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LAND CLASSIFICATION OF SOUTH-CENTRAL IOWA FROM COMPUTER ENHANCED IMAGES

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Final Report:
July, 1977

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt Road
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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

LAND CLASSIFICATION OF SOUTH-CENTRAL IOWA FROM COMPUTER ENHANCED IMAGES

By James R. Lucas, James V. Taranik, and Frederick C. Billingsley

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Type III Final Report for NASA Contract NAS5-20832

This paper is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards or nomenclature.

Sioux Falls, South Dakota

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ABSTRACT

The Iowa Geological Survey Remote Sensing Laboratory (IGSRSL) has been using Landsat data for mapping landforms, materials, and land use in Iowa. The Jet Propulsion Laboratory (JPL) Image Processing Laboratory has developed computer processing techniques for producing enhanced images from Landsat computer compatible tapes. Together, IGSRSL and JPL applied digital image processing techniques to produce enhanced images for land classification purposes in an eleven county area in south central Iowa. The primary objective of this project was to investigate alternatives of computerized image processing techniques that could enhance Landsat data to assist the extraction of land use information from imagery. From this enhanced imagery, land analyses were conducted in the study area with the level and type of classification selected to meet the needs of the Area XV Regional Planning Commission. A secondary objective was to investigate photographic enhancement techniques as they may be applied to standard and computer enhanced image data. Project research determined that the optimization of the photographic process must be achieved if the advantages of computer processing were to be evaluated.

Contrast stretching of image data was found to be a critical consideration in digital enhancement. Truncation must be pursued vary cautiously to attain the maximum scene contrast while preserving maximum tonal variation. Both the amount of truncated data and the location of saturated picture elements (pixels) must be determined by an interactive analysis system to monitor the data to white or black thus tracing the losses in tonal variation (or detail) within the scene. The use of automatic truncation limits (saturation of a specified percentage of picture elements) is not recommended. This approach to contrast enhancement does not take into account the location of pixels that are being transformed to white or black brightness values. Significant losses in image tones may be concentrated in critical areas important for land classification.

Another approach to Landsat image enhancement involves the use of both digital and photo-optical enhancement. Digital techniques would be used to cosmetically enhance and geometrically correct image data with contrast stretching being limited only to expansion of data to fill the full brightness value range. When all densities for the MSS bands are recorded on black and white film, photo-optical enhancement techniques could be implemented to photographically contrast stretch the bands to selectively enhance land classification categories. Image enhancement could be done iteratively in a photo lab, not requiring the use of computer facilities to produce a different scene enhancement. Photo-optical enhancement would be a more cost-effective method of selectively enhancing land classification categories rather than the application of additional computer processing.

When comparing satellite image products, the primary limitation in utilizing Landsat standard products and photo-optically enhanced standard products for land classification is the inability to print these images at large enough scales, such as 1:63,360, to display large variations in color on the composite or tones on the black and white bands. In addition, when large scale enlargements are made from these products, MSS striping becomes very prominent. JPL computer enhanced false-color composites have been routinely printed to 1:63,360 scale at the Iowa Geological Survey. Individual picture elements are clearly visible but are not so large that image patterns are obscured. The ability to see individual picture elements is an advantage for land classification because the extreme details of the landscapes have been aggregated by the multispectral scanner into approximately 1.1 acre blocks. Being that planners in south central Iowa organize land classification data on a cell basis, this lack of detail on Landsat scenes makes the decision process easier for the assignment of data cells to a specific land class. Enhanced Landsat imagery can also be used as a photo base on which other spatially referenced data such as soils reports, urban zoning maps, and mineral resource documents can be overlaid and compared either individually or collectively to assess regional planning alternatives. Inexpensive color printing and processing systems have proved to be effective in obtaining suitable Landsat photo base products. Color balance, exposure, and scale can be controlled by users to produce color photographic products that best serve their needs for image analysis and interpretation. Both the low cost and limited photographic expertise required for color photographic processing makes the implementation on the regional planning commission level a realistic goal.

The advantages of using Landsat data in regional planning are: 1) the initial image acquirement is cheaper than low altitude black and white imagery, 2) the image analysis time is approximately one third less when using a 40 acre data cell, and 3) Landsat data costs less to update on a five year basis. The use of Landsat data does, however, have some disadvantages in regional planning: 1) there is less utility in Landsat imagery for other aspects of planning that could be supplied from higher resolution imagery, and 2) Landsat image analysis requires slightly more training or experience.

If greater acceptance of Landsat data is to be gained in land use planning, NASA must "market" these products to make practicing planners more aware of the system's capabilities. Training and assistance should also be given more emphasis. In addition, if Landsat data is to be operationally used for planning purposes, there must be a consistent national land planning program in which Landsat data could be used to meet the criteria of the program.

ACKNOWLEDGEMENTS

The proposal for this NASA contract was originally written by James V. Taranik and Frederic C. Billingsley in December 1972. When the project was approved for funding by NASA in the summer of 1974, James Taranik was designated as Principal Investigator. In January 1975, James Taranik accepted a position with the U.S. Geological Survey at the EROS Data Center. The principal investigatorship was transferred to Samuel J. Tuthill, State Geologist of Iowa. In July 1975, Samuel Tuthill was appointed to the position of Chief Science and Energy Advisor to C. B. Rogers Morton in Washington DC. James R. Lucas, the current project manager, was named as Principal Investigator under the direction of Stanley C. Grant, the newly appointed State Geologist of Iowa. The help and cooperation of Stanley Grant in the completion of this NASA investigation has been greatly appreciated.

Andrée Yvonne Smith of the JPL Image Processing Laboratory did much of the programing for producing the enhanced imagery used in the investigation. John D. Addington and Richard J. Blackwell provided technical evaluations of image processing techniques employed. The documentation of the JPL photographic processing techniques would not have been possible without the help of Ron Wichelman.

This final report for the investigation was written at the EROS Data Center while the Principal Investigator was under the employment of Technicolor Graphic Services (TGS), Inc. Joseph N. Pfliger, General Project Manager for the Technicolor South Dakota operations, is acknowledged for his support and encouragement in the concluding months of the investigation. Several other TGS staff members made valuable contributions to the completion of this project. Richard L. Nelson, Assistant Supervisor of the EDC Custom Color Laboratory, and Darrell C. Ramerth, also of the Custom Laboratory, are acknowledged for their cooperation in producing imagery and documentation for the photo-optical enhancement techniques that are discussed in this report. Keith A. Maas and T. Lincoln Perry of EDC provided material and guidance concerning the color compositing process and other photographic techniques. The philosophical guidance received from Frederick A. Waltz, Chief of the Data Analysis Laboratory at EDC, is gratefully acknowledged. David D. Greenlee, Senior Systems Analyst in the Data Analysis Laboratory, provided constructive comments concerning the project. Cynthia A. Sheehan, Junior Applications Scientist in Geology at EDC provided assistance on the project work while at the University of Iowa.

The cooperation of Bruce W. Bullamore, Director of the Area XV Regional Planning Commission, in the development of the application strategy for Landsat imagery to regional planning was greatly appreciated. The assistance of Rick Harper, Associate Planner, was helpful for documenting the final report. The technical illustrating in this report was completed by Joyce A. Fry. A special thanks is given to Linda L. Phillips for her constant advice during the typing of the preliminary versions of the manuscript. Dee Rons is gratefully acknowledged for her help in editing and typing of portions of the final manuscript. Great appreciation is extended to Donna J. Stetz of the University of Wisconsin, Department of Civil and Environmental Engineering for exceptional dedication in reviewing the completed final report.

