared Color
SKYLAB S-190B Color	SKYLAB S-190B Color
	SKYLAB S-192 Color Composite

TABLE III.- CRITERIA FOR RATING THE EASE AND CERTAINTY OF DELINEATING BOUNDARIES

Rating 1.	Boundary line easy to decide, clear, and distinct.
Rating 2.	Boundary delineation presents some problems, some area of diffuse boundary but mostly fits condition 1.
Rating 3.	Boundary definition has some alternatives; specifically, half or more of boundary shows diffuse change, thus allowing for different interpretations of where the boundary should fall. However, for any of these alternatives, differentiation definitely appears stronger after line is drawn. Line is not significantly arbitrary.
Rating 4.	Boundary definition is quite arbitrary, likely to be made with marked difference by different people; only small portions of boundary (<30%) are distinct as in 1, 2, or 3.

TABLE IV.- CRITERIA FOR RATING THE IDENTIFIABILITY OF IMAGES

Rating 1.	Positive; little likelihood of identification errors.
Rating 2.	Reasonable certainty; probably a few inconsequential identification errors.
Rating 3.	Moderate chance of error; identification highly dependent on associated convergence of evidence or local familiarity.
Rating 4.	Substantial chance for error; attempted identification is little better than a guess.
Rating 5.	Inadequate information to identify; no identification.

TABLE V.- ANALOGS USED IN INTERPRETATION TESTS ONE AND TWO

Numeric Symbol	Vegetation Type	Alpha Symbol	Used in Test	
			One	Two
315	Meadows	W	√	
325.1	Sagebrush	Sa		√
341.2	Ponderosa/Jeffrey Pine Forest	P	√	√
341.1	Pinyon-juniper Woodland	J	√	√
341.4	Spruce-fir	S	√	
342.4	Aspen	A	√	
347	Oakbrush/Mountain Chaparral	B		√
	Other Vegetation Types	X	√	√

TABLE VI.- RANKING OF IMAGES IN DECREASING

ORDER OF INTERPRETABILITY

Image Type	Overall Average Correct Responses (All crop categories)[1/]
EREP S-190A Color IR	7.9
LANDSAT-1 Color Composite	7.0
EREP S-190B Color	6.4
EREP S-190A B/W IR	6.4
LANDSAT-1 Band 7	6.2
EREP S-190A Color	5.5
EREP S-190A B/W Red	5.2
LANDSAT-1 Band 5	4.6

[1/] Maximum possible value = 10. Test is by Tukey's method of pairwise comparison.

TABLE VII.- ANALYSIS OF TEST DATA

(NATURAL VEGETATION IDENTIFICATION TEST)

RANKING OF IMAGE TYPES BY COMMISSION ERROR

For each of the natural vegetation categories listed below, the image type(s) are given which form a group that is significantly different from all others in terms of commission error (using Tukey's method of pairwise comparison). These images are those for which commission errors are lowest.

Natural Vegetation Category	Image Type
Pinyon-juniper	EREP S-190A Color IR
Ponderosa pine	EREP S-190A Color IR
Sedge meadow	EREP S-190B Color
Aspen	EREP S-190A Color IR EREP S-190A Color EREP S-190A B/W IR
Spruce-fir	EREP S-190A Color IR EREP S-190A B/W IR ERTS Color Composite
Other natural vegetation	EREP S-190A Color IR EREP S-190A B/W IR EREP S-190B Color

TABLE VIII.- COMPARATIVE INTERPRETATION ERRORS BY IMAGE TYPE FROM TEST ONE (2400 DECISIONS)

Image Type	Percent Correct	Percent Commission Errors	
		Range in %	$\bar{x} \pm SE_{\bar{x}}$
LANDSAT-1 Color	71	11-43	30.33 ± 5.02
LANDSAT-1 Band 7	62	16-58	37.33 ± 6.81
LANDSAT-1 Band 5	46	44-67	53.50 ± 3.50
S-190A CIR	78	10-26	21.51 ± 2.81
S-190A Color	55	35-50	44.7 ± 2.11
S-190A B/W IR	64	12-56	35.8 ± 7.01
S-190A B/W Red	52	42-57	48.7 ± 2.67
S-190B Color	65	18-46	33.3 ± 4.59

TABLE IX.- SIGNIFICANCE OF DIFFERENCE MATRIX

COMPARING IMAGE TYPES FROM TEST ONE

Image Type	LS-1 Color	LS-1 B-7	LS-1 B-5	S-190A CIR	S-190A Color	S-190A B/W IR	S-190A B/W Red	S-190B Color
LS-1 Color	X							
LS-1 B-7	7.06	X						
LS-1 B-5	** 13.17	+ 16.17	X					
S-190A CIR	8.83	+ 15.83	*** 32.00	X				
S-190A Color	* 14.37	7.37	+ 8.80	*** 23.20	X			
S-190A B/W IR	5.47	1.53	* 17.70	+ 14.30	8.90	X		
S-190A B/W Red	** 18.37	11.37	4.80	*** 27.20	4.00	12.90	X	
S-190B Color	2.97	4.03	*** 20.20	+ 11.80	* 11.40	2.50	* 15.40	X

TABLE X.- PERCENT CORRECT INTERPRETATION BY TEN INTERPRETERS

FOR FIVE IMAGE TYPES IN TWO REGIONS

Group	Interpreter	Colorado Plateau					Sierra-Lahontan					
		192	190B COLR	190A COLR	190A CIR	LS-1		192	190B COLR	190A COLR	190A CIR	LS-1
1	H	79	80	92	84	76		48	52	56	64	92
	M	63	76	68	68	60		56	68	84	84	92
	O	67	52	48	60	44		56	76	60	80	88
	S	58	76	72	60	56		60	68	60	72	80
	V	67	84	84	84	60		60	64	60	80	92
	$\bar{X}$	66.8	73.6	72.8	71.2	59.2	$\bar{X}$	56.0	65.6	64.0	76.0	88.8
	$SE_{\bar{X}}$	3.47	5.60	7.53	5.43	5.12	$SE_{\bar{X}}$	2.19	3.92	5.06	3.58	2.33
2	C	54	80	88	76	68		68	52	64	68	68
	Ho	79	72	80	80	48		76	72	64	80	92
	L	67	88	76	80	80		60	56	60	76	100
	P	63	84	68	56	60		64	64	60	72	88
	Vo	79	72	72	72	64		64	52	48	72	80
	$\bar{X}$	68.4	79.2	76.8	72.8	64.0	$\bar{X}$	66.4	59.2	59.2	73.6	85.6
	$SE_{\bar{X}}$	4.81	3.20	3.44	4.45	5.22	$SE_{\bar{X}}$	2.71	3.88	2.94	2.04	5.46
	GRAND $\bar{\bar{X}}$	67.6	76.4	74.8	72.0	61.6		61.2	62.4	61.6	74.8	87.2
	$S_{\bar{\bar{X}}}$	2.81	3.18	3.96	3.32	3.54		2.39	2.81	2.87	1.98	2.85

TABLE XI.- SIGNIFICANCE OF DIFFERENCE MATRIX COMPARING IMAGE TYPES BY GROUP I INTERPRETERS IN THE SIERRA-LAHONTAN REGION

Image Type	192	190B Color	190A Color	190A CIR	LS-1
192	X				
190B Color	9.6	X			
190A Color	8.0	1.6	X		
190A CIR	** 20.0	+ 10.4	12.0	X	
LS-1	*** 32.8	** 23.2	** 24.8	±̲ 12.8	X

LEGEND:

*** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

±̲ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

TABLE XII.- SIGNIFICANCE OF DIFFERENCE MATRIX COMPARING IMAGE TYPES BY GROUP II INTERPRETERS IN THE SIERRA-LAHONTAN REGION

Image Type	192	190B Color	190A Color	190A CIR	LS-1
192	X				
190B Color	7.2	X			
190A Color	7.2	0	X		
190A CIR	+ 7.2	±̲ 14.4	** 14.4	X	
LS-1	±̲ 19.2	** 26.4	** 26.4	+ 12.0	X

LEGEND:

*** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

±̲ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

TABLE XIII.- SIGNIFICANCE OF DIFFERENCE MATRIX COMPARING
IMAGE TYPES BY GROUPS I AND II INTERPRETERS
IN THE COLORADO PLATEAU REGION

Image Type	192	190B COLR	190A COLR	190A CIR	LS-1
192	X				
190B COLR	8.8 +	X			
190A COLR	7.2	1.6	X		
190A CIR	4.4	4.4	2.8	X	
LS-1	6.0	14.8 **	13.2 **	10.4	X

LEGEND:

*** = Very highly significant, greatly exceeding P=0.99

** = Significant at P=0.99

$\underline{*}$ = Significant at P=0.98

* = Significant at P=0.95

+ = Significant at P=0.90

TABLE XIV.- COMPARATIVE INTERPRETATION ERRORS BY IMAGE TYPE FROM TWO REGIONS, TEST TWO (1,250 DECISIONS)

Image Type	Percent Correct		Percent Commission Errors			
	Colorado Plateau	Sierra-Lahontan	Colorado Plateau		Sierra-Lahontan	
			Range	$\bar{x} \pm SE_{\bar{x}}$	Range	$\bar{x} \pm SE_{\bar{x}}$
LANDSAT-1 CIR	62	87	20-45	36.8 ± 4.06	0-21	12.7 ± 2.79
S-190A CIR	72	75	13-36	27.5 ± 2.26	6-34	24.4 ± 3.11
S-190A Color	75	62	16-40	28.9 ± 5.39	11-68	39.5 ± 5.61
S-190B Color	76	62	0-33	22.9 ± 3.13	13-49	37.2 ± 6.08
S-192, 1, 7, 9, Color	68	61	0-38	33.2 ± 8.43	28-52	37.4 ± 4.81

TABLE XV.- VEGETATION ANALOGS MOST LIKELY TO BE CONFUSED

IN VISUAL INTERPRETATION OF SPACE IMAGERY

Photo Interpretation Identification	Ground Truth							
	Sa	J	B	P	W	A	S	X
Sa	XXX	+						
J	+	XXX	++	+			-	++
B		-	XXX	++				
P		-	++	XXX	++	+		+
W		+			XXX	-		++
A				+	+	XXX	+	+
S		-		-		+	XXX	+
X	+	++	+	-	+	-	-	XXX

Numeric Symbol	Vegetation Type	Alpha Symbol
315	Meadows	W
325.1	Sagebrush	Sa
341.2	Ponderosa/Jeffrey Pine Forest	P
341.1	Pinyon-juniper Woodland	J
341.4	Spruce-fir	S
342.4	Aspen	A
347	Oakbrush/Mountain Chaparral	B
	Other Vegetation Types	X

++ = Most likely
+ = Moderate likelihood
- = Some likelihood

TABLE XVI.- EARTH RESOURCE DISCRIMINATING POWER

IMAGERY FROM SPACE

Film Type	Number of Image Classes	
	Total Discerned	Easily Discerned
S-190A CIR	50	41
S-190B COLOR	40	29
S-190A Red	36	24
LANDSAT-1 CIR	31	29
LANDSAT-1 Band 5	30	19
S-190A IR	25	19
LANDSAT-1 Band 7	24	21

TABLE XVII.- COMPARATIVE COST FACTORS TO ANALYZE

AND MAP FROM SPACE IMAGERY

Image Type	Man-hours Interp./ 2,000 Sq. Km.	Number Delin./ 2,000 Sq. Km.	Man-min./ 100 Delin.	Man-min. 100 Sq. Km.	% Pure Types	Avg. Boundary Score
LANDSAT-1 CIR	2.37	56	255	6.99	50	2.03
S-190A COLOR	2.56	84	182	7.67	35	1.69
S-190A CIR	3.56	86	247	10.67	30	2.08
S-190B COLOR	5.02	99	305	14.48	35	1.65
S-192 COLOR	1.40	43	224	4.18	30	2.23

TABLE XVIII.- ACCURACY OF IDENTIFICATION OF DELINEATIONS IN MAPPING, PRELIMINARY DATA

IMAGE TYPE AND LEGEND LEVEL	PERCENT CORRECT
LANDSAT-1 CIR	
320	50
325.1	33
327.1	58
341	86
341.1	67
341.2	100
S-190B COLOR	
320	71
325.1	57
326.1	54
341	61
341.1	59
341.2	38

TABLE XIX.- EVALUATION OF GROUND RESOLUTION

AT TWO SCALES FOR EACH IMAGE TYPE

Relative Score; 1 Best, 5 Poorest

Features Judged	LANDSAT-1, CIR	S-190A, COLOR	S-190A, CIR	S-190B, COLOR
Cortez--Business District	3	1	1	2
Cortez--Residential District	5	1	4	1
Dolores--Townsite	4	2	2	1
Escarpments and linears	2	1	3	1
Average Ground Resolution Score with its standard error	3.50 ± .91	1.25 ± .35	2.50 ± .92	1.25 ± .35

Relative Score:

1 = ++ Both scales = Very clear or obvious
2 = ++ One scale + other scale
3 = + Both scales = Evident
4 = + One scale - other scale
5 = - Both scales = Not evident

TABLE XX.- EVALUATION OF RELIEF DETECTION BY STEREO AT TWO SCALES FOR EACH IMAGE TYPE

Relative Score; 1 Best, 5 Poorest

Features Judged	LANDSAT-1, CIR	S-190A, COLOR	S-190A, CIR	S-190B, COLOR
Elevation change of 65'	5	5	5	5
Elevation change down drainage 600'	1	1	1	1
250' escarpment	3	2	4	2
300' escarpment	1	1	1	1
Less than 200' escarpment	3	2	5	1
1,000' escarpment	1	1	1	1
400' hill on top of mesa	1	2	1	2
600' hill on top of mesa	3	4	4	2
850' ridge and valley	1	1	3	1
200'/mile valley floor	5	4	3	3
225'/mile dip slope	1	2	2	1

Relative Score:

1 = ++ Both scales = Very clear or obvious
2 = ++ One scale + other scale
3 = + Both scales = Evident
4 = + One scale - other scale
5 = - Both scales = Not evident

TABLE XX.- (CONTINUED)

Relative Score; 1 Best, 5 Poorest

Features Judged	LANDSAT-1, CIR	S-190A, COLOR	S-190A, CIR	S-190B, COLOR
200'/mile toe slope	2	1	2	1
170'/mile bajada	4	3	4	3
Elevation difference, high peaks, 8,400' to 9,300'	1	2	2	1
Slope break 2950'/mi.-750'/mi.	2	1	4	3
Slope break 750'/mi.-350'/mi.	2	3	2	1
Average Relief Detection Score with its standard error	2.25 ± .36	2.19 ± .32	2.75 ± .36	1.81 ± .29

Relative Score:

1 = ++ Both scales = Very clear or obvious

2 = ++ One scale + other scale

3 = + Both scales = Evident

4 = + One scale - other scale

5 = - Both scales = Not evident

TABLE XXI.- CHANGE IN MONOCULAR DELINEATION AND IDENTIFICATION BY STEREO EXAMINATION AT 1:250,000 SCALE IN A 1761 SQ. KM. AREA

Image Type	Line Change		Identification Changes	
	cm.	Ratio of Delin. Den.	Landform	Veget. Ident.
LANDSAT-1	9.3	0.1660	15	12
S-190A CIR	6.5	0.0756	2	6
S-190A COLOR	9.1	0.1083	12	9
S-190B COLOR	6.0	0.0606	30	16

TABLE XXII.- PERCENTAGE CHANGES (IMPROVED CONFIDENCE OF DECISION) BY STEREO INTERPRETATION OF SPACE IMAGERY (ALL TYPES CONSIDERED)

Ground Cover Analog Class		Land Surface Class	
Item	% Changed	Item	% Changed
130, Rockland	11.6	1.2 Flat, riparian bottom-lands	1.9
310, Herbland	14.0	2.2 Undul./Rolling, bottom-lands	1.9
320, Shrub/Scrub	4.6	2.3 Undul./Rolling, planar surfaces	43.3
325, Shrub Steppe	7.0	2.4 Rolling, slope systems	5.7
327, Macrophyl. Shrub	25.6	3.3 Hilly, planar surfaces	3.8
341, Conifer Forest	24.9	3.4 Hilly, slope systems	17.0
342, Hardwood Forest	7.0	4.4 Mountainous, slope systems	26.4
510, Agric. Cropland	2.3		
	100.0		100.0

Figure 1.- Location of the two interregional test areas used in this study: Sierra-Lahontan and Colorado Plateau. (Also noted are two test areas used for a rice study performed as part of this investigation but not reported here: Northern Great Valley and Louisiana Coastal Plain.)