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INTRODUCTION

The Iowa Geological Survey (IGS) has been using Landsat data for mapping materials and landforms in the Midwest. Land classificatory information derived from Landsat data has been supplied by IGS to regional and local planners in an eleven county area of south central Iowa. The Jet Propulsion Laboratory (JPL) Image Processing Laboratory had developed computer processing techniques capable of producing enhanced images from Landsat computer compatible tapes. Because JPL had existing computer hardware and software, and because IGS, especially personnel of the Remote Sensing Laboratory, had identified midwestern land use themes for use with Landsat data, the two organizations jointly proposed to apply digital image processing techniques to produce enhanced images for land classification purposes in south central Iowa. The project proposal was written in December 1972 and was funded by NASA in February 1975. The documentation in this final report for the investigation has been separated into two major sections of discussion. The first section deals with how optimal computer enhanced images have been produced for the delineation of land use in south central Iowa. Attempts to reach this goal are discussed in detail including the interactive determination of contrast stretch limits, photo-optical enhancement techniques, and the use of a combination of both approaches.

The second major section of this report deals with the application of Landsat imagery to the regional planning process. Alternatives available to planners for the production of Landsat products are discussed in relation to the cost-effectiveness of these approaches.

Research leading to project proposal

The Iowa Geological Survey (IGS) has had two previous grant contracts to investigate the midwestern landscape using Landsat-1 data. In May 1972 the Survey received a $40,000 grant from the Department of the Interior, U.S. Geological Survey, EROS Program, to apply Landsat-1 data to the mapping of Quaternary landforms and materials in the Midwest and Great Plains. This project (SR 238) required the coordination of efforts between six co-investigating midwestern geological surveys. Soils maps, surficial geological maps, subsurface geologic maps, and surface drainage maps were produced using Landsat-1 data. This study provided basic information on midwestern land use as related to materials.

In November 1972, IGS received a second grant from the EROS Program to further the application of remotely sensed data from Landsat to resource development including both land and water management of south central Iowa. This project used repetitive, synoptic Landsat-1 multispectral data as it applied to county information needs. Eleven counties were studied using satellite imagery and low-altitude multispectral overflights. An atlas of maps was prepared for these counties illustrating thickness of unconsolidated materials, engineering characteristics of materials, and bedrock topography. A second series of maps in the atlas outlined the distribution of water and mineral resources, and a third series showed land utilization and potential for land reclamation (see Hoyer, et. al., 1973). These two projects, though seperate in scientific scope from this NASA project, formed the basis for identifying the parameters of land classification to be enhanced for midwestern land use planning purposes.

The Iowa Geological Survey Remote Sensing Laboratory (IGSRSL), a division within the Iowa Geological Survey, has used three methods for producing thematic displays of remotely sensed data: 1) conventional photo interpretation, 2) multi-spectral color additive viewing, and 3) density slicing with false-color enhancement. The equipment used in these analyses included a Mini-Addcol Multispectral Viewer model 6040, manufactured by International Imaging Systems, and Digicol, a density slicer with digital image processor, analog signal processor, and density control unit, manufactured by the same company. Conventional photo interpretation of Landsat-1 imagery in the previous projects was accomplished by the use of negative prints of bands 5 and 7 enlarged to scales of 1:500,000 and 1:250,000. Evaluation by IGSRSL of these three techniques of information extraction found limitations related to equipment, imagery, and cost effectiveness of the method employed. The extraction of land classes from imagery was found to be dependent upon the relationship between image density and land class to be delineated. Single band products, for example, do not uniquely depict land classification groups by one discrete image density. Several levels of image density can represent a single land class. In addition, the variations in image densities are frequently too subtle to differentiate selected classes on imagery. Similarly, land classification categories cannot be uniquely defined on color composites by individual hues of color. Color additive viewing also was found to have limitations in portraying land classes because image density controls the mixtures of primary red, green, and blue which dictates the hue, saturation, and brightness of the projected colors.

Staff members of the Iowa Geological Survey Remote Sensing Laboratory began investigating possible methods for enhancing land use classes on Landsat imagery when the limitations of these three methods of information extraction were initially evaluated. Digitally enhanced multispectral Landsat products appeared particularly attractive because the data could be furnished in computer compatible tape form in addition to providing synoptic, repetitive data at scales applicable to the information needs of midwestern land use planners. Staff from IGSRSL met with staff from the Jet Propulsion Laboratory (JPL) of the California Institute of Technology, and through an exchange of ideas it was established that JPL possessed the staff, computer facilities, and existing computer programs capable of producing enhanced imagery from Landsat digital tapes. Because JPL already had the computer hardware and software needed to produce enhanced imagery, and because ongoing projects at IGSRSL had defined midwestern land use classifications for use with Landsat data, the two organizations decided to jointly submit this Landsat-2 project to NASA for funding.

Effects of changing technology on project

When this project was originally proposed in December 1972, it was decided that computer enhanced images were to be produced for portions of an eleven county area in south central Iowa. The technological objective was to apply existing computer enhancement techniques to Landsat-2 computer compatible tapes (CCT's) to produce enhanced images in which land use classes are related to sufficiently separate density levels on film. Single band and multiple band products from Landsat, enhanced specifically for land classification purposes, were to be used in a color additive viewer and Digicol, respectively, to produce thematic displays depicting land use in the south central Iowa study area. This data was then to be supplied to planners in the study area for suitability evaluation. In the time span from December 1972, when the proposal was submitted, to February 1975, when the proposal was funded by NASA, modification of project objectives was required to fit developing technology. Preliminary analyses with the Digicol at IGSRSL indicated that the production of thematic land use maps would be difficult for both standard and enhanced Landsat products because of the subtle nature of tones associated with many land classification categories. Further work with the Digicol was precluded by an electronic failure of the system. In addition, formulation of suggestions for changes in enhancement techniques at JPL to best portray land classes required substantially more research than simple manipulation of black and white bands in the color additive viewer. The detailed analysis and evaluation of digital enhancement as well as photographic enhancement techniques that have been undertaken in this project were necessitated because of the complex problems encountered while attempting to represent distinct land classes on computer enhanced images. Furthermore, the implementation of color photographic processing at the Iowa Geological Survey was needed because the JPL photographic technicians found it difficult to determine the optimal photographic prints for land classification purposes in Iowa. Low cost "custom" color prints that were produced in the IGS photo laboratory gave significant flexibility to planners in the use and incorporation of Landsat images into land planning analyses. These photographic endeavors at the Iowa Geological Survey also gave impetus to the development of a photo-optical enhancement process at the EROS Data Center.

Investigation objectives

The primary objective of this project has been to investigate various alternatives of computerized image processing techniques which can enhance Landsat data to assist the extraction of land use information from imagery. From this enhanced imagery, land use analyses for portions of the eleven county area were conducted with the level and type of classification selected to meet the needs of the planners, primarily from the Area XV Regional Planning Commission. In the course of this study a secondary objective was defined to investigate photographic enhancement techniques as they may be applied to standard and computer enhanced image data. This was required because project research determined that optimization of the photographic process must be achieved if the advantages of computer processing were to be evaluated. The long term objective of this project was to gain an increased understanding of the application of digital processing to the analysis of remotely sensed data. Achievement of this objective would facilitate the incorporation of such data into a computerized data base if one were implemented in the state of Iowa.

Upon assessing the needs of the planners in the study area, it was determined that low cost sources of data and low cost methods of analysis are required for regional planning purposes. Because state level planning agencies in Iowa traditionally have had small operating budgets, another project objective became the investigation of the cost effectiveness of utilizing Landsat imagery for planning purposes. Emphasis on low cost data sources and methods of analysis consequently limited the extraction of land use from Landsat data to manual image analysis with no emphasis on computer extraction of land use themes through statistical classification procedures. Landsat image analysis led to a strategy in which satellite data could be incorporated into the regional planning process.

Factors to be considered in the enhancement of images for regional planning purposes

Data for regional land use planning in the Midwest is often inaccessible and of uneven quality and quantity. The synoptic coverage of Landsat data is presently the only type of data collection which provides information of uniform quality at scales appropriate for regional planning purposes. The objective of image enhancement for land use classification is to make cover patterns more distinct and thereby expedite image analysis. Factors to be considered in image enhancement are related to the scene dependent nature of satellite data. The repetitive coverage of Landsat coupled with uniform image quality facilitates extraction of land classificatory information throughout the year. Seasonality and land use are closely related in the Midwest. Pattern analysis of specific land cover categories relates directly to the season in which the scene was recorded. Vegetative growing cycles, for example, are dependent upon moisture availability dictated by the seasons. The angle of sun illumination also varies with season. Low sun angles accentuate topography by producing more pronounced shadows. In addition, atmospheric scattering and absorption affect Landsat data and can degrade the imagery.

Information extraction from imagery is dependent upon the relationship between image density and land use patterns. A single band product does not, by itself, uniquely define land classes because several different levels of image density can represent a single land classification theme and one level of image density can depict several cover types. In addition, variations in image densities on individual bands are most often too subtle to detect for the definition of discrete classes. Color composite products do not uniquely define land classifications because they are not distinguished by individual hues of color and because dye densities on these false-color prints and transparencies are not directly related to these classes. No suite of four multispectral images from a single Landsat scene uniquely differentiates all land classes because of the seasonality of midwestern land use. Therefore, information from one band, or suite of bands, does not necessarily coincide with the information on other bands. Extraction of information from combinations of bands has great potential for providing essential information for midwestern land classification. Spectral quality, synoptic aspect, and repetitive coverage make Landsat a powerful tool for providing land classificatory information at scales appropriate for midwestern land use planning.

Alternatives for producing enhanced images

Landsat images can be enhanced through digital processing, special photographic techniques, or by a combination of both methods. Digital processing of Landsat data improves both the geometric accuracy and the visual appearance of imagery. Computerized image enhancement procedures include such functions as contrast enhancement, destriping, replacement of lines of missing data, edge enhancement, and geometric correction. Scene contrast may be increased by expanding the range of image gray tones over the entire brightness value range and thereby accentuate subtle tonal differences in land cover. Striping due to differences in detector response of the multispectral scanner (MSS) can be removed. Lines of missing data can be replaced with synthetic lines through a linear interpolation process. An image optimization program can enhance edges of features within a scene. Landsat data can be geometrically corrected for skew, panoramic distortion, and variation in scanner mirror velocity. In addition, image rotation to true north can be accomplished with digital enhancement techniques.

Although no image corrections can be routinely introduced through the use of special photographic techniques, increased scene contrast and color saturation permit easier image interpretation. By analysis of minimum and maximum densities on an image with a densitometer, the range of tones within a scene can be determined. These established density values can be reassigned to an expanded gray level range by photo-optical techniques and thereby contrast enhance image data. On black and white products, the amount of contrast can be controlled through variation in exposure and development time. The level of color saturation can be altered by exposure and filtration of the exposing light source.

Digital image processing and photo-optical techniques can be used together to produce Landsat scenes that accentuate cover patterns for land classification purposes. This is accomplished by first producing black and white bands with digital distributions that fill the entire recording range of the photographic film. Photo-optical techniques then can be employed to additionally enhance selected land cover features. Manipulation of scene contrast and color saturation can produce images that are optimal for the delineation of land use classes on photographic products.

Physical and cultural characteristics of project area

The project area for this NASA investigation includes eleven counties in south central Iowa (Figure 1). This region

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Figure 1 near here.

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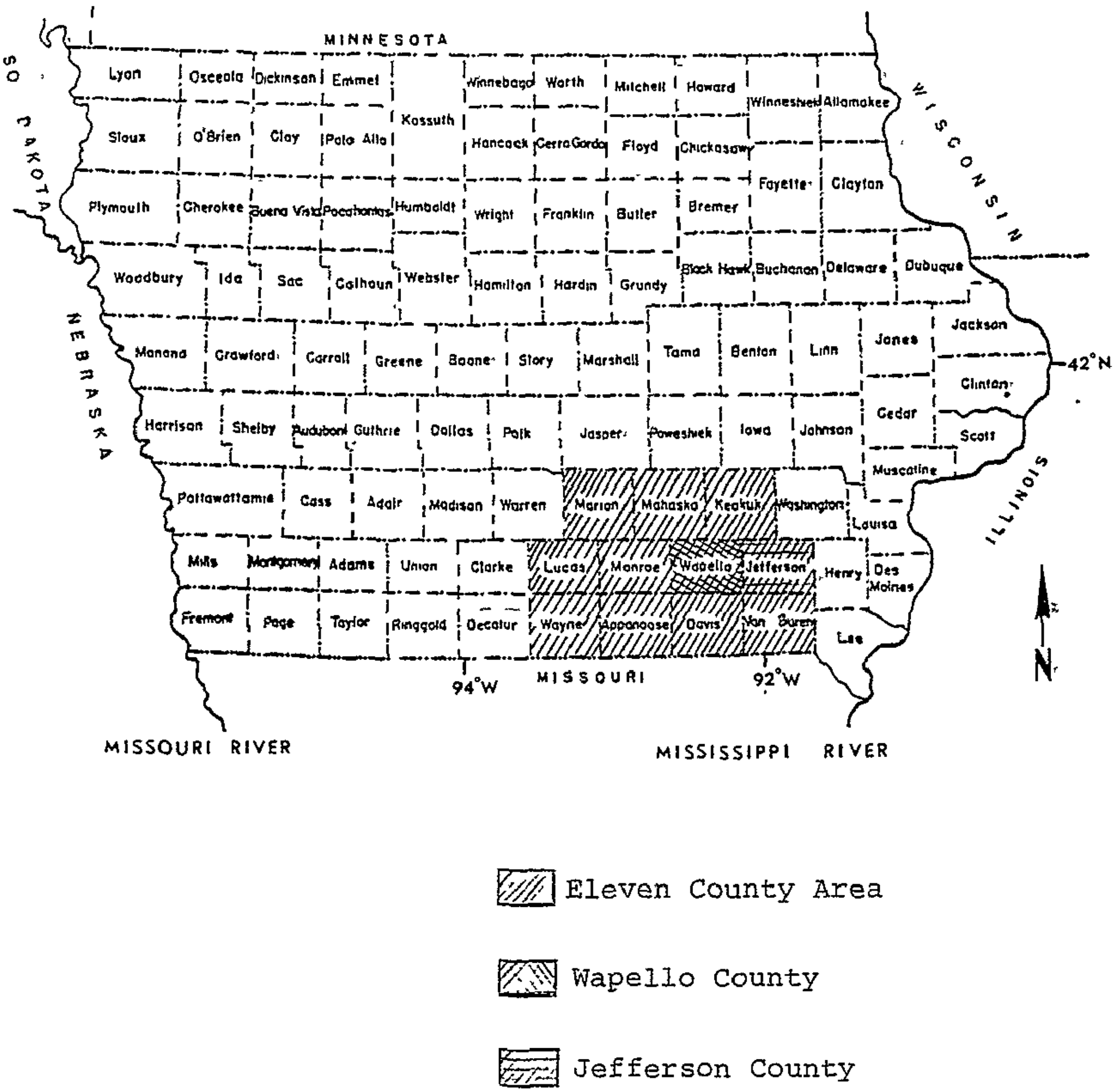
is basically rural covering an area roughly 154 kilometers east-west by 101 kilometers north-south for a total area of 15,504 square kilometers. The largest city, Ottumwa (approximately 30,000), is located in Wapello County. The counties in this region range in population from Wapello (42,149) to David (8,207). The total population of the project area is 180,177.