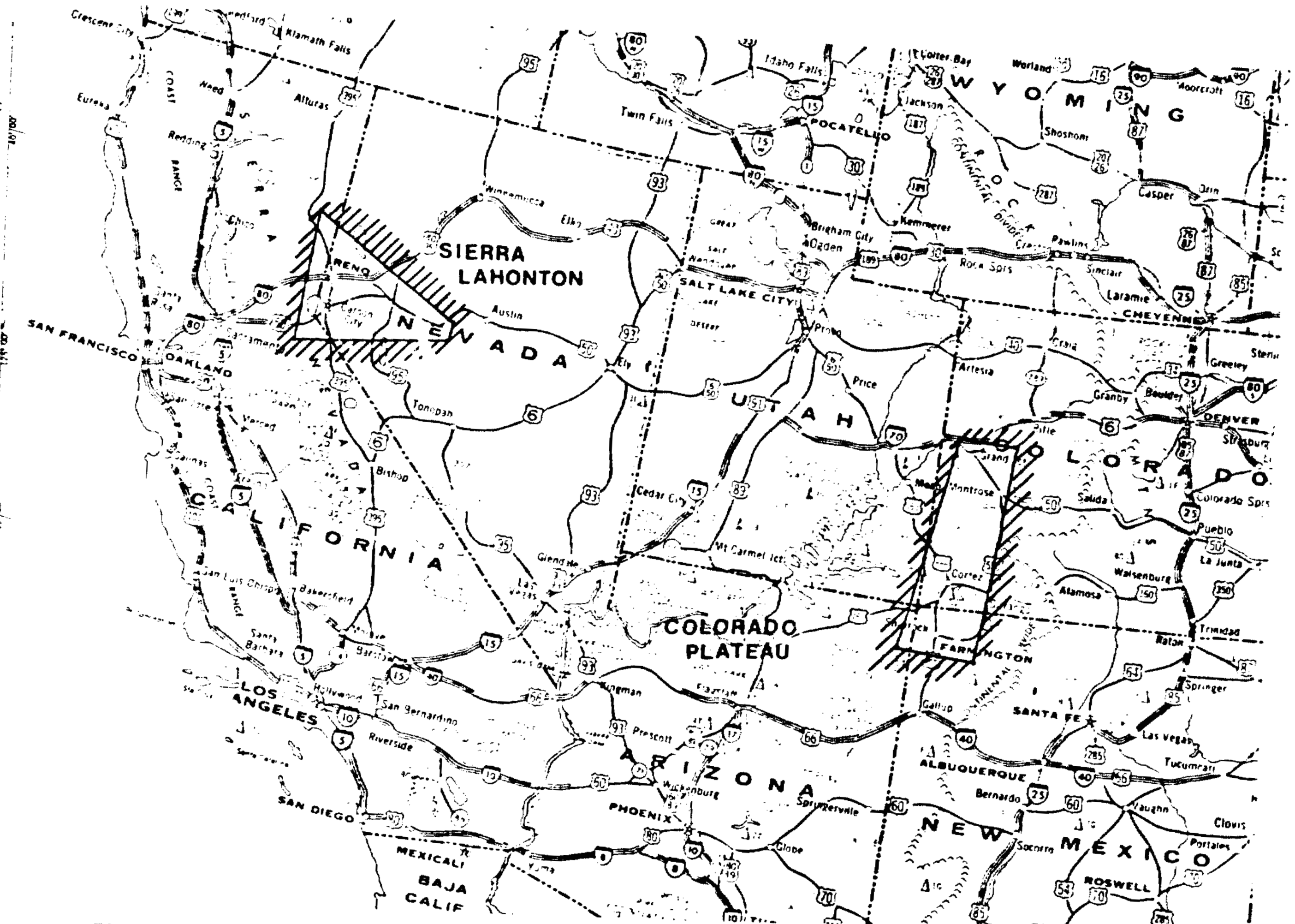
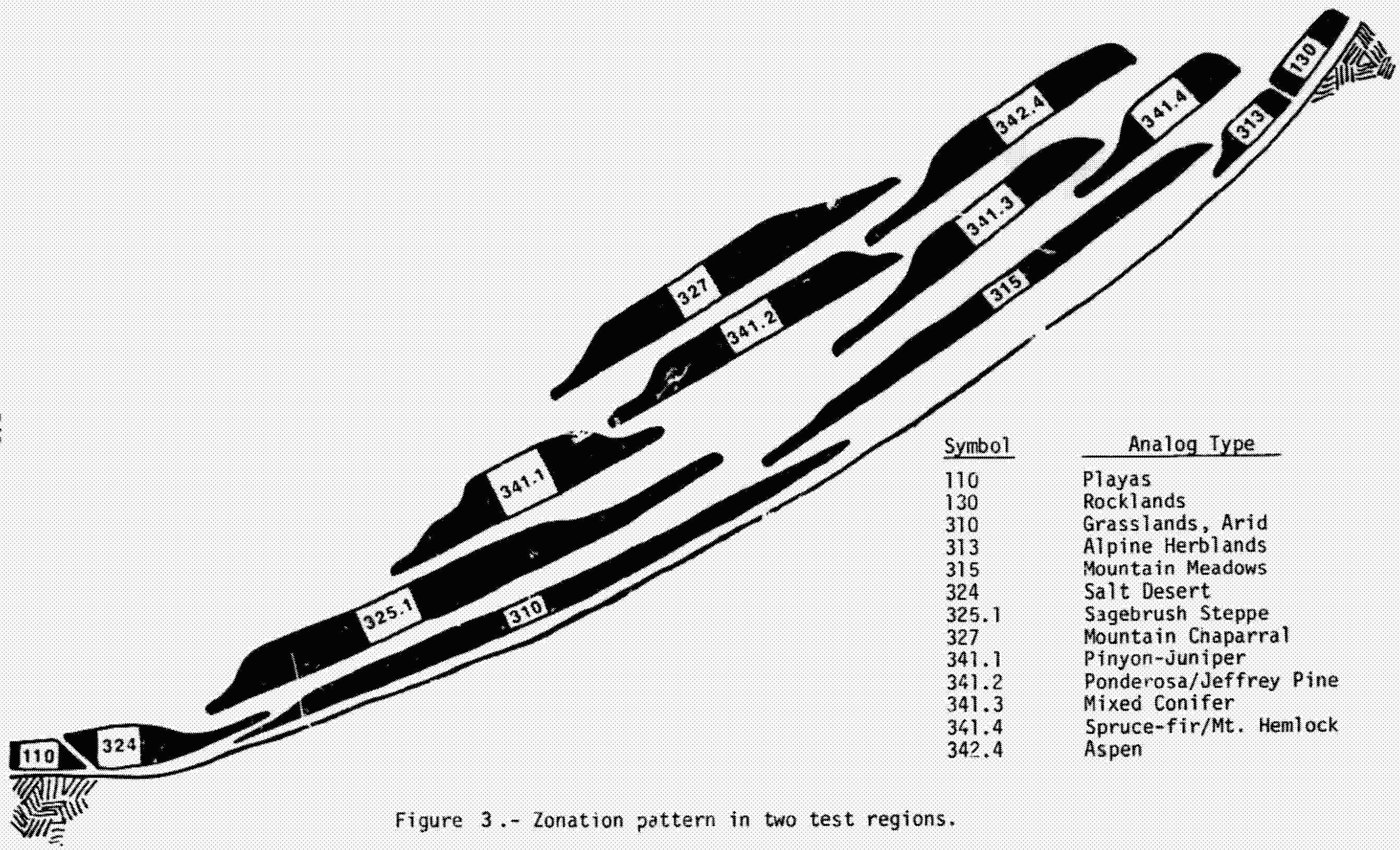


Figure 2.- Approximate boundaries of the two natural vegetation test areas.



Symbol	Analog Type
110	Playas
130	Rocklands
310	Grasslands, Arid
313	Alpine Herblands
315	Mountain Meadows
324	Salt Desert
325.1	Sagebrush Steppe
327	Mountain Chaparral
341.1	Pinyon-Juniper
341.2	Ponderosa/Jeffrey Pine
341.3	Mixed Conifer
341.4	Spruce-fir/Mt. Hemlock
342.4	Aspen

Figure 3.- Zonation pattern in two test regions.

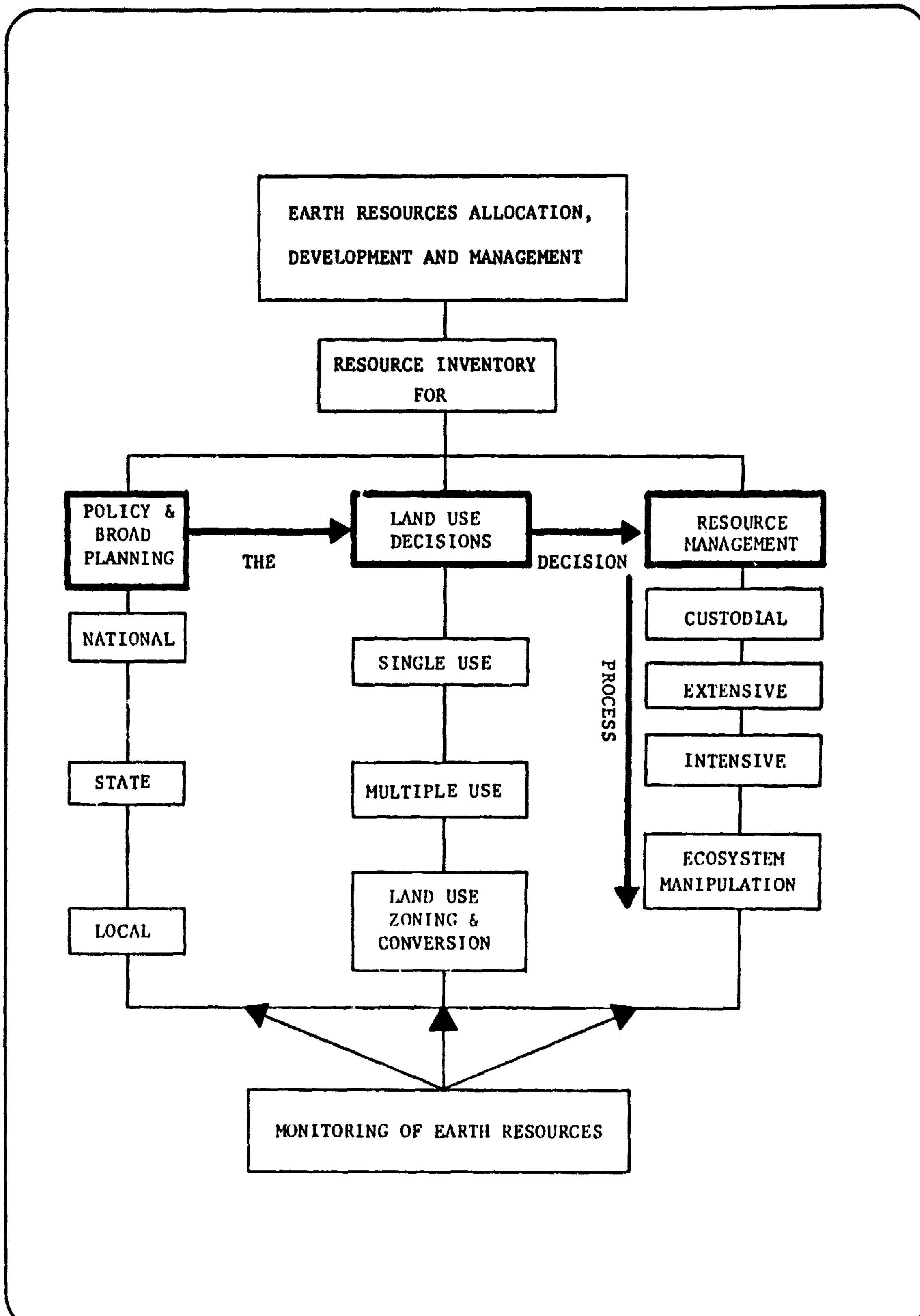


Figure 4.- The decision process in resource allocation and management as it relates to level of problem, scale, and resolution.

Figure 5.- All ground truth observations were located as they were acquired on 1:250,000 scale topographic maps. Support aerial photography missions were also charted on the same maps as indicated by the SW-NE trending black line in this illustration. Locations of key examples of each analog were then transferred to 1:250,000 scale LANDSAT color enlargements for use in interpretation testing experiments. Maps such as these are essential to the accessing of the ground truth record once it has been obtained and filed. The ideal way to match ground truth with the LANDSAT enlargement is by use of a mylar print of the 1:250,000 planimetric and topographic detail.

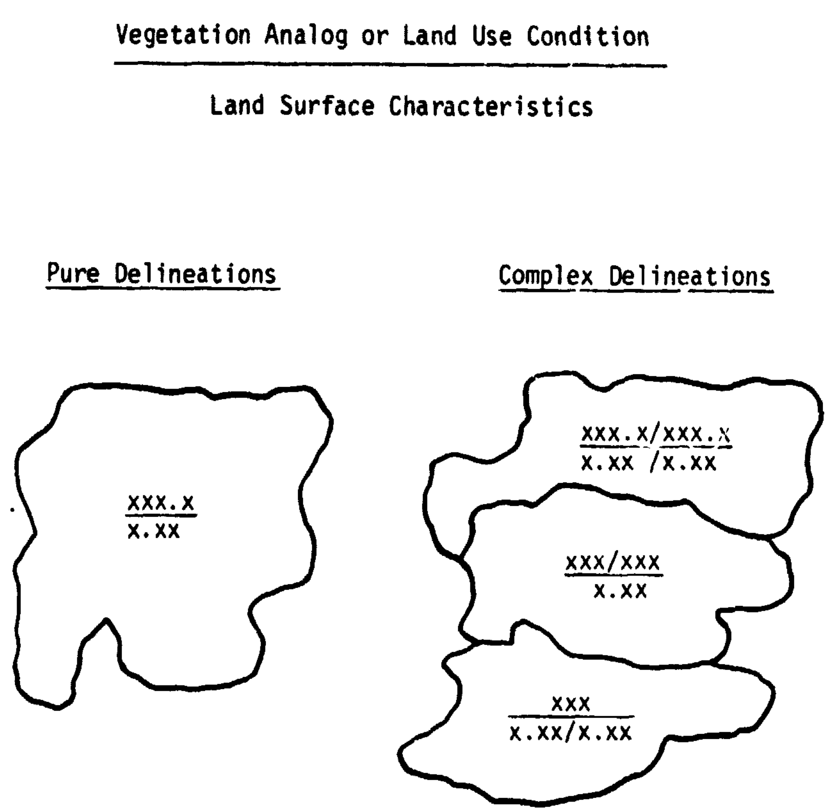
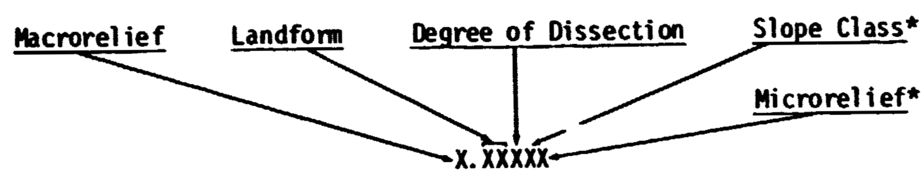
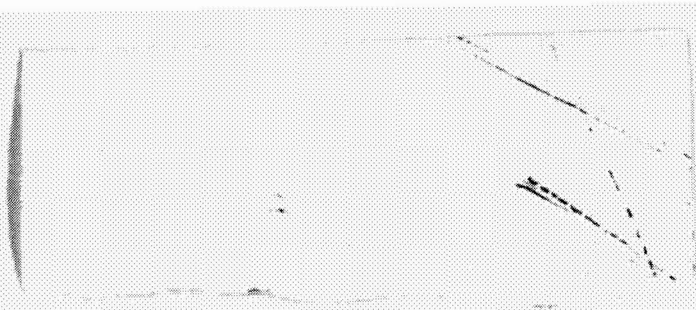


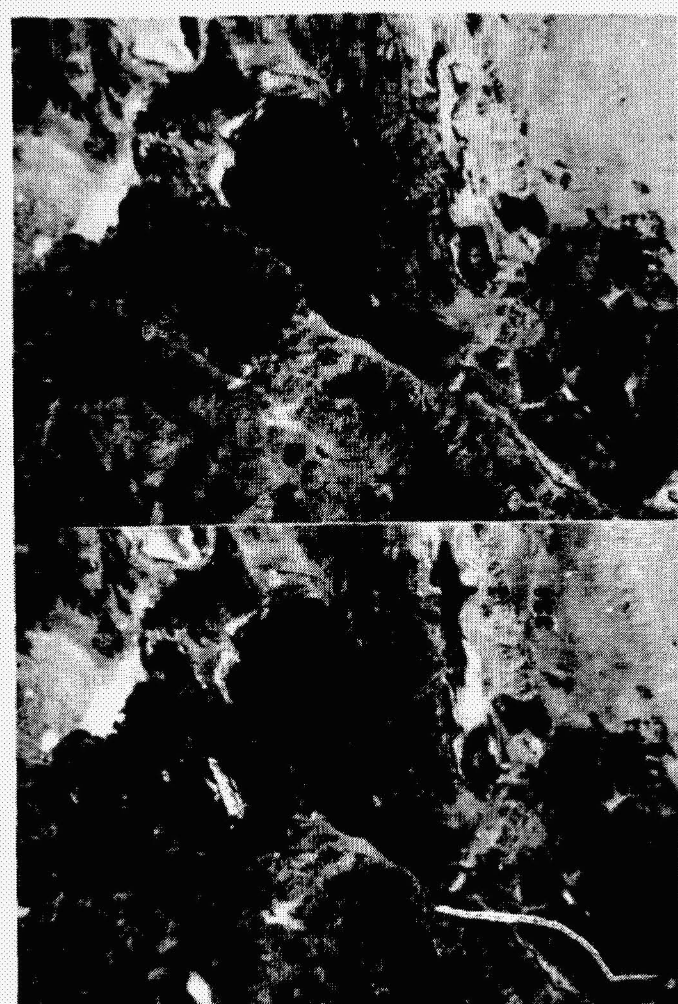
Figure 6.- The symbolic legend format for use in delineation identification or in entry into a computerized data base.



*These two levels are generally appropriate to use only with intensive large-scale inventories at scale of about 1:25,000 and larger.

Figure 7.- Symbolic legend format for annotation and description of land surface characteristics.





1002-18125
July 25, 1972

1290-18115
May 9, 1973

Figure 8.- The advantages of multidate imagery for the evaluation of natural vegetation of both range and forest lands must not be discounted. This scene shows how spring vs. late summer imagery can be combined, in the first instance to differentiate lower elevation grasslands (312), sagebrush steppe (325), and even the more productive phases of the salt desert (324). The latter differentiations are very difficult or impossible in late summer imagery. Similarly late spring imagery does not differentiate the mountain brush or chaparral (327), aspen (342), and the mixed pine-oak (343) types but mid- to late-summer imagery (top example) does an excellent job of this discrimination.

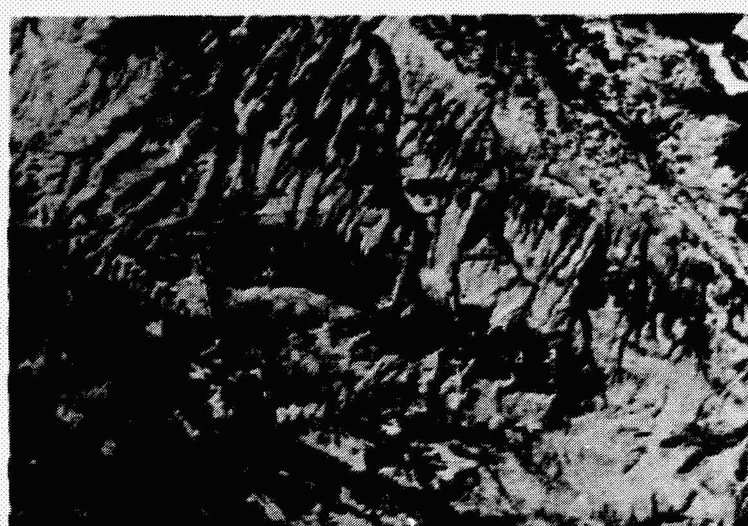


Image ID: 1210-17262
February 18, 1973
LANDSAT-1

Figure 9.- A snow background increases the contrast among many features of importance. The brownish colors in this winter scene of the Uncompahgre Plateau in southwestern Colorado represent coniferous forests and woodlands (341). It is not possible visually to separate the various kinds of these forests except by inference from topographic position. One could reason that most woodlands at the lowest elevations and on south-facing canyon slopes would be juniper woodlands (341.1), that the intermediate forests on the broad plateaus and dip slopes would most likely be ponderosa pine (341.2) and that most of the coniferous forests on protected slopes at middle and upper altitudes would be mixed conifer (341.3) types. Note the sharpness with which the cleared juniper areas (400) southwest of Montrose, Colorado (arrow) are contrasted by the snow cover.

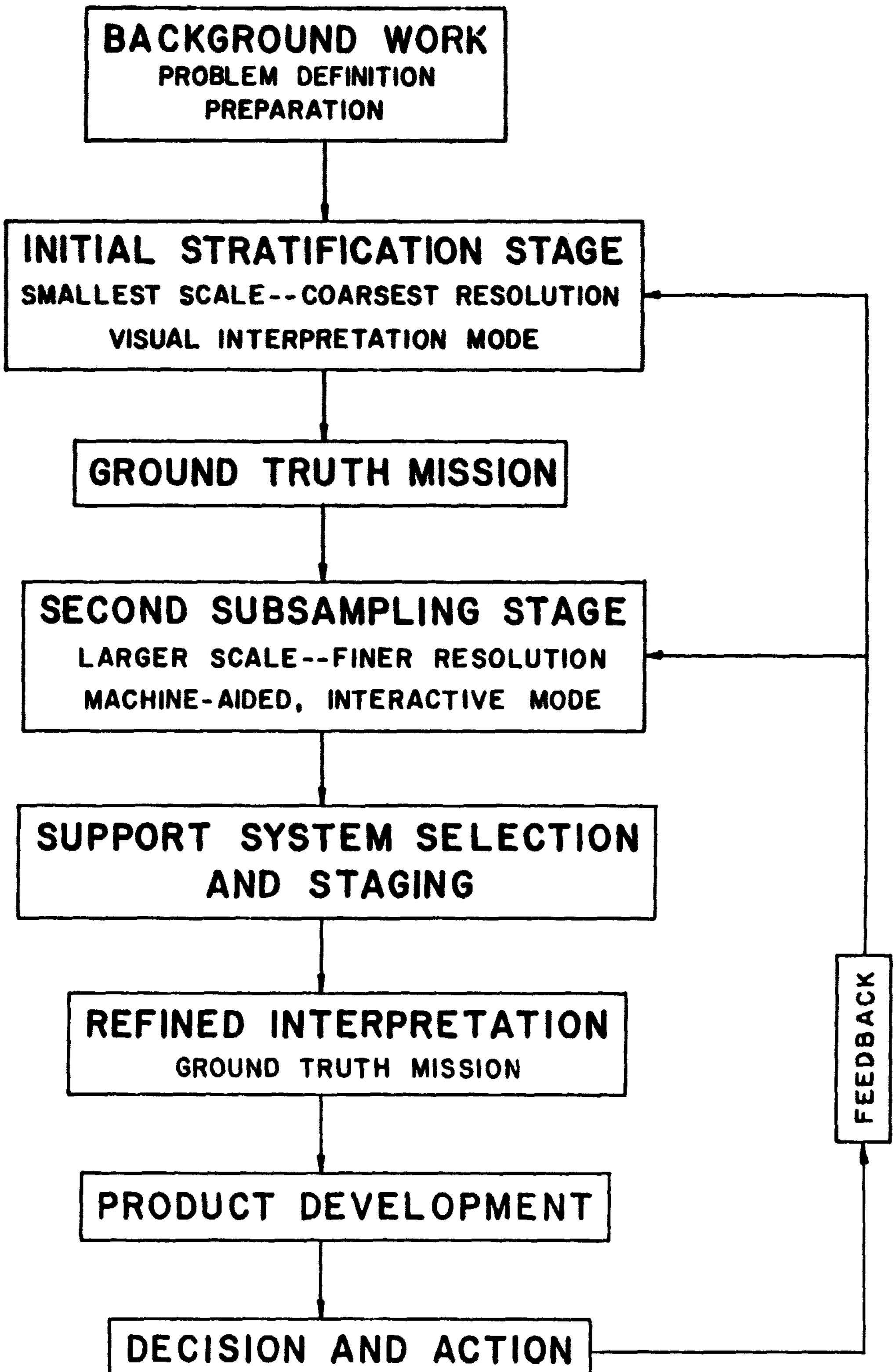


Figure 10.- A generalized flow chart for an operational remote sensing system involving space acquired imagery.

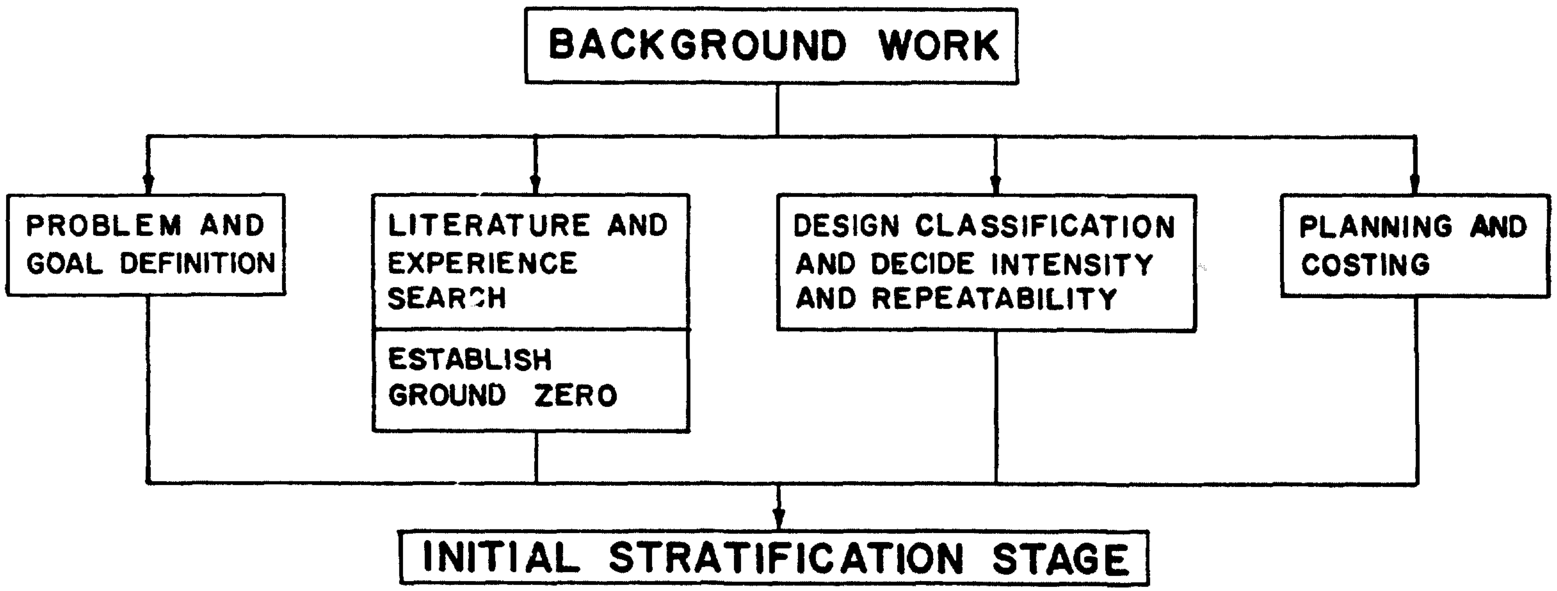


Figure 10a.- Some important details of background to set the stage for effective remote sensing of earth resources subjects.

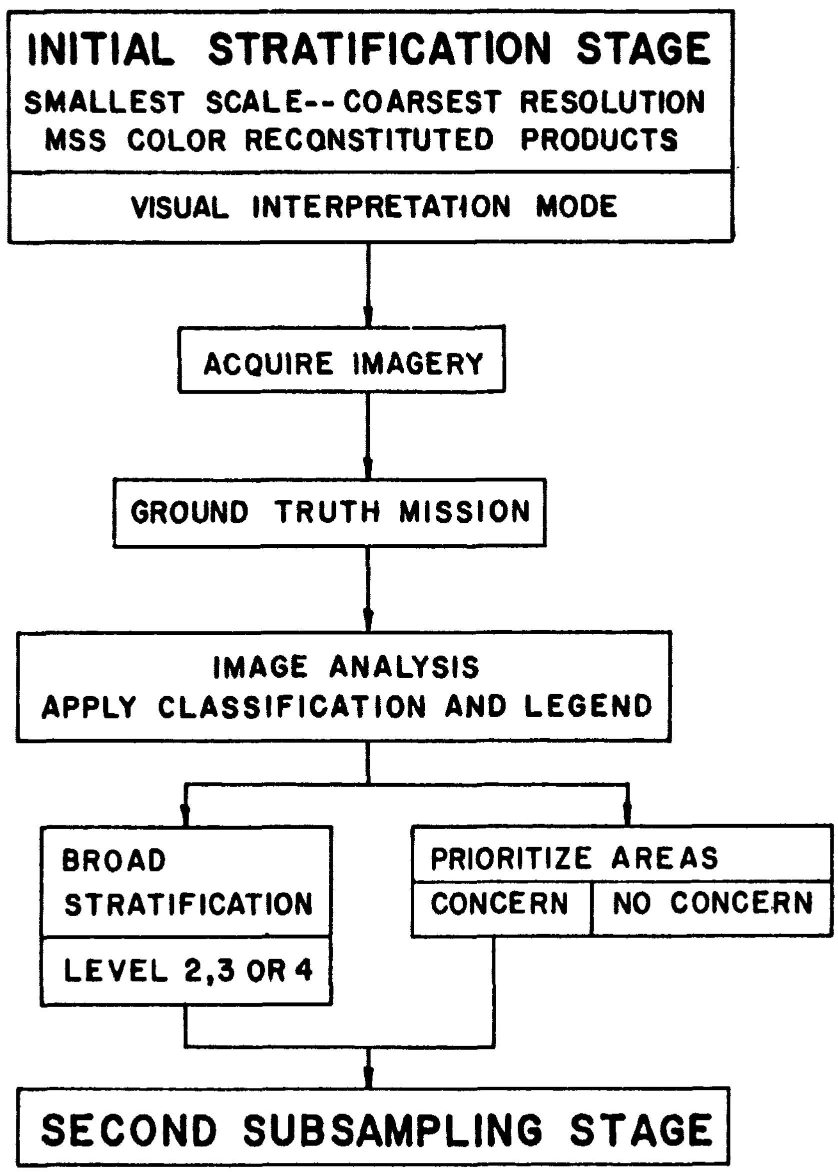


Figure 10b.- The initial stratification and area priority stage of inventory.

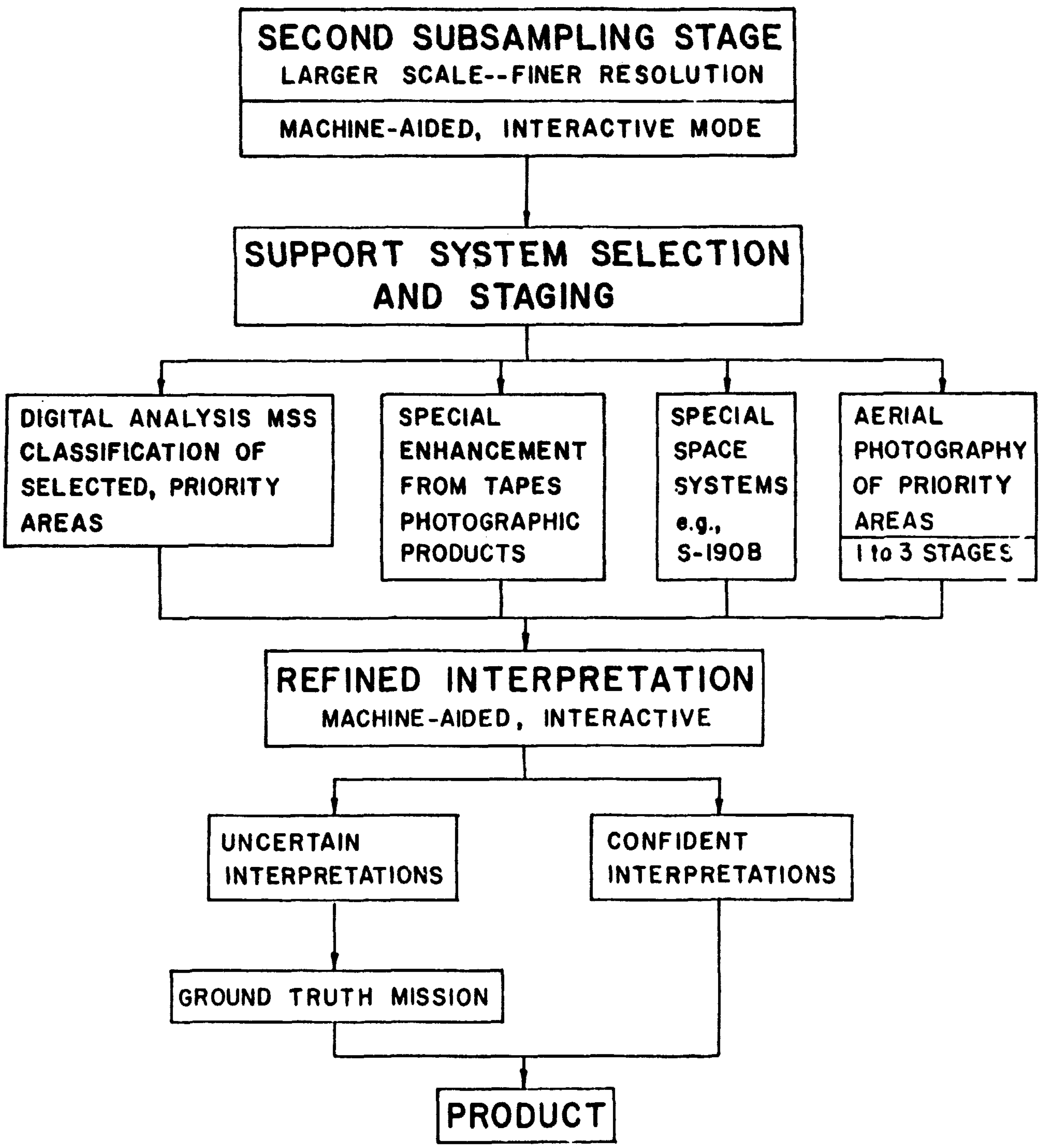


Figure 10c.- The alternative selection and in-depth interpretation stage.