The eleven county region was chosen as a study area because it typifies many of the problems facing rural Iowa. Recently, the region has been losing population, its coal industry has been declining, and its rail network has been shrinking. These trends, combined with the fact that the region contains little of the highest quality Iowan agricultural land, have made these eleven counties some of the poorest in Iowa. The average family income in 1970 was $7,258 compared to the statewide average of $9,018. Hopes of reversing these negative trends may lie in the utilization of effective regional planning. Natural resource inventory provides the first step in the planning process.

Figure 1. Map of Iowa showing the eleven county area



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Within the eleven county region, two subareas were selected for detailed analysis. Wapello County was chosen to illustrate variations in image processing techniques because of great diversity in land cover types as related to regional geomorphology, in addition to possessing the largest urban center in the eleven county area. Jefferson County, located directly east of Wapello County, was selected to demonstrate the integration of traditional and satellite data for regional planning purposes. This locality was chosen because its physical setting is similar to that of Wapello County, yet this test site already possessed comprehensive conventional resource data that was compiled by the Area XV Regional Planning Commission under the direction of Bruce Bullamore. Discussion of the formation of a planning strategy for Jefferson County follows the examination of various image processing techniques utilized for the Wapello County Landsat subscene.

Wapello County was determined to be physically and culturally representative of the region. The county possesses a variety of surface topographies which, in turn, influence the area's land use activities. In the north-eastern portion of the county, flat lying, highly productive agricultural lands are found. The southwestern portion is an area of rolling hills with patches of forest land. The Des Moines River, which cuts diagonally across the county, acts as a rough dividing line for these topographic regions. A topographic map of Wapello County is shown on Figure 2. In addition

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Figure 2 near here.

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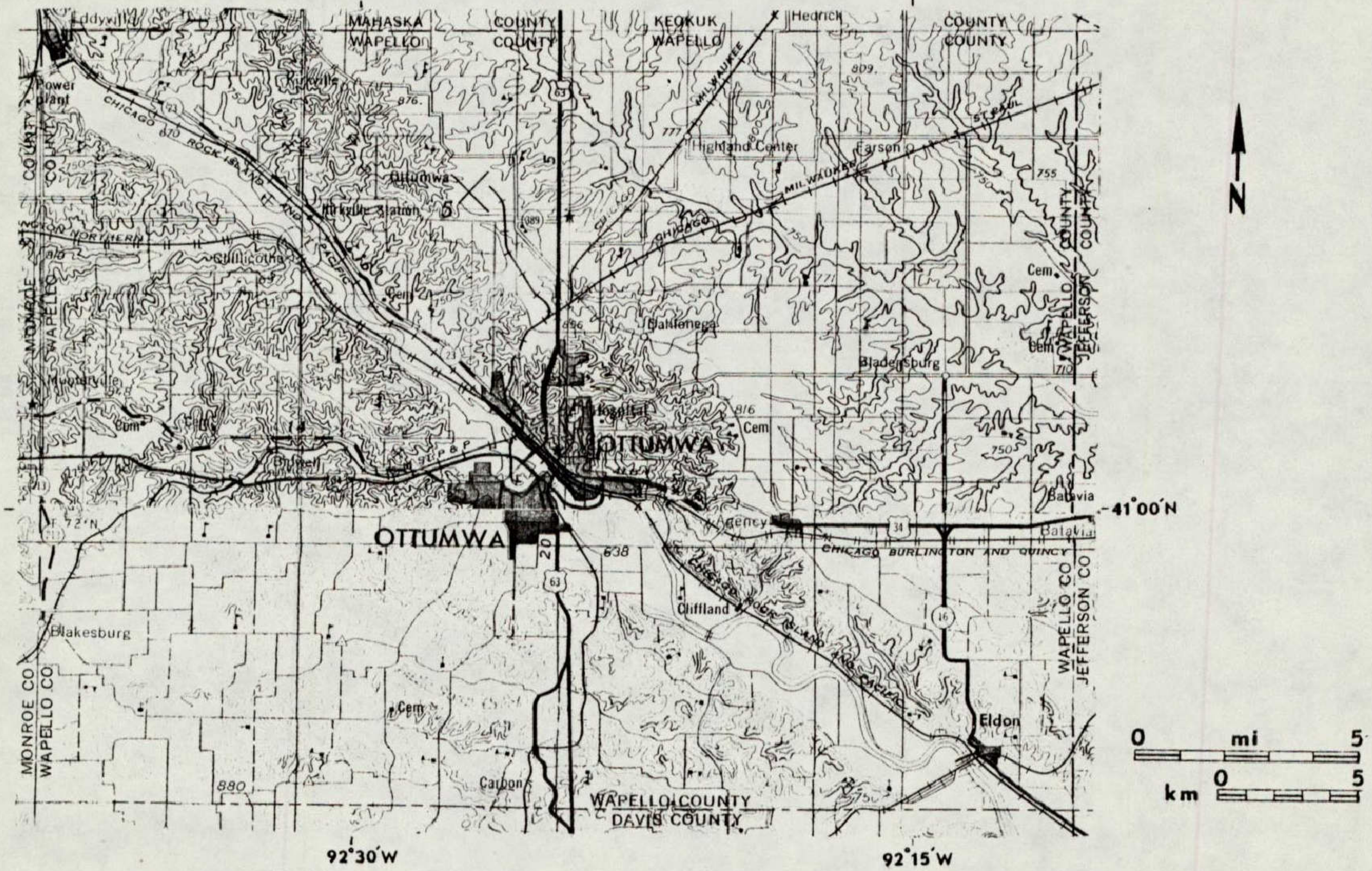
to its rural and agricultural base, Wapello County possesses the relatively large (by Iowa standards) urban area of Ottumwa.