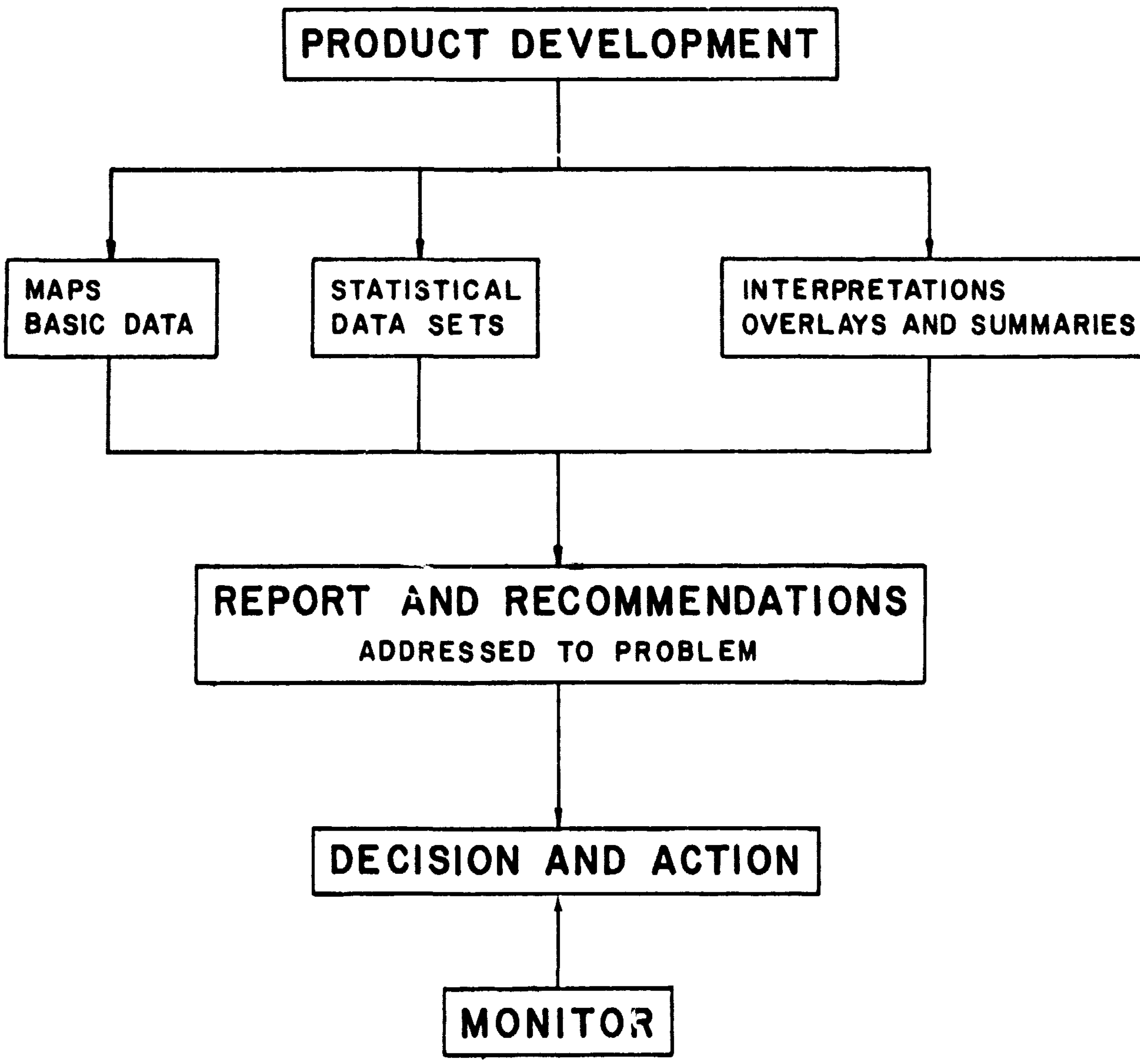


Figure 10d.- The product development presentation and action stages in the use of remote sensing systems.

APPENDIX A

TABLE AI.- Analogs Represented in Test Regions
(+ = well represented with useable examples;
x = poorly represented, marginally
useful examples)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
100-700	All primary classes	+	+
100	Barren Land	+	+
110	Playas	+	x
120	Aeolian barrens	x	+
130	Rocklands	+	+
150	Badlands	x	x
160	Slicks	+	
180	Man-made barrens	x	x
200	Water Resources	+	+
210	Ponds, lakes, and reservoirs	+	+
220	Water courses	x	x
280	Snow/Ice	+	+
300	Natural Vegetation	+	+
310	Herbaceous types	+	+
312	Annual types (mostly *Bromus tectorum* L.)	+	+
313	Forb types (Broad-leaved, herbs dominant)	x	x
314	Steppe, grassland, and prairie	+	x
315	Meadows	+	+
315.1	Sedge and sedge-grass meadows	+	+
320	Shrub/scrub types	+	+
324	Halophytic shrub types	+	+

Table AI (cont'd.)

Symbol	Name	Occurrences in	
		Sierra-Lahontan	Colorado Plateau
324.1	Greasewood types (Sarcobatus vermiculatus (Hook.) Torr.)	+	+
324.2	Saltbush types (A. nuttallii Wats., A. confertifolia (Torr. and Frem.) Wats., A. obovata Mog.)	x	+
324.3	Shadscale/Budsage types (Atriplex confertifolia-Artemisia spinescens Eat.)	+	+
324.4	Bailey's greasewood (S. baileyi Cov.)	+	
324.5	Blackbrush types (Coleogyne ramosissima Torr.)		+
325	Shrub steppe types	+	+
325.1	Sagebrush types (Artemisia spp.)	+	+
325.2	Sagebrush-Bitterbrush types (A. tridentata Nutt.-Purshia tridentata (Pursh) D.C.)	+	x
325.3	Bitterbrush types	x	x
326	Sclerophyllous shrub	+	x
326.1	Manzanita chaparral (Arctostaphylos spp.)	+	x
326.2	Oakbrush chaparral (Sclerophyllous-Evergreen Quercus spp.)	+	
326.3	Snowbrush (Ceanothus velutinus Dougl.)	+	+
326.4	Chamise (Adenostema fasciculata H. & A.)	+	
326.5	Curlleaf Mountain Mahogany (Cercocarpus ledifolius Nutt.)	x	x
327	Macrophyllous shrub	+	+
327.1	Oakbrush chaparral (Q. gambelii Nutt.)	+	
327.2	Mountain brush, Serviceberry-Snowberry-Birch leaf Mountain Mahogany (Amelanchier spp.-Symphoricarpos spp.-Ceanothus montanus)	+	+

Table AI (cont'd.)

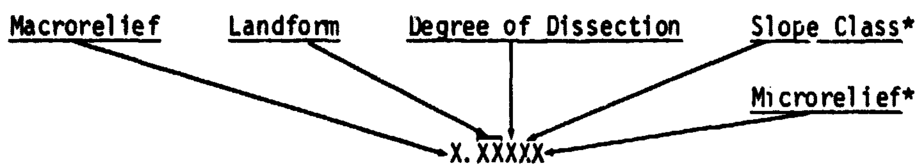
Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
327.3	Willow (Salix spp.)	+	+
330	Savanna-like Types	+	+
336.1	Pinyon (Pinus spp.)-Juniper (Juniperus spp.)-Shrub Savanna	+	+
340	Forest and Woodland Types		
341	Conifer forests	+	+
341.1	Juniper or Pinyon-Juniper (Pinus monophylla Torr. and Frem. or P. edulis Engelm., Juniperus osteosperma (Torr.) Little)	+	+
341.2	Ponderosa or Jeffrey pine forests (Pinus ponderosa Dougl., P. jeffreyi Grev. and Balf.)	+	+
341.3	Mixed conifer forests (Pine-Douglas fir-true fir-Hemlock) (Pinus-Pseudotsuga-Abies-Tsuga)	+	+
341.4	Spruce-fir forests (Picea engelmannii Parry ex Engelm, Abies lasiocarpa)	+	+
341.5	Lodgepole pine forests (Pinus contorta Dougl.)	+	+
342	Broadleaf forests	+	+
342.1	Deciduous oak woodlands (Quercus kelloggii Hewb.)	+	x
342.2	Evergreen oak woodlands	+	-
342.3	Bottomland cottonwood (Populus wizlizenii (Wats.) Sarg.)	+	+
342.4	Aspen types (Populus tremuloides Michx.)	+ x	+
343	Conifer-hardwood forests	+	+
343.1	Aspen-spruce-fir forests	-	+

Table AI (concluded)

Symbol	Name	Occurrences in Sierra-Lahontan	Occurrences in Colorado Plateau
343.2	Pine-oak forests	+	-
414.0	Cleared juniper rangeland, seeded to grass	+	+
425.1	Cleared juniper rangeland, sagebrush understory	+	+
500	Agricultural cropland	+	+
600	Urban and industrial lands	+	+
700	Extractive industry	x	x

APPENDIX A

TABLE AII.- MAPPING CLASSES AND FORMAT FOR THE ANNOTATION AND DESCRIPTION OF LAND SURFACE CHARACTERISTICS



MACRORELIEF:

1. = Flatlands

2. = Undulating to rolling lands

3. = Hilly lands

4. = Mountainous lands

LANDFORMS:

.10 = Depressional, non-riparian

.11 = Basins (interior drainage, usually with playas or lakes)

.12 = Basins, calderas

.13 = Peneplanes

.20 = Bottomlands, riparian

.21 = Stringer or narrow river and stream bottomlands and limited terraces

.22 = Wide river bottomlands with floodplain and terraces

.23 = Depressional drainage ways

.24 = Desert wash

*These two levels are generally appropriate to use only with intensive large-scale inventories at scale of about 1:25,000 and larger.

Table AII (cont'd.)

.30 = Planar surfaces (upland, above classes X.1 and X.2)

.31 = Valley fill (down slope erosional)

.32 = Fans and bajadas

.33 = Lake or marine terraces

.34 = Pediments

.35 = Flat to strongly undulating plateaus, mesas, benches, and broad ridgetops

.36 = Flat to strongly undulating dip slopes

.XX1 = Smooth, undissected

.XX2 = Moderately dissected

.XX3 = Strongly dissected - secondary erosional cycle

.40 = Slope Systems (vegetation and soils tend to change with slope)

.41 = Escarpments

.42 = Valley or canyon slope systems (the valley floor falls in X.3 class). Tertiary levels based on drainage pattern.

.43 = Strongly undulating to rolling uplands

.44 = Butte and isolated hill slope systems

.45 = Hill and mountain, more or less angular slope systems. Tertiary levels based on drainage pattern.

.000X* = Exposed (1), or protected (2)

MICRORELIEF:*

.XXXX1 = Convex

.XXXX2 = Concave

.XXXX3 = Ridge and swale

.XXXX4 = Mounded

.XXXX5 = Pitted/slumped

.XXXX6 = Patterned ground

.XXXX7 = Badlands

SLOPE CLASSES:*

Slope Range %	Slope Class Digit
Simple Slope Systems	
0 - 5	.XXX1
5+ - 15	.XXX2
15+ - 30	.XXX3
30+ - 50	.XXX4
50+ -100	.XXX5
100	.XXX6
Complex Slope Systems	
0 - 30	.XXX7
0 - 50	.XXX8
30 -100+	.XXX9

*Generally used only on intensive inventories done at scales of 1:25,000 and larger.

APPENDIX B1 - GUIDELINES FOR DELINEATION AND IDENTIFICATION IN MAPPING EXPERIMENTS

DELINEATION GUIDELINES

The imagery will be delineated by considering vegetation, land uses that have changed the earth surface feature, barren land, water resources, macrorelief and landform. A specific numerical legend is provided for each of these categories. Study the legend classes before you start actual delineation to become familiar with the criteria for delineation.

When you are ready to begin delineation, fill out the top of the record form, paying particular attention to the time of starting, time of ending, and a best estimate of lost time through interruption during the working period. Try to do the work in a period when you can eliminate interruption.

Pure Delineations

1. Map pure delineations whenever possible. Map pure delineations first and work to harder and harder examples.

2. First delineate the most contrasting subjects and work to the less and less contrasty until a further subdivision of the landscape is no longer practical and meaningful.

3. Map strongly contrasting, highly important features (such as highly productive types and urban or agricultural areas) to a minimum area of 1/2 sq. cm. *

4. Map contrasting, moderately important features to a minimum of 1 sq. cm. *

5. Allow inclusions (i.e., small areas that do not match their homogeneous surroundings) that are ignored in symbolization up to an aggregate of 10% of the delineation area as long as they do not fit condition 2 or 3. Avoid "lumping" for reasons shown in the accompanying example. Figure 1.

6. If the macrorelief-landform changes but the vegetation does not, make separate delineations with a common numerator, and vice versa.

Complexes

1. Delineate the obvious and simplest complexes first, work toward hardest.

2. When mapping complexes, never map more than 3 characteristics or earth surface features in the same delineation--strive generally for two, and remember that

* The "minimum area" specified represents the smallest area as seen on the imagery, which, if found to exhibit a unique appearance, will be separately delineated. Many delineated areas, however, will be much larger than the minimum because they are essentially homogeneous despite their large size.

Appendix B1 (cont'd.)

a significant change in the proportion of any <u>one</u> characteristic or earth surface feature can necessitate separate delineation of the area in which it is found, provided that it exceeds the "minimum area" standard.

3. Inclusions aggregating less than 10% of the area should be ignored.

IDENTIFICATION GUIDELINES

1. Enter identification symbol(s) by number.

   a. Push identification as far toward refined classes as you can, to the point that you consider the odds favor the probability of a right decision, i.e., >50 percent.

   b. If you can't make an identification or distinction at one hierarchical level, back up to the most refined level that does permit you to meet condition 1.a.

2. Do not symbolize inclusions.

3. In identification of complexes, enter symbols of components or features in decreasing order of areal extent within the delineation.

4. Symbolize both numerator and denominator as follows:

$$\frac{\text{SURFACE FEATURE}}{\text{LANDFORM}}$$

APPENDIX B2.- MAPPING EXPERIMENT, NATURAL VEGETATION

Name of P.I.:____________________

Date:____________________

TIME START:__________ TIME FINISH:__________ LOST TIME:__________

Delin. No.	In Image Quad.	Boundary Rating	Ident. Rating	IDENTIFICATION						Propor- tion of Area
				Symbol	%*	Symbol	%	Symbol	%	

*If pure type leave blank; if complex enter in 10% classes 2, 3,...8 (remember a 10% class is ignored as an inclusion).

REMOTE SENSING APPLICATIONS IN KANSAS

B.G. Barr, Jerry C. Coiner, and Donald L. Williams
The University of Kansas Space Technology Center
University of Kansas, Lawrence, Kansas 66045

ABSTRACT

The Satellite Applications Laboratory of the University of Kansas Space Technology Center has since April 1972 carried out a program designed to assist decision makers in local, state and regional agencies in the application of remote sensing techniques to their activities. To date twenty projects have been initiated in support of twenty-nine separate municipal, county, regional, and state agencies or entities. Several data products have been prepared for the use of these agencies based on LANDSAT imagery; high altitude color, color infrared, and multispectral black and white photography; and imagery from a Hasselblad camera cluster flown in the University's aircraft.

Projects are organized in six sequential phases designed to demonstrate the utility of remote sensing in the context of the user agency. After reviewing these phases, four projects are detailed to illustrate the methods and results of applications projects. Two of these projects have resulted in single user decisions during the past year related to: (1) completion of an interstate highway and cancellation of construction plans for a large reservoir, and (2) zoning changes around a smaller reservoir. Two on-going projects are also discussed: (1) a multi-user project related to the expansion of irrigation in Kansas, and (2) a program of activities leading to incorporation of remote sensing into the data acquisition methods of Kansas City, Kansas.

INTRODUCTION

Officials at all levels of government are daily faced with requirements for objective data to be employed in the decision-making process. At lower levels of government, acquisition of data by traditional methods is often beyond the physical and economic resources of the governing body. Consequently, decisions are frequently based upon incomplete or potentially biased data sets.

Since 1972, the staff of the University of Kansas Satellite Applications Laboratory has, with the assistance of the NASA Office of University Affairs, engaged in a program of activities designed to acquaint state and local officials of Kansas and neighboring states with the potential of remote sensing as an alternative data collection system. This review outlines the procedures employed in acquainting officials with the potential of employing remote sensing data within their own context and summarizes results obtained in four projects with which the Applications Laboratory has been associated. These projects have been designed both to answer specific questions of officials and to provide a basis for communication by demonstration.

Organization of a Project

Six phases of application activity may be identified in projects undertaken by the Applications Laboratory (Figure 1). The Contact Phase is intended to establish rapport between experts in the use of remote sensing technology and the government official in need of data. Activities in this phase have taken the form of two Kansas Governor's Conferences on Remote Sensing, short courses on the interpretation of LANDSAT and high- and low-altitude aircraft imagery for state and local government officials, articles in such magazines as the Kansas Government Journal (ref. 1) and the Kansas Water News (ref. 2), and individual contact between government officials and Laboratory personnel trained in specialties paralleling those of the government official, i.e. urban and regional planning or natural resources.

This Contact Phase may lead to agency personnel and/or Laboratory staff identifying a data requirement which can be solely or partially met from imagery sources. At this point an attempt is made to specify a project and the agency/Laboratory relationship is extended to the Project Definition Phase. During this phase questions about the scope of the project, the intended use of data interpreted from the imagery, and how costs will be shared are answered. Upon mutually satisfactory assessment of the project, a task group is organized among personnel within the Laboratory. This task group may include agency personnel working in the University's Space Technology Center and/or Laboratory per--nnel working within the agency.

Actual utilization of remotely sensed data begins with the Project Initiation Phase. During this period critical operations are conducted which may be focal to the success or failure of agency use of remotely sensed data. These include sensor selection and mission planning. After sensor selection, image acquisition is undertaken from existing sources (EROS data center, NASA Houston, etc.) if the imagery is not already available in the Laboratory's film library. Alternatively, imagery may be acquired by the University's aircraft or by a private contractor. Parallel to image acquisition is interpretation development. This activity relies on the experience of the Laboratory's image interpreters and literature review to determine if the interpretation has been undertaken before. If it has, the methods and accuracy of the effort are elicited from the literature. If not, suitable interpretations to successfully accomplish the project are developed and documented.

After imagery has been acquired and effective interpretations developed, the actual interpretation and preparation of final products for use by agency personnel occur during the On-going Project Phase.

When the products required for the project have been developed, they are delivered to the user agency and Laboratory personnel prepare documentation for further reference and to support the agency in using the products in the Project Completion Phase. Efforts are also made to document the use of the remote sensing products in the agency environment.

This leads to the Continuing Support Phase of the application effort, in which support to state and local agencies is provided in the form of personnel training, product improvement, fulfillment of new product requirements, and consultation services in data utilization. The continuing support phase can be seen as the culmination of the Laboratory's effort. Agency/Laboratory projects which reach this phase explicitly indicate agency acceptance and continuing utilization of remotely sensed data.

SELECTED PROJECTS

The following projects illustrate some of the contexts into which remote sensing is finding its way in the governments of Kansas and Missouri. Although the attention of the Laboratory staff has been directed primarily to meeting the needs of Kansas officials, on three occasions officials of Missouri, introduced to the program through the Kansas Governor's Conferences, have requested assistance on specific projects. The projects, from both Kansas and Missouri, described below illustrate both the range of potential application and the ways remote sensing may be used in single-decision and multi-user problems. The first two problems discussed illustrate the single-decision approach and their relationship to the methodology outlined above is transparent. Multi-user, multi-decision problems of the type discussed later are less sharp but, in the long run, potentially more significant in that they represent full acceptance and incorporation of remote sensing into the data collection methodology used by state and local governments.

Pattonsburg Reservoir and Interstate-35

In early 1973 the Governor of Missouri was faced with a decisional situation concerning completion of Interstate-35 and the proposed Pattonsburg Reservoir project in northwest Missouri (Figure 2). Completion of I-35 had important economic consequences for the Kansas City Metropolitan Region, since the highway provides a direct route from Chicago to Kansas City. At that time I-35 was complete except for a fifteen mile segment in the area of the proposed Pattonsburg Reservoir. In addition to the traffic hazard problems created by the detour over a narrow, dangerous two-lane highway, engineers had estimated that construction of a crossing over the proposed reservoir would cost $30 million, while construction of the segment without the crossing would cost $10 million.

The Governor's staff determined that a need existed for additional analysis on the desirability of the reservoir project before committing funds for the completion of the more expensive reservoir bridge crossing for I-35. The Applications Laboratory was requested to provide objective data to support the group conducting the supplementary analysis.

Color infrared and black-and-white aerial photography was acquired to provide a data base for the reservoir site and the proposed dam. Four classes of land use (crops, pasture, forest, and urban) were interpreted for the Governor's committee and compiled into a map of the proposed inundation area. Statistics on acreage of each land type to be inundated above and protected below the dam were provided. These statistics compensated for a deficiency in the original Environmental Impact Statement which, because it had been prepared for the entire Grand River Project, did not separate data for the Pattonsburg Reservoir from that for several other projects on the river (ref. 3). Analysis of these statistics revealed that without the dam, 58,615 ha (144,780 A.) would be available for agricultural production, while with the dam, agricultural land would be reduced to 45,749 ha (113,000 A.). Based on U.S.D.A. data related to crop values and the image analysis, it was estimated that the loss of agricultural production between 1980 and 2020 would average approximately $5 million per year if the dam were constructed.

The analysis and related maps were sent to the Governor's committee on 31 July 1973, approximately 90 days after the initial request. On 27 August 1973, the committee reported to Governor Bond its conclusion that it would be an unwise use of public funds to proceed with the high bridge crossing and the Pattonsburg Reservoir project with the information currently available. The Governor then decided to postpone construction of the high bridge crossing of the Grand River one year and asked the Corps of Engineers to re-study the justification for the Pattonsburg project in collaboration with several state and federal agencies. On 18 August 1974, at the end of the re-study, the Corps of Engineers announced that the reservoir had been cancelled. The following day the Missouri Highway Department announced that work would begin immediately on the design of a low crossing of the Grand River to allow the completion of I-35.

The decision to cancel the proposed Pattonsburg Reservoir project and thus save $20 million in the construction of I-35 rested substantially on an analysis supported by remotely sensed data.

Measuring the Impact of Clinton Reservoir

In contrast to the preceding problem of whether or not to build a reservoir, Clinton Reservoir is being constructed by the U.S. Army Corps of Engineers near Lawrence, Kansas. When completed in 1978, the reservoir is expected to attract heavy recreational use from the two million residents of the Topeka-Kansas City Corridor (Figure 3). Perry Reservoir, the only comparable facility in the area, has been subjected to overuse and uncontrolled development of the adjoining lands. Citizens of the Clinton Reservoir area, which includes the city of Lawrence, Kansas, have demanded an orderly development program for the reservoir site which will preserve the environmental quality of the area.

In response to this demand, in late 1972 the Lawrence-Douglas County Commission placed a moratorium on any zoning changes in the area of the reservoir and directed the Lawrence Planning Department to prepare a comprehensive development plan by July 1973. The plan was required to identify privately owned lands which were best suited for urban development and those lands best suited to remain rural, agricultural or natural. The planning department requested assistance from the Applications Laboratory in the employment of remote sensing to inventory specific characteristics of the area so that planning policy could be based on current unbiased data.

Large-scale multiband aerial photography similar to that acquired at Pattonsburg was used to meet this requirement. Image interpretations included (1) selection of areas of scenic value; (2) mapping of vegetation, including dense and open woods; and (3) mapping of wildlife habitat quality. Interpretations were then converted to legend classes which were established by planning department personnel and indicated the compatibility of each area to urban development or to the desire to preserve current use.

Maps of each of the development factors were combined to produce a development potential map. The potential map (Figure 4) has the following structure: areas with dense woods, high quality wildlife habitat, and scenic areas were most suitable for preservation; areas with open woods, low quality wildlife habitat and scenic areas were most compatible with urban development. Based on these data, the Planning Department recommended a development policy and the Planning Commission made the following policy decisions.

1. Densely wooded areas were to "be treated as a unique resource and retained wherever possible."

2. Areas of high wildlife habitat quality would be preserved while those of low quality would be available for development.

3. Areas of steep slopes would be denied to development.

The first test of this policy came in late 1974 when a local developer requested re-zoning for the Yankee Tank Subdivision. The developer had used the general plan and the Applications Laboratory imagery in preparing his site plan. Because the site plan conformed to the established policies, the Commission re-zoned the area.

In this case remotely sensed imagery was used to provide inputs to one of the most controversial problems in the United States today: land development. A significant aspect of this project, which points out the strength of remotely sensed data, was the use of the same imagery by both the planning commission and the developer in establishing their positions and policies.

Center Pivot Irrigation

The preceding two projects have illustrated the SINGLE DECISION orientation in which many of the program's operational projects have been framed. This next use of remote sensing deals with a much more pervasive and complex issue of interest to many governmental organizations: the rapid increase in irrigation, particularly in the form of center pivots, and its possible long-term consequences.

Center pivot sprinkler irrigation is a recent innovation to agricultural practice in the Great Plains of North America. The system was first employed in southwestern Nebraska in the early 1950's and has since spread throughout North America wherever suitable conditions for this type of irrigation have been found. The circular shape of fields irrigated with center pivots is anomolous on images of Kansas because most fields are rectilinear. Consequently, center pivots are readily distinguishable on aerial photographs and on images produced by LANDSAT (ref. 4).

One area of high suitability for the use of center pivot irrigation is in southwestern Kansas (Figure 5). Since center pivot irrigation was introduced into this region in the early 1960's it has undergone a rapid expansion and by early 1974, 2,223 center pivots had been installed in 12 southwestern Kansas counties, thereby bringing more than 121,000 ha (300,000 A.) into sprinkler-irrigated crop production[1]. This represents approximately 12 percent of all land annually harvested for crops in the region. Expansion has been and continues to be rapid throughout the region primarily because the availability of center pivot systems has made possible the opening of new land to cultivation and has proved extremely productive in terms of crop yields on these newly cultivated lands. The availability of well drillers and sprinkler systems appears to be the only factor limiting installation rates.

Because of the periodic coverage supplied by LANDSAT, it has been possible to monitor the annual increase of center pivots in the region. How growth may be charted is exemplified by the case of one county where 11 center pivots were present in 1965. U.S. Department of Agriculture aerial photographs acquired in 1971 were interpreted to indicate an increase to 252 center pivots by that year. The annual increases for 1972 through 1974 were, respectively, 86, 121, and 131 new installations, giving the total of 590 units in the county in 1974. The pattern of growth illustrated by Figure 6 clearly demonstrates the continued rapid diffusion of the innovation in this region.

The primary impact of the growth of center pivots may be stated with respect to three factors. First, this irrigation system has affected crop production in two ways: (a) by shifting production away from wheat and into feed grains, particularly corn, and (b) by sharply increasing total production of agricultural crops in the region. Second, as is evident on Figure 6, natural vegetation is being removed from substantial areas, particularly in the Sand Hills south of the Arkansas River, because of the effectiveness of center pivots on sandy soils. The new irrigation system has, then, greatly reduced the area of

[1] It should be noted that in early experiments in Finney County it was discovered that very few center pivots were mapped if they were not actually present but that as many as 6 or 7 percent of those present were not detected by interpreters of LANDSAT images (ref. 4). Consequently, the actual number installed may be slightly higher than the number reported here. For example, present information indicates that 200 units are installed in Seward County, although only 185 units were interpreted from the imagery and therefore appear on the map.

native grassland and replaced it by irrigated cropping. Third, the use of groundwater to supply this irrigation system as well as flood irrigation systems already in place is leading to a decline in the availability of groundwater since use exceeds the recharge to the rock formations which yield water in this area (ref. 5).

The 2,223 center pivots presently installed in southwestern Kansas are not uniformly distributed over the region but are concentrated in several areas. Three primary factors operate to determine this distribution. Two of these are physical and one is cultural. The two physical factors are soil type and availability of groundwater while the cultural factor is the alternative type of land use which exists on each parcel of land. The two physical factors are jointly indicated on Figure 5 to suggest the potential of each part of the area for the installation of center pivots. Four major types of soil are indicated on the map: (1) clayey soils on sloping sites, (2) clayey soils on nearly level sites, (3) complex mixtures of clay and sandy soils or loamy soils generally on nearly level sites, and (4) sandy soils. The nature of water application under this sprinkler irrigation system is such that any salts present in the water will be rapidly concentrated in the upper part of the clayey soil profiles. Thus, although some center pivots are installed on relatively clayey soils, their returns are less satisfactory than are those that are placed on very sandy sites. At the same time, flood irrigation cannot be used on very sandy soils because the water soaks into the ground so rapidly that it cannot be applied over the whole length of a normal size field. Therefore, the higher the sand content of the soil, the more suitable the site is for installation of a center pivot system. Center pivots have made it possible to irrigate areas which are not suited to other types of irrigation (ref. 6). In the most extreme cases, they have opened to cultivation lands which were previously not suitable for crop production. For example, in the soil survey report for Finney County, Kansas, published in 1965, it was stated that a large stabilized sand dune area was not suited to any type of cultivation (ref. 7). At present, this area contains large acreages of cultivated land as a result of center pivot irrigation.

Since irrigation water is derived almost entirely from wells in southwestern Kansas, the availability of groundwater supplies is also a limiting factor on the installation of any type of irrigation system. Four classes of water availability are indicated on the map (Figure 5). These classes range from groundwater not generally available to abundant quantities of groundwater. The color scheme used on the map results in the display of the joint consequences of water availability and soil type. Increasing water availability is indicated by the increasing degree of blueness of the map unit. Soil type is indicated by the yellowness of the area. Consequently, those areas which have both sandy soils and abundant groundwater are indicated in dark green, while those areas with neither sandy soils not substantial quantities of groundwater are indicated in very pale green. Other colors develop as a result of various combinations of the two factors. The resulting patterns demonstrate that, while there are substantial areas suited to center pivot irrigation, there are also substantial areas which are unsuited to the system's use. As is readily evident, most center pivots are located in those areas favorable to such installations. The concentration of center pivots, particularly in the central portion of the area, are so located because groundwater is abundantly available and the soils are distinctly sandy. However, there are several other areas which are suitable for this type of system which contain very few center pivots. Often, these areas are already completely occupied by other forms of irrigation or some other intensive type of land use which will not be replaced by center pivots.

In contrast to this great concentration, center pivots are completely absent from the sandy soils in the northwest part of the area. Consideration of the availability or, in this case, non-availability of groundwater makes it readily apparent that although the soils may be suitable, the western sandy area is not suited to irrigation because water is unavailable. In contrast, the area along the northern edge of the map contains very few center pivots because of generally unsuitable soils. Frequently, groundwater is unavailable in the same region.

Using the preceding analysis of growth and diffusion of center pivot irrigation in combination with the total irrigated acreage also interpreted from LANDSAT images, the Applications Laboratory, with the encouragement from legislative leaders, has established a joint program with the Kansas Geological Survey, the state agency primarily responsible for preservation of natural resources. This program envisions the development of a series of recommendations on irrigation based on both existing well records of water table drawdown and areal expansion elements from LANDSAT to provide the state regulatory agencies with the information necessary to decide how the limited water resource should be used for the maximum social benefit with minimum environmental disruption. Results of this investigation are also of value to the Kansas Forestry, Fish & Game Commission in analyses of prairie chicken habitat destruction and the Kansas Department of Economic Development and regional planning commissions in planning for future population and land use changes in Kansas.

Remote Sensing in the Urban Milieu

In addition to analyses in rural areas, the Applications Laboratory has been supporting urban governing and planning bodies. The increased application of remote sensing data in this context, as illustrated by the case of Kansas City, Kansas, is encouraging.

Kansas City, Kansas, is a city of 180,000 located at the confluence of the Missouri and Kansas Rivers (Figure 7). The city is part of the Kansas City Standard Metropolitan Statistical Area (SMSA) of approximately 1,250,000 (1970 census).

In recent years, Kansas City, Kansas, has suffered the ill effects of urban decay noted in many U.S. cities and the city government has faced demands for improved services throughout a growing urbanized area. These conditions have in turn increased the pressure on the governmental agencies for data to support the decision making process. In the main, responsibility for the acquisition of data about conditions in the city has fallen to the Department of Planning and Development. The growing requirement for specific social and economic indicators about the city and the increased cost for acquiring a unit of data caused the city planner to initiate a search for alternative methods of data gathering to allow proper assessment of infrastructure as a surrogate for more abstract social indicators.

The Department of Planning and Development first came into contact with remote sensing techniques through conferences held at the University of Kansas Space Technology Center. However, the utility of the techniques was driven home by events which occurred during the Kansas and Missouri River flooding of October 1973. Image interpreters of the Applications Laboratory provided data on a rapid response basis to support the Kansas City, Kansas/Wyandotte County Civil Defense efforts by identifying weakened areas of dikes, points where dikes were breached, debris jammed into bridges, and assessing flood damage (Figure 8).

Based on this experience, the Department recognized that remote sensing could provide timely, accurate data not available from other sources. They then requested the Applications Laboratory to aid in an assessment of remote sensing data collection for the city government. Initially the program provided examples of high resolution color and color infrared, medium resolution color and color infrared flown by the NASA high altitude aircraft, and LANDSAT-1/2 data over the city. The Department first concentrated on two projects: (1) assessment of dwelling unit conditions in an urban renewal area, and (2) development of simple techniques to acquire data for environmental impact statements. Both of these projects were accomplished with the aid of Applications Laboratory personnel. The number of dwelling units were counted from the photographs. The photo counts indicated substantially more dwelling units in the affected area than had been expected from 1970 census data. The environmental impact data interpreted from 70 mm imagery provided the city with social, economic and physical environment data in a 5 km^2 (2 mi^2) corridor for a total cost of less than $500.00, including data interpretation.

Based on the positive outcomes of the three initial actions that had encompassed the use of remote sensing, the Department of Planning and Development made the decision to use remote sensing as an integral part of their data acquisition effort and a full time image analyst was employed by the planning staff. Since then, the Department of Planning and Development, in consultation with Applications Laboratory personnel, has initiated three major projects of their own.