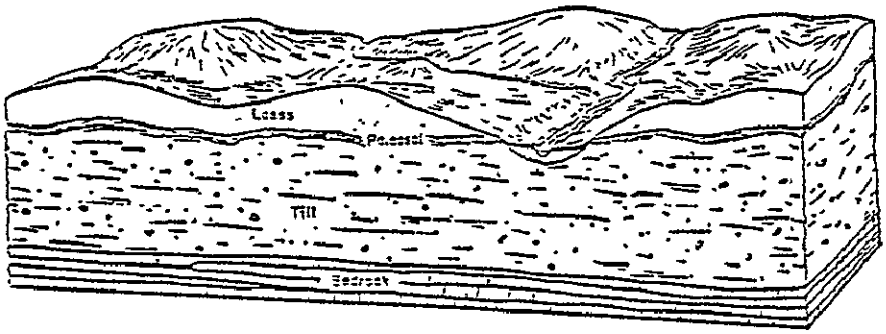
Figure 2. Topographic map of Wapello County, Iowa



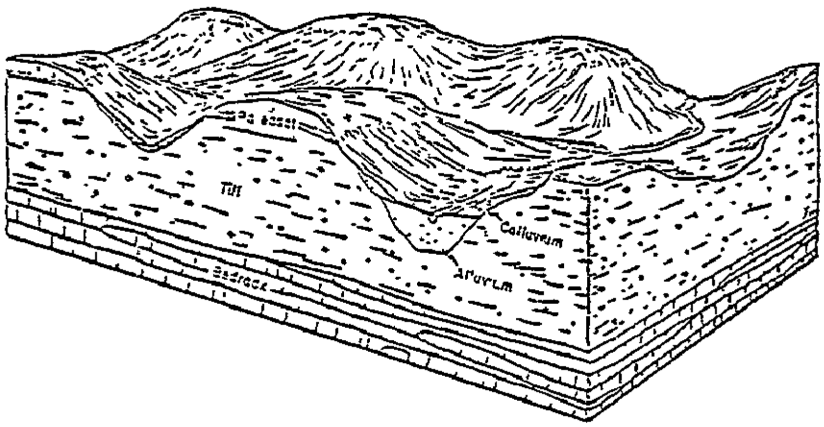
Map sources: USGS NK map series, Des Moines (NK-15-8) and Centerville (NK-15-11) quadrangles (scale 1:250,000; contour interval 20 feet).

Figure 3. Landscape models of south-central Iowa

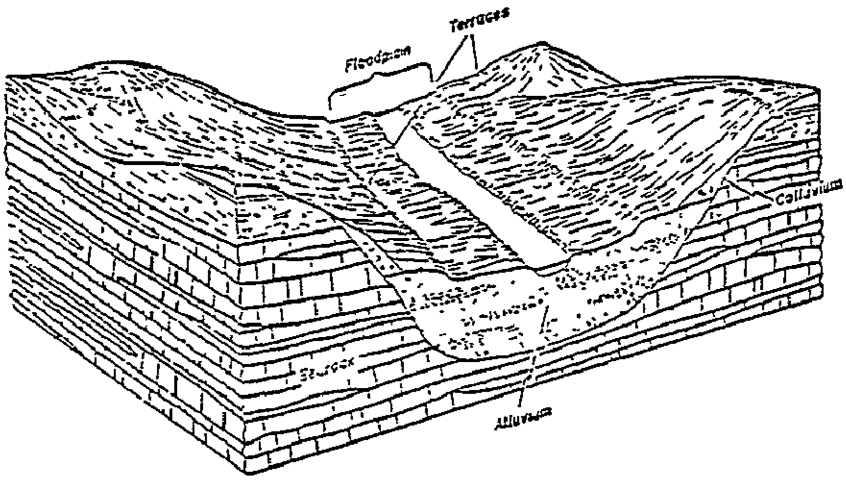
Model I--Loess Uplands



Model II--Hills of Glacial Till



Model III--Valley Complex



Source: Hoyer, B., et al., 1973, IGS Misc. Map Series #4.

Examples of the second geomorphic model are characterized by hills which are comprised of glacial till. Loess may cap the hills, but buried soils and glacial tills are exposed on the hillsides. Because the physical characteristics of the till make farm management difficult, these areas are less intensively cultivated. For this reason, stands of forest in addition to pasture land are frequently encountered in this geomorphic setting.

The third landscape model is the valley complex. The surficial deposits in the valley areas consist of slope wash deposits (colluvium) on the valley sides and alluvial materials (water-laid) on the floodplains. In some places, stream terraces are found on the valley sides, marking the extent of past floodplains before downcutting of the stream occurred. The materials in the valley complex range from clay to gravel in size. Minor valley streams interrupt the topography of the loess uplands area in northeastern Wapello County, while a major valley system is associated with the Des Moines River. This river valley has an extensive deposit of water-laid materials within its confines.

The soils and agricultural land use in Wapello County are closely related to the geomorphology of the area. In northeastern Wapello County, the relatively flat upland is somewhat poorly drained. In terms of the geomorphic models discussed previously, this area is termed loess uplands. Windblown silts, called loess, form the parent material for these highly productive soils. The area is well adapted for intensive farming of row crops, especially corn and soybeans. Fields in this area, commonly about 40 acres each, are generally square. Because of the relatively flat terrain, roads are spaced regularly on a one-mile grid pattern corresponding to the public land survey system. Several small upland areas of this type of landscape are also found in the southern and western portions of Wapello County. Stream development has slightly dissected these loess-mantled uplands. On the valley-side slopes, row crops (such as corn and soybeans) are often found, but pasture and cover crops (alfalfa, etc.) dominate.

Within the southwestern half of Wapello County is a hilly region less adapted to intensive agricultural use. This area is represented by the third geomorphic model--hills of glacial till--and is characterized by much pasture land, patchy woodland areas, and small irregularly-shaped fields. Small coal strip mines are common as well as one-acre or smaller farm ponds. The hilltops in this region are loess-mantled with underlying glacial till and associated paleosols exposed on the hillsides. This land is subject to severe erosion when over-grazed or farmed continually with row crops.

The Des Moines River Valley with its associated alluvial materials cuts diagonally across Wapello County. The bottomland areas are heavily cropped with corn and soybeans. The soils in this alluvial valley have a highly variable texture, ranging from sandy to clay rich.

The understanding of physical landscape characteristics (materials and topography which define landforms) gives insight into the type of land use activites and attendant land cover that predominate. For example, flat uplands provide prime agricultural land in south central Iowa and are consequently intensively farmed. Hillsides in this part of Iowa that possess heavy clay soils are most often used for cover crops, pasture, or forest land. Valley bottoms with varying materials also have variable land use activities. These land cover types and land uses can be generally delineated on both standard product and computer enhanced imagery. Enhancement of individual Landsat scenes may accentuate details relating to physical characterisitcs of an area, but more important is the choice of season in which the Landsat scene was recorded. General soil associations, for example, are best shown on springtime images. The extent of forest land in south central Iowa is most easily mapped on early fall images. Transportation networks which traverse the landscape are best displayed on late summer images.

IMAGE CHARACTERISTICS OF LAND COVER IN WAPELLO COUNTY

To test the effects of various image processing techniques on land classification analysis, an August 29, 1972 Landsat scene (1037-16213) was identified. This scene was one of the first cloud free satellite images taken over south central Iowa. In addition, the scene has also been utilized in previous land classification analyses conducted at the Iowa Geological Survey (Hoyer, et. al., 1973). A Jet Propulsion Laboratory computer enhanced false-color composite of the Wapello County subscene (1:250,000 scale) is displayed on Figure 4. A NASA high altitude color infrared

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Figure 4 near here.

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photograph taken August 6, 1971 is included for comparison (Figure 5). The print is at a larger scale (1:118,233) than

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Figure 5 near here.