Data to support the various administrative departments of the city government are maintained in a series of computer files, known generally as an urban information system. These base files contain a map of the urbanized area constructed from the transportation network. The geographic base file project, which was initiated in 1972, had by 1974 reached the level of sophistication where land use data concerning every parcel of land in Kansas City/Wyandotte County could be stored in the file. To determine if this project was feasible the city hired six college students over the 1974 Christmas holidays. After training by Applications Laboratory personnel and using high resolution aerial photography and collateral sources, these employees interpreted and encoded the land use of every parcel of land in a 16 km^2 (10 mi^2) area of the inner city.

In late 1974 the U.S. Congress passed the Community Development Act to replace the existing Urban Renewal Program. The Department of Planning and Development was made responsible for administering the program within the city. They were also told by federal authorities and the City Commission that objective assessment of the program's effectiveness would be required on a periodic basis to determine the level of future funding. With the assistance of the Applications Laboratory, a neighborhood monitoring program was proposed and accepted as a method of measuring the impact of Community Development funds. The entire city has been flown to acquire natural color photography. This photography is being interpreted to determine the states of twelve variables about each block face in the neighborhood. These variables include status of house roof, street, sidewalks, yards, etc. After the states of these variables are determined they will be combined with variables from the 1970 census and local group inputs to present the City Commission with a program for assigning the Community Development funds. Within twelve months the city will again acquire aerial photographic data for neighborhoods. These new data will be analyzed and comparison with the spring data will establish the degree to which social infrastructure change has occurred in both funded and unfunded neighborhoods, thus allowing the establishment of new priorities and the evaluation of existing projects.

The third project concerns solid waste which had, in the past, been collected by a single company for the entire Kansas City, Kansas/Wyandotte County area. However, when the 1975 bids were opened the costs were over that estimated by the city. This caused the city's finance commissioner to consider alternatives to the present single contract system. He decided to divide the city into five contract zones and let each contract separately, hoping to attract more bidders, especially the smaller minority businesses that the large size of single, city-wide contract, had excluded.

To establish the zones so that they represented equal tonnage of waste in each zone, and to design collection routes that would most efficiently utilize fuel, a network allocation technique was used. Because parts of the county are rural, 1970 census data were too coarse to allow allocation by use of the census data alone. The city then asked the Applications Laboratory interpreters to count dwelling structures from the 1969 census city high altitude flight for the two rural census tracts. When these data were encoded and loaded to the existing geographic base, the allocation process allowed the city to define collection zones and provide bidders with accurate estimates of numbers of dwelling units in each collection zone, thus reducing the risks to the bidders.

The Department of Planning and Development of Kansas City, Kansas, with the assistance of the Applications Laboratory, has completed the conversion from total acquisition of data by contact methods to the acquisition and use of data from remote sensors. At the present time this data is principally provided by low altitude aerial photography. However, as interpretation sophistication of the departmental staff increases, more and more emphasis is being shifted toward the use of high altitude and satellite data.

CONCLUSION

In reviewing the projects discussed above and other projects completed or in progress at the Applications Laboratory, it is evident that remote sensing can serve as an effective new or supplementary data source for state and local government officials. As with the introduction of any new technology, a measure of resistance is encountered in convincing officials to adopt remote sensing. Rapidly rising costs of alternative data collection systems, however, are stimulating many officials to examine the technology and as additional successful demonstrations are completed, routine use of remote data acquisition as an integral part of the data collection methodology is becoming increasingly attractive to those concerned with the environmental problems of Kansas.

ACKNOWLEDGMENTS

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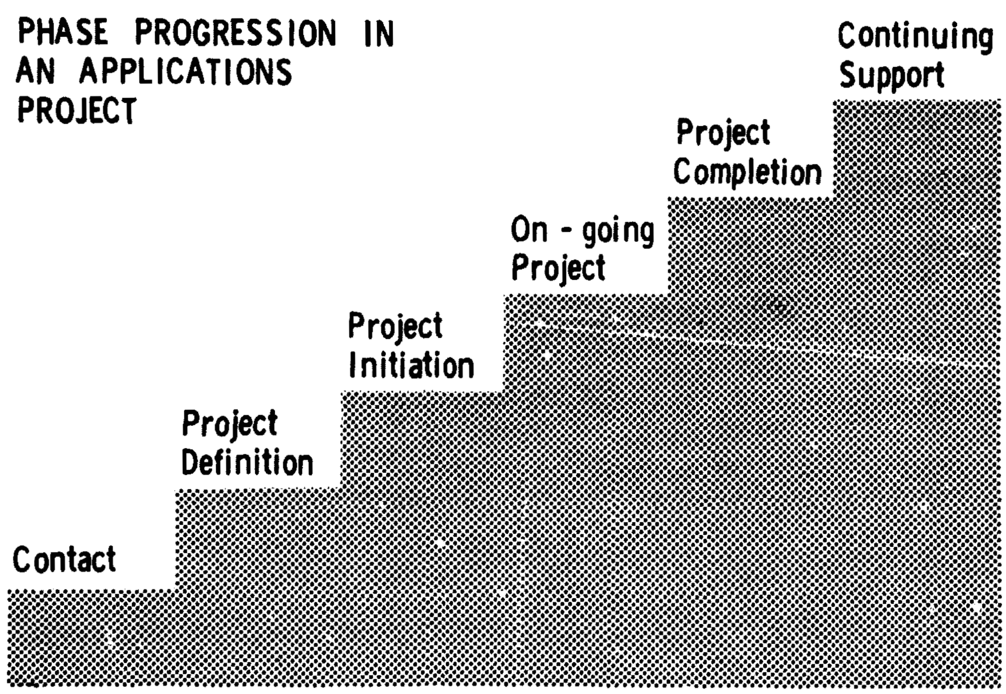


Figure 1. Phase progression in an applications project. The KU Satellite Applications Laboratory may have several projects in various phases at any single time.

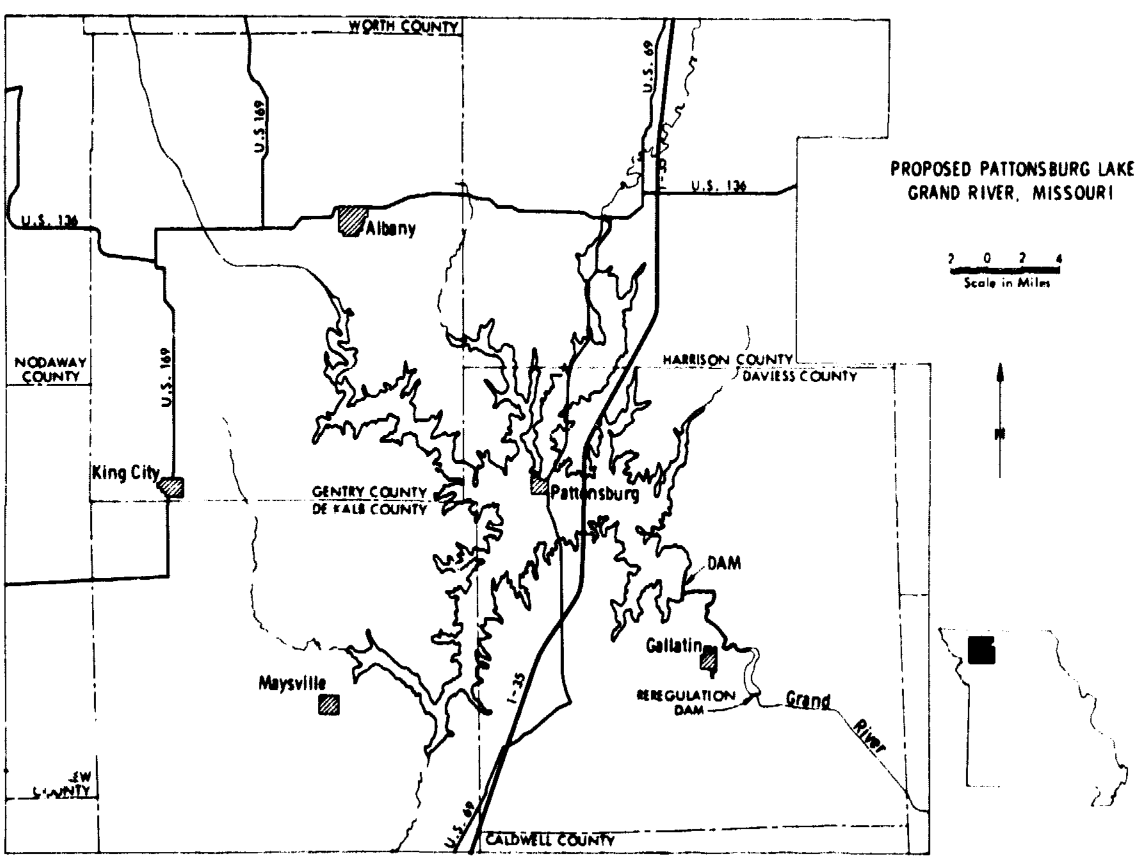


Figure 2. Site of proposed Pattonsburg Reservoir, northeastern Missouri, and the route of Interstate 35.

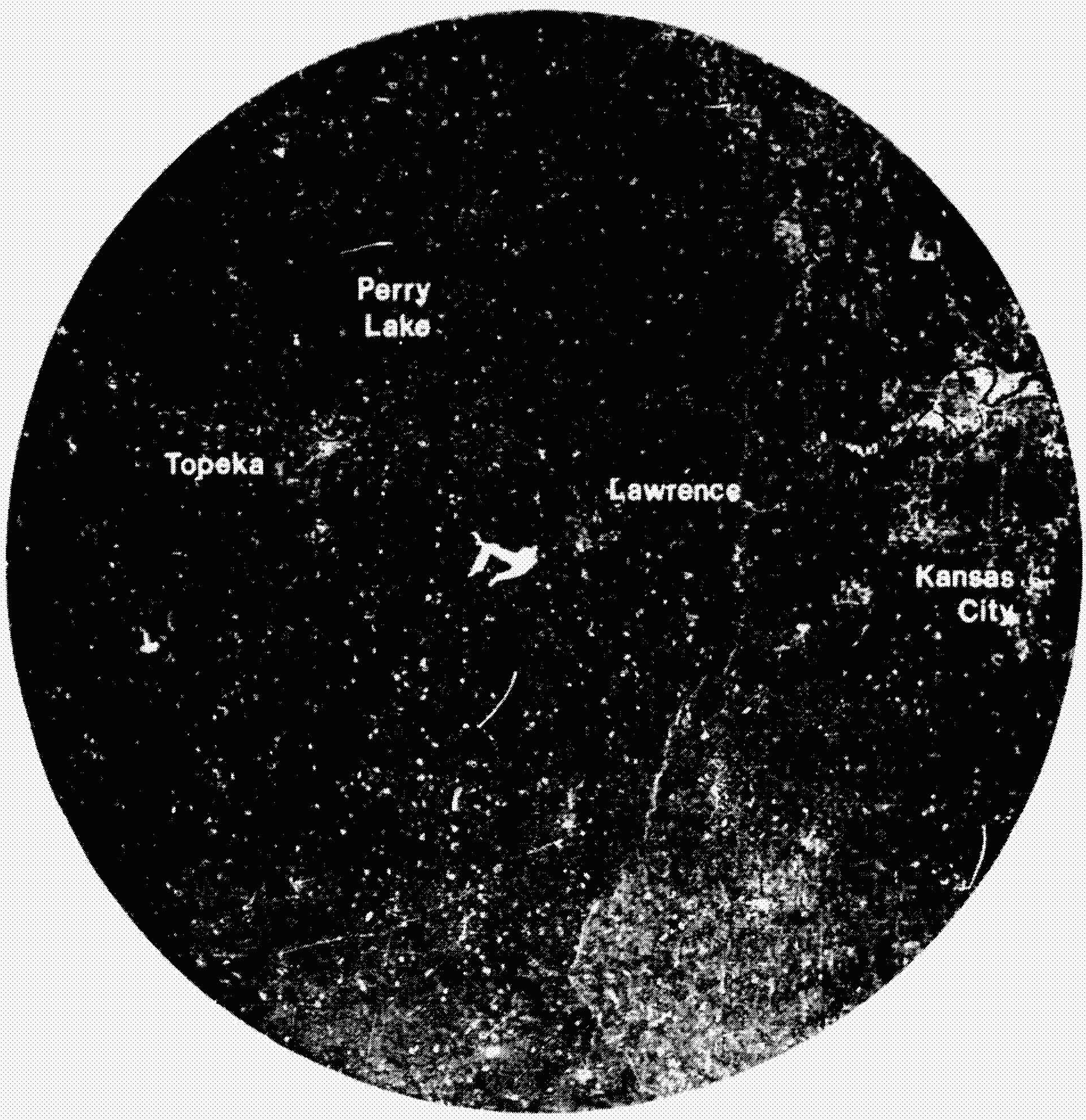


Figure 3. Location of the Clinton reservoir under construction in the Topeka-Kansas City urbanization corridor.

Figure 4. Development potential of areas surrounding Clinton Reservoir. Areas with dense woods, excellent wildlife habitat, and scenic attributes were held suitable for development.

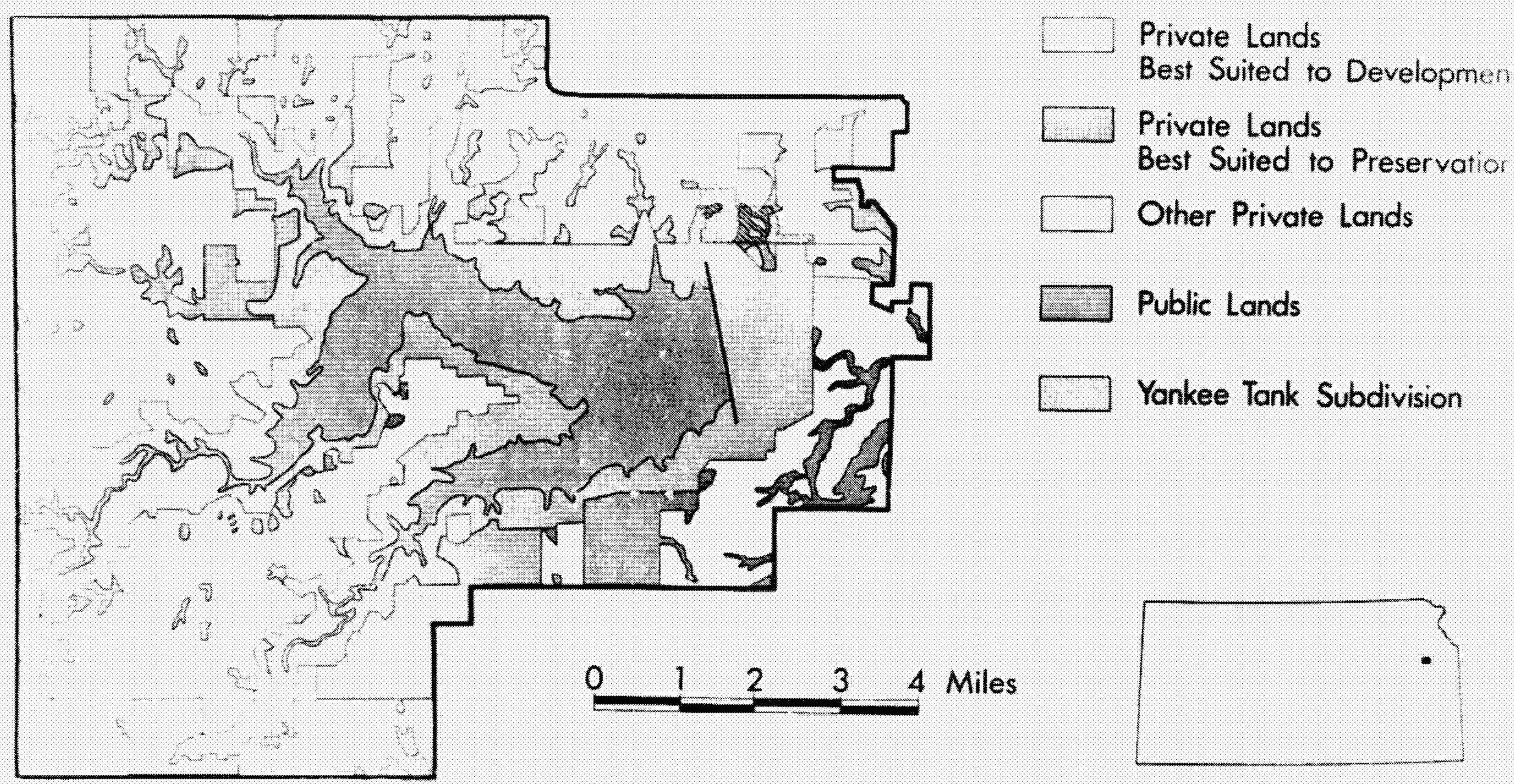


Figure 5. Installed center pivots as of Spring 1974. Note the distribution of the sprinklers relative to the two environmental factors of water availability and soil texture. The variables are related as shown in the legend.

1973

1974

Figure 6. Increase in number of center pivots in southern Finney and Kearny Counties, Kansas, from May 1973 to May 1974. In the illustrated 860 sq. km. the number of center pivots has increased by 114 units, representing 7.3 percent of the area.