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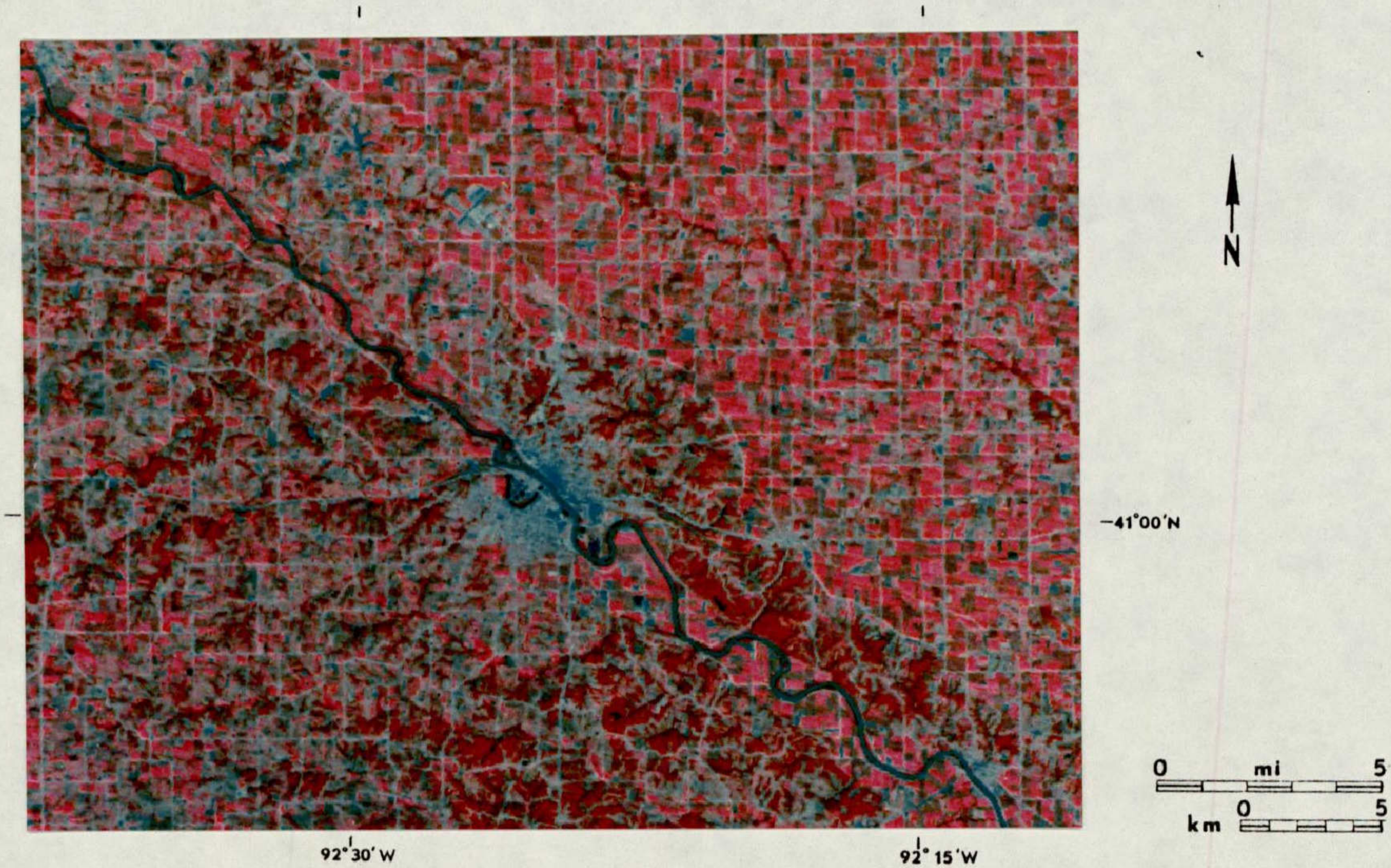
the Landsat subscene and covers only a portion of Wapello County.

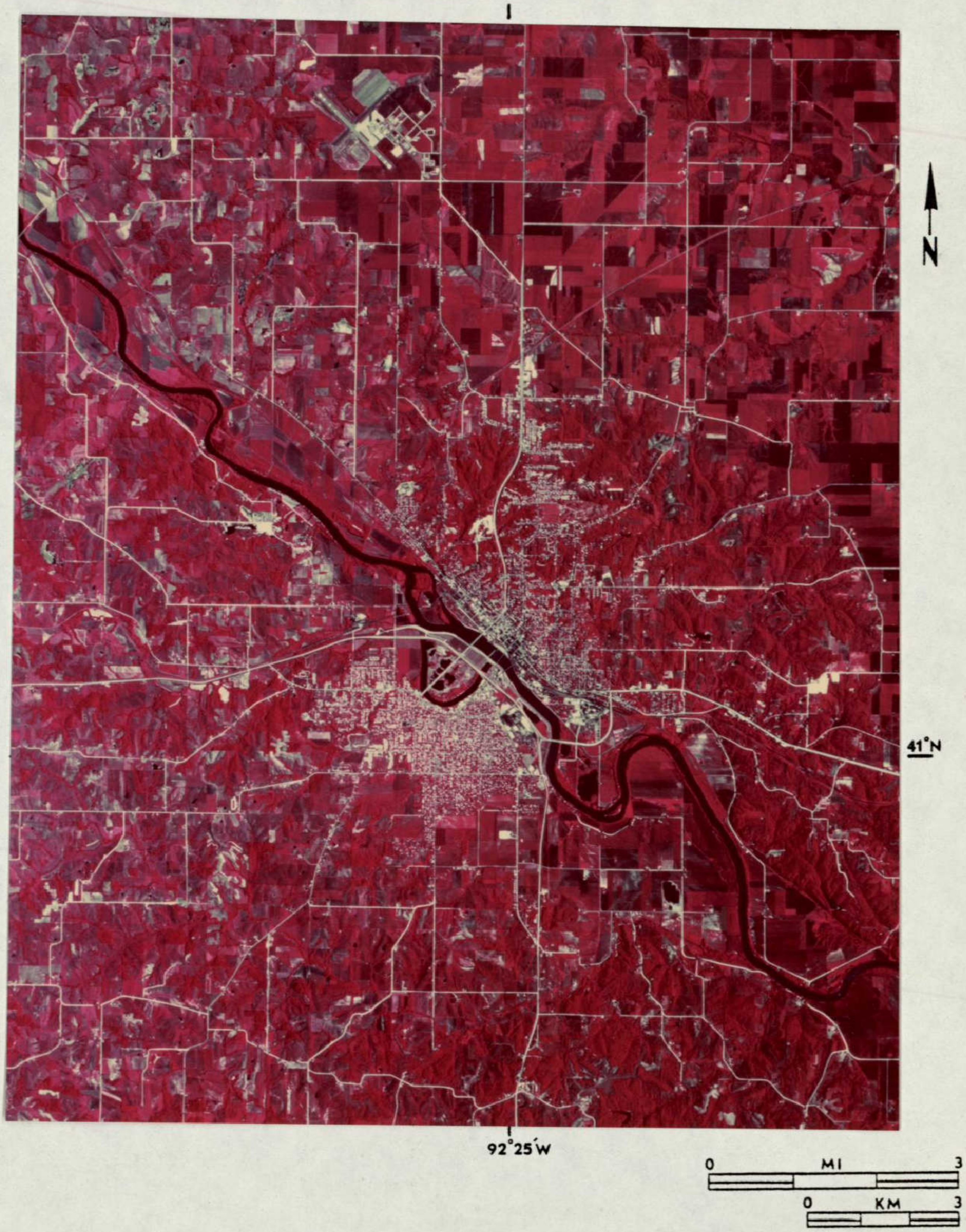
Figure 4. Landsat JPL computer enhanced false-color composite print produced from bands 4, 5, and 6 of the August 29, 1972 Wapello County subscene



Landsat image identification number: 1037-16213

Scale: 1:250,000

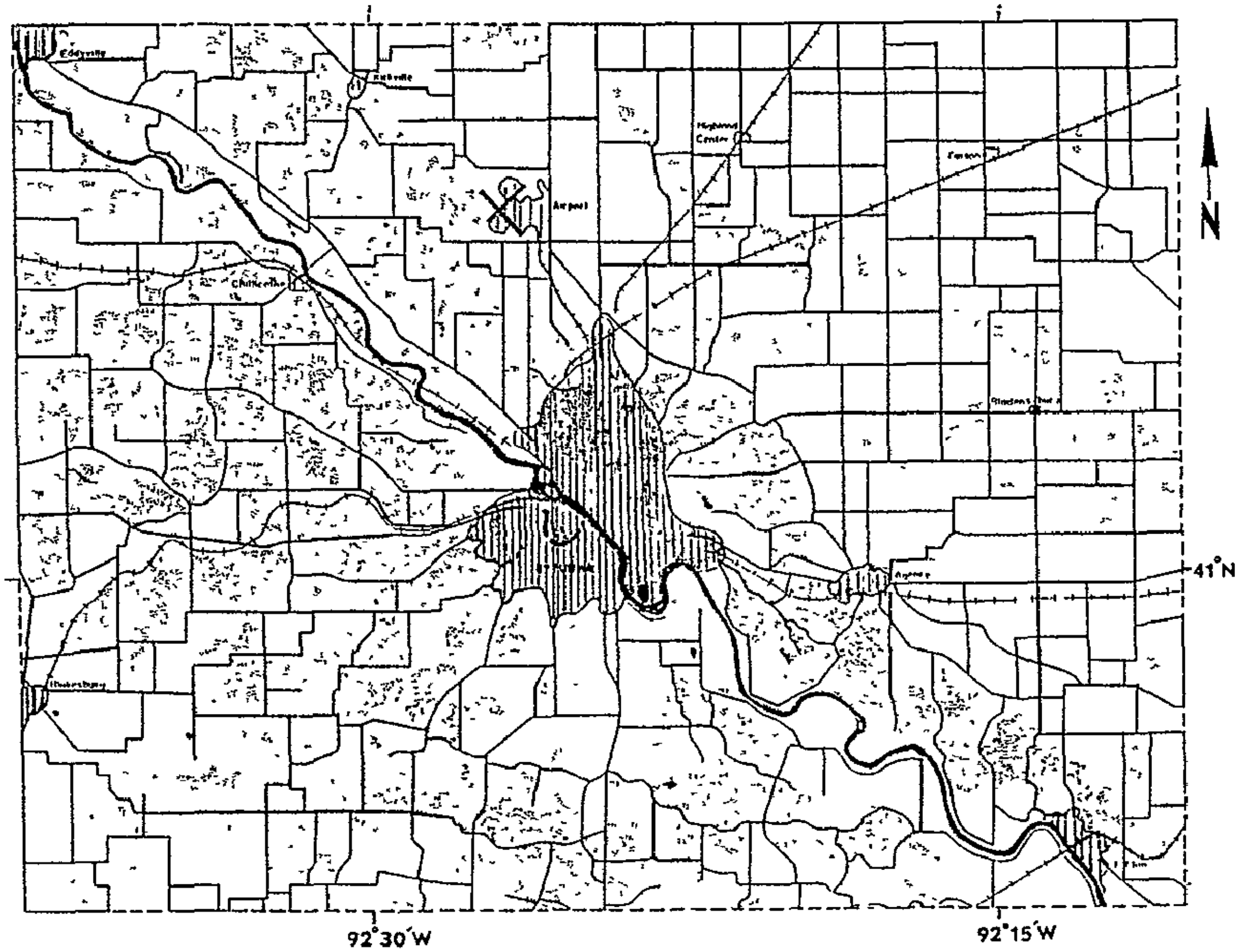
Figure 5. NASA high altitude color IR image centered over Ottumwa, Iowa. Scene taken on July 21, 1971.



Scene ID: 6173000806887

Scale: 1:118,233

Figure 6. Land use classification map of Wapello County compiled by conventional image analysis techniques from the August 29, 1972 JPL subscene shown on Figure 4. Interpretation made from a 1:125,000 scale false-color print produced from bands 4, 5, and 6.



Scale: approximately 1:250,000

0 mi 5
km 0 5

Urban   Roads   Railroads

Forest   Water

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Urban

The urban areas within the county, primarily the city of Ottumwa, have both high and low reflectances. On the false-color composite, urban areas usually have blue-green to bluish-white hues. The darker bluish colors within the Ottumwa area correspond to the commercial-industrial parts of the city where lower reflectance from asphalt and concrete dominates. Newer roofs are constructed from high-reflectance materials that appear bluish-white on the August scene. This combination of low and high reflectance land cover gives the commercial-industrial area a blue to bluish-white color on the August false-color composite. The lighter, varigated blue and red hues surrounding the business district of Ottumwa correspond to the urban-residential area. Vegetation associated with residential sections (lawns and trees) gives a slightly reddish color to these areas on the composite.

On the black and white bands for the August scene, the urban area shows high reflectance on both MSS bands 4 and 5. The image densities in these areas are consequently low. The infrared MSS bands show the urban areas to be poor reflectors of infrared radiation in comparison to the highly reflective summer vegetative cover. The image densities within these localities on MSS bands 6 and 7 are darker than on bands 4 and 5. When bands 4, 5, and 6 (or 7) are composited, the resulting color for the urban area is therefore predominantly blue-green to bluish-white.

Transportation networks

The JPL computer enhanced MSS bands 4 and 5 vividly display the road network in Wapello County. In August, a virtual canopy of vegetation exists across the county and is interrupted only by cultural developments such as towns, strip mines, and roads. The roads, however, are high reflectance features on the red and green spectral bands in contrast to the surrounding vegetative cover and are therefore easy to differentiate. On the MSS infrared bands 6 and 7, the extensive road networks could not be delineated. Roads appear bluish-white to white on a false-color composite. No distinction could be made between gravel, asphalt, or concrete surfaced roads in the county. Railroad lines, on the other hand, are more difficult to delineate as they are narrower and often lack high-reflectance roadbeds. Many of these right-of-ways are relatively old cultural features. Changes in shapes of agricultural fields along the lines usually make it possible to trace railroad routes across the landscape by noting these patterns. Identification of railroads is further facilitated because they differ from the road network as they do not generally follow the public land survey boundaries. Rail lines on the August composite vary between white and bluish-green and generally are less pronounced than roadways. In many places the railroad lines cannot be differentiated.

Forest land

The forest areas in Wapello County occur mostly in hill and valley areas that are usually not suitable for agricultural purposes. Forest lands appear dark on the JPL MSS bands 4 and 5. On the infrared bands, forested areas do not appear as dark as on the green and red spectral bands, but are darker in tone than the surrounding agricultural lands. Forest land on the JPL false-color composite appears dark red in color in contrast to the lighter hue of red that distinguishes vegetated agricultural lands. Although upland and bottomland forest species have not been mapped on Landsat imagery for the Wapello County area, it may be possible to subdivide the forest land category into these two groups because of color variations within the forest areas.