Figure 7. Kansas City, Kansas and Wyandotte County as imaged by a single frame of U-2 imagery acquired in May 1974.

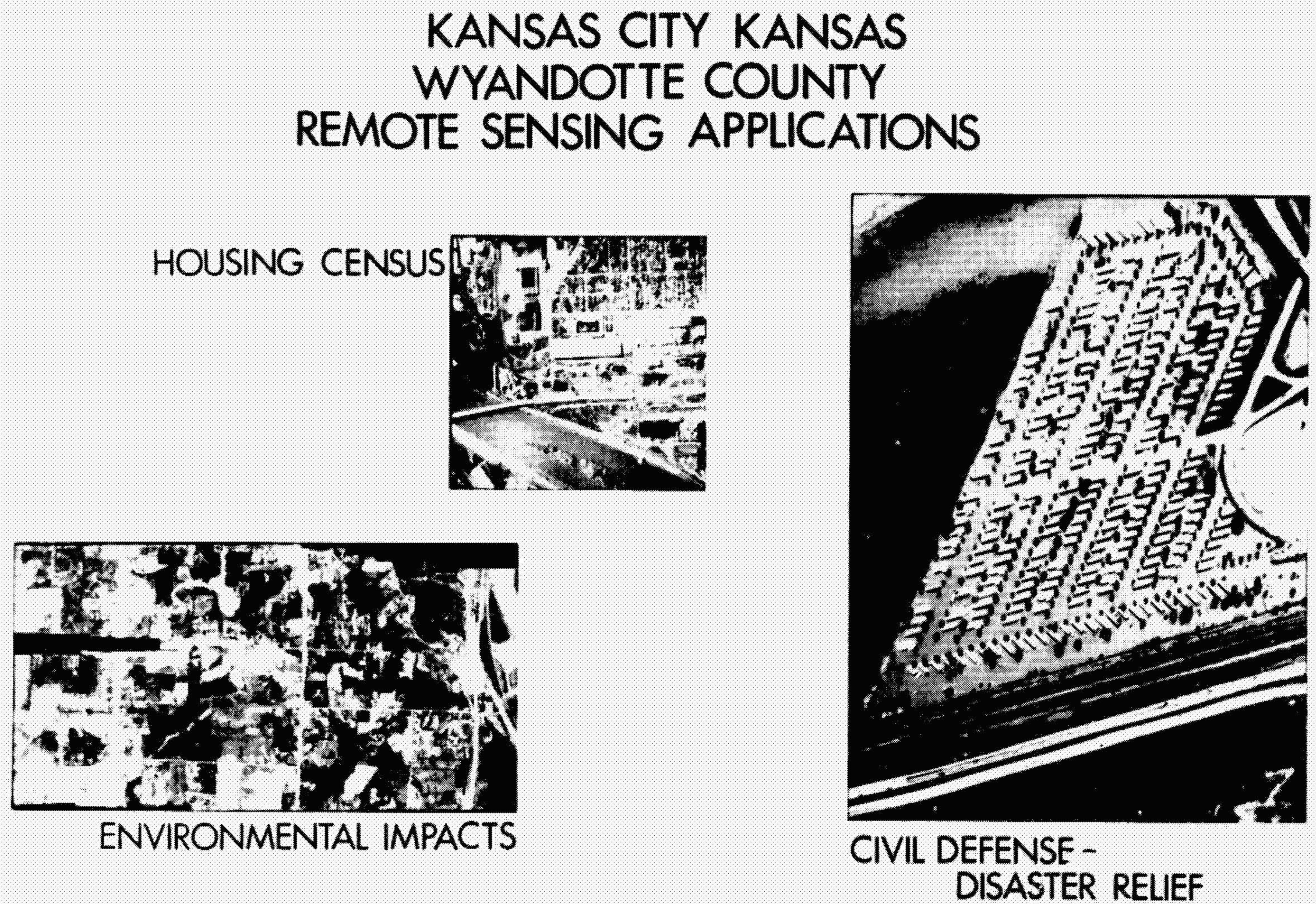


Figure 8. Illustrations from imagery used in projects for the Kansas City, Kansas, Department of Planning and Development.

REMOTE SENSING APPLICATIONS IN THE INVENTORY AND ANALYSIS OF ENVIRONMENTAL PROBLEMS E-18

By Gordon E. Howard, Jr., Environmental Protection Agency, Environmental Photographic Interpretation Center, Vint Hill Farms, Warrenton, Virginia and C. Al Waters, Jr., Environmental Protection Agency, Environmental Photographic Interpretation Center, Vint Hill Farms, Warrenton, Virginia.

ABSTRACT

The U.S. Environmental Protection Agency through the Environmental Photographic Interpretation Center (EPIC) is actively engaged in the extraction of environmentally related data from both high resolution and multispectral imaging systems. From its inception the EPIC has researched the various remote sensing systems available from both a cost effective and information content standpoint. Through interagency agreements and cooperative programs such as the NASA Aircraft Support Program imagery has been acquired in areas where EPA has operational requirements. Presently the efforts of EPIC are directed toward the inventory and analysis of many types of pollution sources both point and non-point.

INTRODUCTION

In early 1972 it became apparent to some in EPA that the sheer magnitude of the 3 1/2 million square miles to be monitored would require the application of the remote sensing techniques long used by many other government agencies. If the environmental monitoring job was to be done confidently, quickly and successfully it would have to use up-to-date remote sensor technology to augment and complement the information collected by the contact or in situ sensors. The most practical and cost effective way to launch EPA into the remote sensing field quickly was to enter into interagency agreements with other federal agencies whose missions have long involved the use of overhead imagery.

It was through the pursuit of these goals that EPA acquired from the Department of Defense a laboratory at Vint Hill Farms, Warrenton, Virginia. Also this same avenue yielded a considerable amount of photo lab and photo interpretation equipment and access to some very valuable domestic imagery files - all this at little or no cost to EPA. The Vint Hill facility was designated the Environmental Photographic Interpretation Center (EPIC) and remained the ward of the EPA Office of Monitoring Systems under the guidance of the Assistant Administrator for Research and Development. In July 1974 it became an associate laboratory of EPA's National Environmental Research Center in Las Vegas.

EPIC MISSION

EPIC was established primarily to accomplish the following objectives:

1. Obtain, reproduce, interpret and analyze domestic imagery from any and all federal film libraries,

2. Secure and maintain for EPA the expertise accruing from the highest technology in the collecting and processing of information to be used for decision making purposes,

3. Provide a focal point for the development of overhead monitoring technology as it applies uniquely to the mission of environmental protection,

4. Introduce into the operational arena, for complete and confident monitoring of the environment, the tools and techniques resulting from remote sensing research and development.

ENVIRONMENTAL PROJECT APPLICATIONS

The examples which follow represent a basic cross-section of the applications that EPIC is currently addressing. The preferred imagery of EPIC for its present requirements, is the high-resolution wide-coverage panoramic type which offers the required information content with a minimum of film surface area (fig. 1). The modified KA-80A panoramic camera scans 140° across track and delivers 130 lines per millimeter over 80% of its format of 5" x 60". A considerable amount of imagery from these high-resolution flights is in the federal film libraries and available to EPIC. It incorporates high resolution capabilities for analysis of minute details with wide area coverage, approximately 140 square miles per frame. EPIC has inhouse a total of approximately 90,000 square miles of this type coverage, all obtained to date on black and white panchromatic. Additionally as principal investigators for Skylab and LANDSAT, we use that material in all ways that apply to EPIC programs.

1. The Monongahela River Basin:

   A non-point pollution source inventory was initiated by a request from the EPA Region III Surveillance & Analysis Division. They were interested in a qualitative and quantitative inventory of such non-point sources as strip mines, junkyards, dumps, sediment producing areas and water impoundments exhibiting eutrophication. The panoramic system was a natural for this task. Additionally the National Environmental Research Center in North Carolina was interested in an R&D effort to determine the feasibility of using this imagery system to locate all potential point emission sources - smoke stacks - along the Monongahela River (fig. 1). This proved to be completely feasible from the interpretation standpoint. Figure 2 illustrates the types of categories included in the program. Figure 3 is an enlargement of the coke works of U.S. Steel at Clairton, Pa., which contains 2100 coke ovens. Figure 4 is an uncontrolled mosaic of the study area.

2. Southern Iowa Water Resources and Pollution Sources Survey:

   This program encompasses an area of eleven counties in which the Region VII office in Kansas City submitted a request for support. The ultimate consumer was the Remote Sensing Laboratory and the Department of Environmental Quality of the State of Iowa. A lack of good map bases necessitated the use of uncontrolled mosaics for inventory purposes only thus forcing us to disregard geographic and geodetic control. However, overprint lines were used to show the state users the mismatch areas. The resulting inventory sheets were very favorably received by the State of Iowa as being very useful to their desired purposes - inventorying and monitoring of environmental factors. Figure 5 is a typical example of a small private feedlot.

3. Cattle Feedlot Inventory in Nebraska:

   This study was similar in nature to the Iowa study, but the feedlots were much greater in size and capacity (Figure 6 - Manley Feedlot). The area from Stanton to West Point on the Elkhorn River was inventoried to measure the cattle waste effect on the river. Some 480 farms were located within the drainage basin along this 30 mile stretch of river. Figure 7 shows some of the larger commercial feedlot operations in this area. This was also a test study area in the National Water Quality Survey Sites program of EPA which included 67 station pairs located throughout the 10 EPA Regions in the U.S.

4. Lower Calcasieu River All-source Pollution Inventory:

   The EPA Region VI, Dallas, Hazardous Materials Division requested an all-source pollution inventory of the lower Calcasieu River in Louisiana, including Beauregard, Calcasieu and Cameron Parishes. The program consisted of locating and plotting all industrial complexes, petroleum fields, car dumps, garbage and municipal dumps and feedlots in the 3400 square mile study area. The format of the final product consisted of thematic overlays keyed to 7 1/2" and 15" USGS quadrangle sheets (Figure 8).

5. Cornell University Leachate Migration Study:

In consortium with Cornell University, EPA/EPIC entered into a feasibility research study to attempt to locate, identify and map the migration of leachates from landfills (Fig. 9). The study area centers around Syracuse, New York, and is employing color infrared, conventional color and thermal sensors. To date flights have been accomplished on a seasonal basis in order to determine if and when these migrations occur and can be detected. The essential ground truth is being supplied by the Department of Environmental Conservation in the State of New York. An initial finding, using December 1974 coverage, utilizing no ground truth, displayed ten representative leachate areas detected for the first time. Of these ten, using remote sensor analysis only, six were classified as definite leachate areas, three as probable and one as doubtful. Subsequent ground truth confirmed the photo interpretation in nine of the ten areas - one of the probables being negated. This 90% accuracy rate seems to confirm at least, the feasibility of our approach for similar environmental problems in other areas of the U.S.

6. Muskegon County, Michigan Wastewater Treatment Project:

This project was suggested to EPIC by the EPA Region V support office in Muskegon. It involved the plotting of a newly integrated series of wastewater treatment processes which may serve as a prototype for areas throughout the country. After storage and disinfection of the water, with its nutrient loads, it is spray irrigated on crops, predominantly corn. The water then is filtered through the soil to an underdrainage return system and is discharged to the surface waters of Muskegon County. The entire system is monitored to assure that all effluents meet drinking standards. The secondary benefit of crop irrigation is welcomed in this area because of the lack of economic vitality in an area not noted for its agricultural accomplishments. The methodology used on this project was to superimpose Skylab imagery over prior Department of Agriculture photography to delineate the confines of the approximately 10,000 acre facility.

7. Colstrip Montana Coal-fired Power Plant Study:

This project is a cooperative effort between EPA's National Environmental Research Center in Corvallis, Oregon, the State of Montana and several universities with remote sensing support supplied by EPIC. The primary purpose of the study is to develop the expertise to predict the effects of air pollution on an ecosystem by analyzing the ecological condition of an area <u>before</u> the introduction of a pollution source and comparing, on a periodic basis, the stresses exhibited over a period of four years after production is generated. A request for NASA aircraft support has been made and accepted by NASA Ames for mid to late 1975, utilizing a panoramic imaging system at high altitudes. Other imagery will be acquired through the State of Montana with reproduction services and analysis performed by EPIC. It is anticipated that the results of this study will provide an excellent photo interpretation key for the assessment of environmental impacts and compliance monitoring.

8. Technical Support to the City of Chicago, Illinois:

Through the efforts of the Regional Counsel of Region V EPIC and the Remote Sensing Branch of the Monitoring Applications Laboratory of NERC, Las Vegas were asked to analyze a Skylab photograph of the Chicago metropolitan area (fig. 10). The intent was to enter the analysis into evidence in a court case involving the City of Chicago versus a major steel producer.

The first phase of the program involved providing expert testimony in the interpretation of a "plume" seen on the photo and providing an approximation of its extent. This was accomplished on May 1, 1974.

The City's case contended that the discharging plume from the Indiana Harbor Ship Canal was entering the intake of the Chicago water supply. This would conceivably occur under the proper wind and current conditions of Lake Michigan. However, the plume exhibited on the Skylab photo was curling in the wrong direction for use as direct evidence.

It was felt by the on site EPA personnel that, given the proper wind and current conditions, it would be advantageous to overfly the discharge area using a thermal infrared scanner. As a result a NERC Las Vegas aircraft and sensor crew were dispatched to Chicago and the overflight was accomplished. The imagery obtained clearly showed that the waters of the canal had shifted and were heading toward the water intake.

Further testimony was presented to the court and the thermal images and a deposition were entered into the prosecution's case.

SUMMARY

To date, in its brief 1 1/2 year existence, EPIC has found that the nature of its requirements has almost exclusively demanded the use of high resolution photography. Our requirements run the gamut from long term programs such as the development of environmental photographic interpretation keys and the stresses introduced into the ecosystems by man made changes in the environment to the detection, indentification and analysis of cattle and swine feedlot operations.

In some of our other studies we have used combinations of simultaneously acquired imagery. In a study of a series of sanitary landfills, conventional color, color IR and thermal scanner imagery are being used in a research effort to detect and study leachate migration from the landfills.

In some of our Fiscal Year '76 projects, we have been fortunate enough to have four programs approved for high altitude panoramic imagery acquisition by NASA using the KA-80A camera system. The EPIC Director, Mr. Vernard Webb, is a Principal Investigator for LANDSAT and Skylab imagery and EPIC has been able to utilize all the Skylab imagery available. We use this imagery to the extent possible in accomplishing our mission.

EPIC's most valuable operating asset is its wealth of interagency agreements. This saves us the cost and unnecessary loss of time which would be expended in starting our operation from square one. It is also very important to us to have a high level of experience in our photointerpreter/analysts and a multidisciplinary academic background.

Figure 1.- Monongahela River non-point inventory.

MONONGAHELA RIVER BASIN

NON-POINT SOURCE POLLUTION INVENTORY

PARAMETER	DATA REQUESTED
Junk car dumps	Location
Strip mines, active and inactive	Location and size
Stri[illegible] mines spoil areas	Location and size
Acid mine drainage discharges	Location
Solid waste dumps	Location
Sediment producing areas	Location and size
Timber cutting areas	Location
Mine tailings impoundment dams	Location
Industrial effluents	Location
* Eutrophic impoundments	Location
* Thermal effluents	Location

* limited returns - additional imagery required

Figure 2.- Categories included.

Figure 3.- Clairton Coke Works in Pennsylvania.

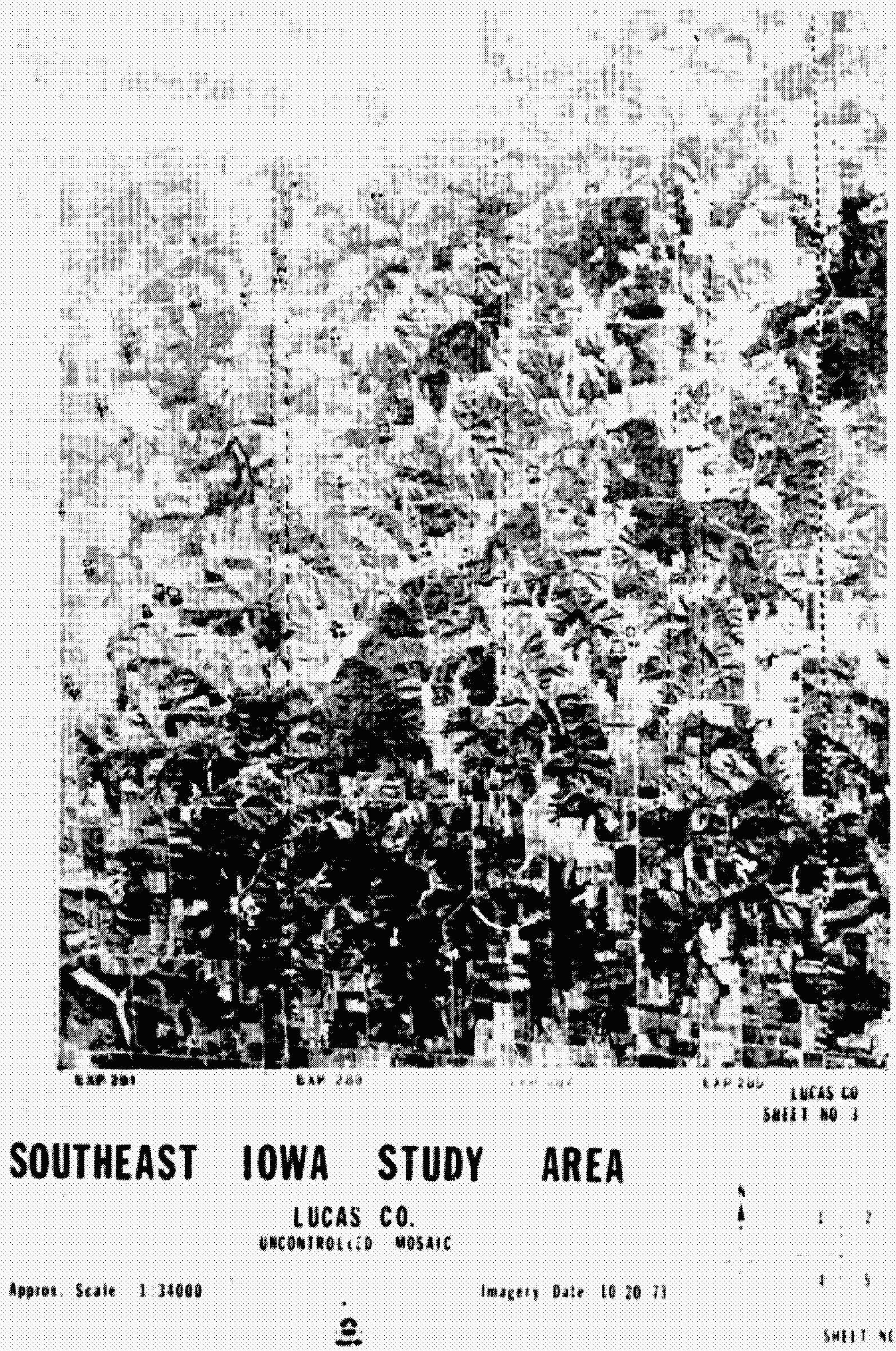


Figure 4.- Example of uncontrolled mosaic in Iowa study.

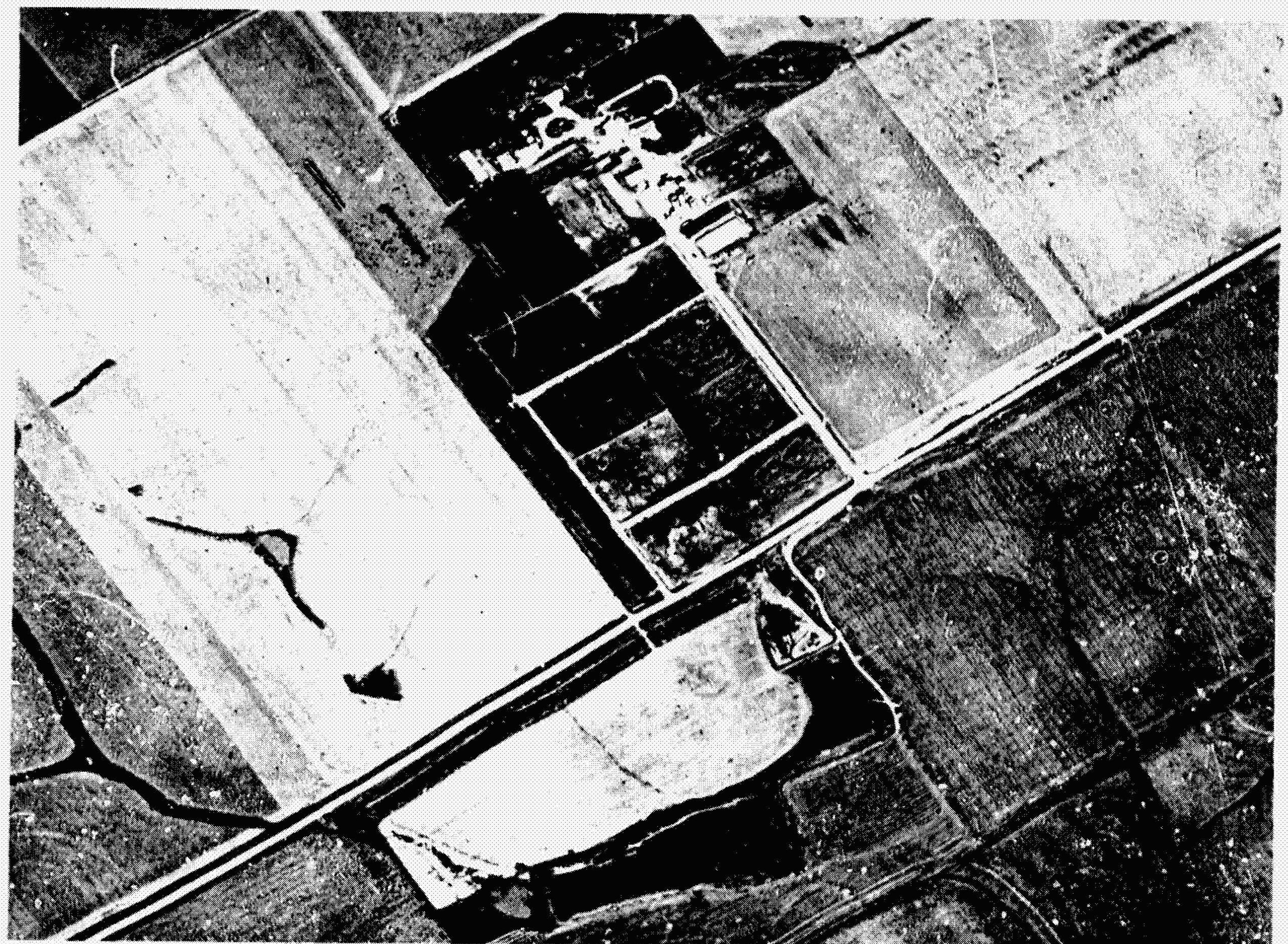


Figure 5.- Small cattle feedlot in Iowa.

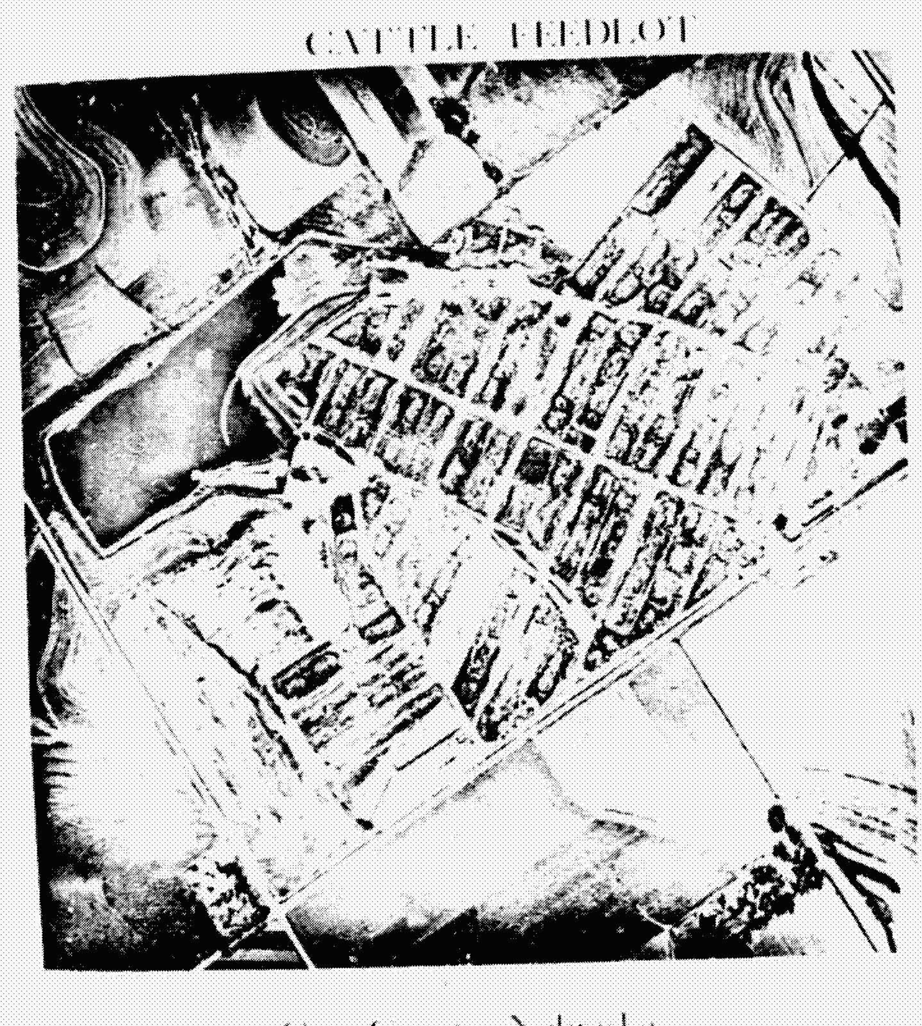


Figure 6.- Manley commercial feedlot, Nebraska.

Figure 7.- Examples of feedlots between Stanton and West Point, Nebraska, on the Elkhorn River.

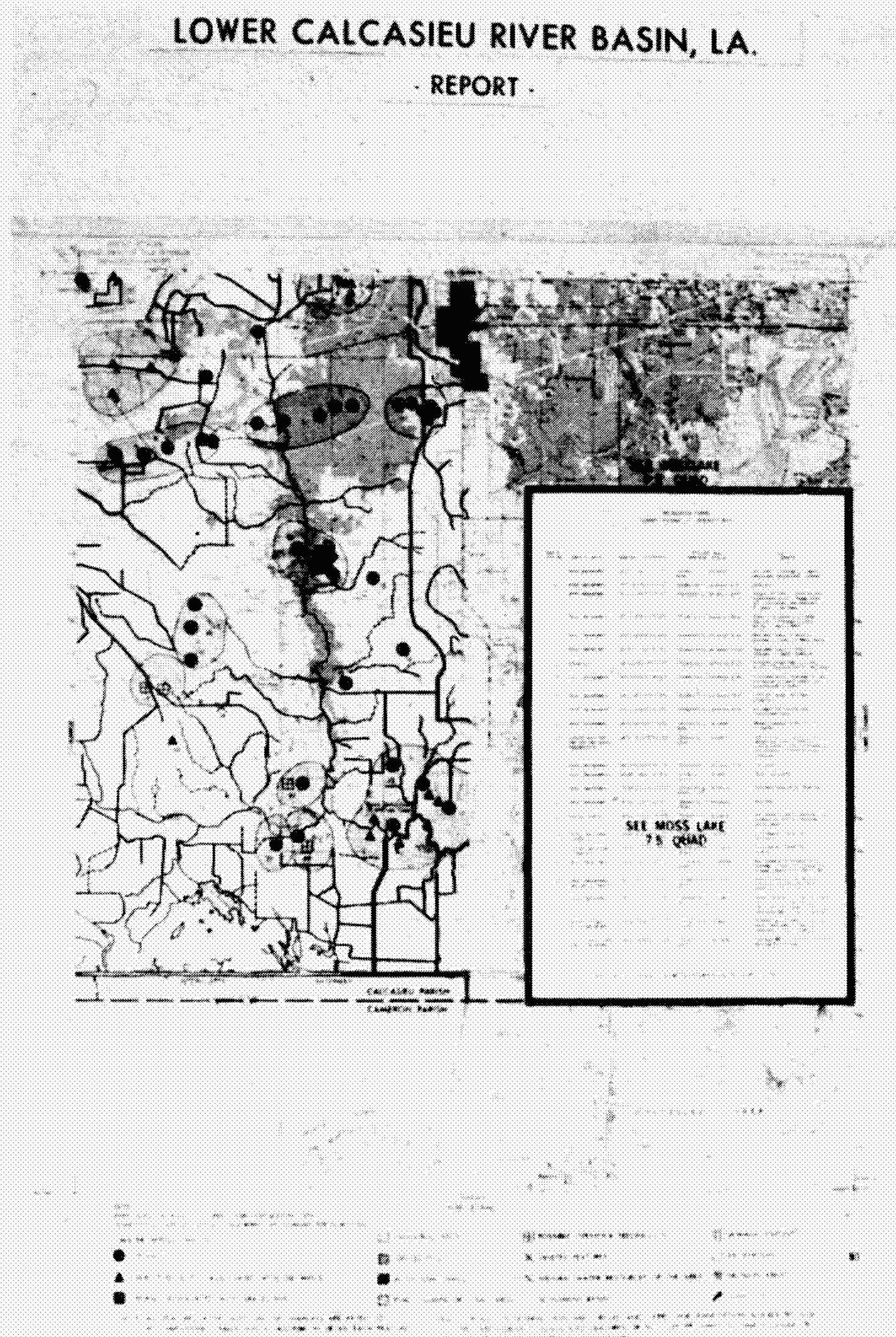
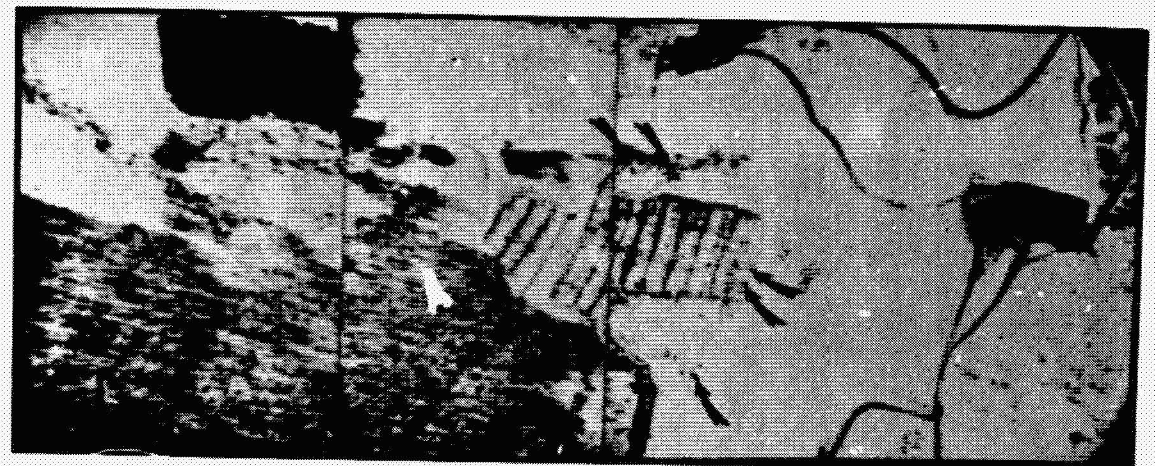


Figure 8.- Example of Calcasieu River pollution inventory.



MOSAIC - CONVENTIONAL COLOR - 1254 HRS. - ALT 2,500 AGL

MOSAIC - I.R. COLOR - 1254 HRS. - ALT 2,500 AGL

Figure 9.- Example of imagery used in Cornell study.

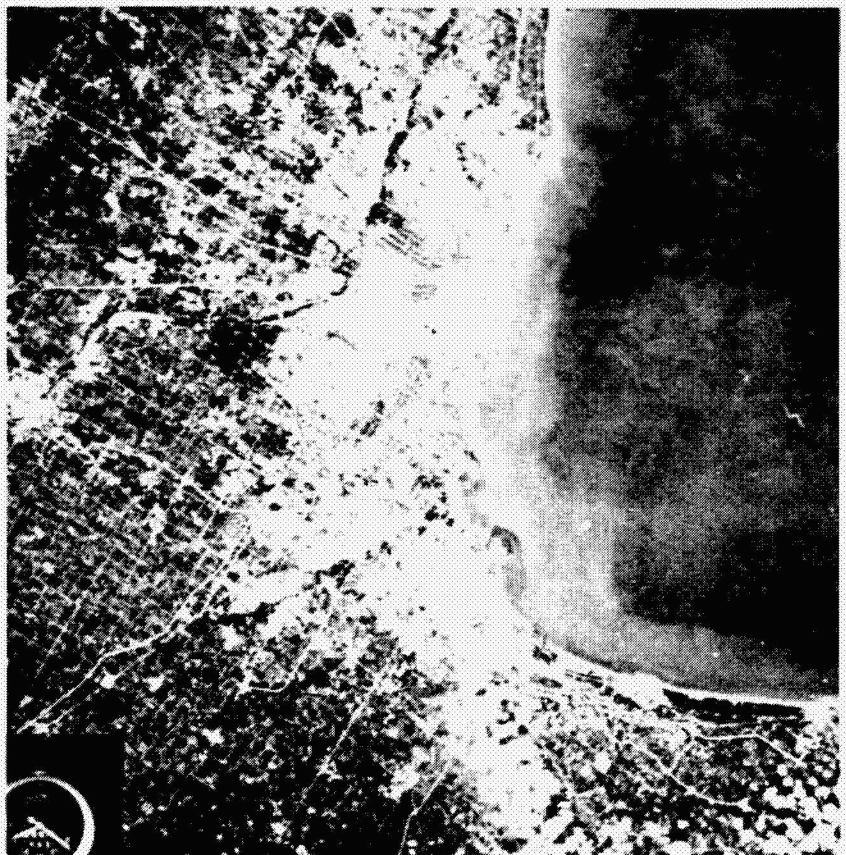


Figure 10.- Skylab image of Chicago area.