Water

The water bodies in Wapello County occur as river systems, the most prominent being the Des Moines River, as manmade farm ponds, or as water in abandoned strip mines and quarries. The spectral reflectance of these water bodies relates directly to the clarity of the water. On the JPL false-color composite, the Des Moines River, which is carrying sediment, has a bluish-green hue. The associated ox-bow lakes near Ottumwa, however, gave an almost black color due to the lack of sediment present in the water. A bluish-black color is also characteristic of most manmade ponds except when polluted or supporting abundant algae growths. On the August 29, 1972 Landsat scene, water bodies are most distinct on MSS bands 6 and 7 because of the contrast produced by the low infrared reflection of water as compared to the high infrared reflection from vegetation. On the JPL enhanced false-color print, ponds greater than five acres in size could be easily delineated. The numerous smaller ponds, ranging from one to two acres, could not be accurately mapped from the Landsat image because the multispectral scanner integrates reflectance over an area slightly greater than one acre. Reflectance from both water and the surrounding land cover are integrated by the scanner. The resulting colors of these ponds on the JPL print range from bluish-black to a blue-green that is similar in color to some agricultural fields. These smaller ponds are best mapped from higher resolution images.

Agricultural land use

Agricultural lands have highly variable surface reflectance due to great differences in vegetation types and degrees of vegetation maturity. Canopy reflectance is an integrated response of plant structure and soil background. Therefore, differentiation of crop types on Landsat imagery is highly dependent upon knowledge of seasonal crop variations. Factors affecting homogeneity within crop types include variations in soil moisture and soil type, disease infestation, and use of herbicides. Extensive field checking is essential for proper identification of agricultural land cover types on Landsat imagery. On the August computer enhanced JPL composite, agricultural land varies in color from red, pink, green, to bluish-green. On the black and white MSS bands, there is a great variety in tones. Many fields have high reflectance characteristics on bands 4 and 5 while on bands 6 and 7 these fields show a low reflectance. The resulting color of these fields are blue-green on the false color composite. Fields that have a low reflectance on bands 4 and 5 and have a high reflectance on bands 6 and 7 are characteristically red or pink in color, indicating flourishing vegetation. Other combinations in reflectance shown on the black and white bands for agricultural lands result in various other colors on the composite. Because of complexity of delineating specific cover types, the general classification of "agricultural land" was assigned to the previously unclassified areas in Wapello County, and includes both tilled fields as well as pasture land.

Land use and landscape models

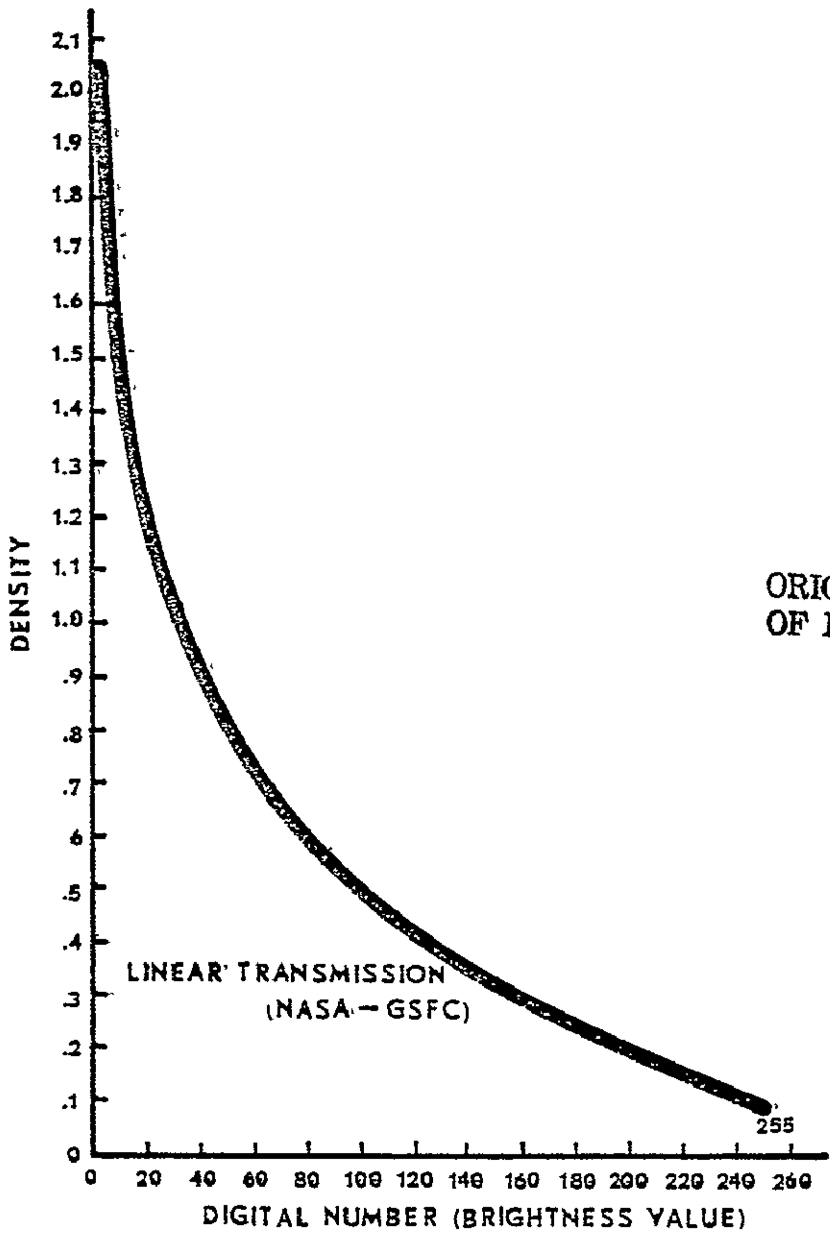
Prime agricultural lands in northeastern Wapello County occur mostly in the areas of loess uplands. Flat topography in this area favors large fields that are farmed by highly mechanized techniques. Regular road patterns are also indicators of the flat terrain. Hills of glacial till are characteristic of southwestern Wapello County. Forest land and agricultural land are both found in this area. Road patterns are irregular in comparison to those on the loess uplands. Valley complex areas are found in varying degrees in all parts of the county. Land uses for this landscape vary from forest to agriculture and pasture.

EROS DATA CENTER PROCESS FOR THE PRODUCTION OF LANDSAT STANDARD PRODUCT IMAGES

The standard Landsat images available from the EROS Data Center represent the lowest cost satellite products available to users. When digitally or photo-optically enhanced Landsat imagery is obtained, comparison to standard products is necessary to evaluate what has been gained through the enhancement process. For this reason, the elements of the existing data processing path for Landsat scenes are included for discussion. The first generation positive (P-1) is created at the Goddard Space Flight Center (GSFC) on the electron beam recorder (EBR). The brightness values (or digital numbers) modulate the EBR to expose the 70 mm recording film. The image data are recorded linearly with transmission over a density range of 2.0 on the recording film (Figure 7).

Figure 7 near here.

Figure 7. EBR film recording function of Goddard Space Flight Center



The production of Landsat standard products at the EROS Data Center begins with a second generation negative (N-2) which is received from the Goddard Space Flight Center. This N-2 is an unsprocketed 70 mm film, type SO-467, which has been processed to a system gamma of 1.0. From the N-2, a 70 mm third generation positive (P-3) is contact printed on Kodak film type 2421. This P-3 is often referred to as a UVP-3 because the tungsten printing lights used to produce the P-3 are filtered through a Corning 5970 glass filter. This filter is highly transparent to ultraviolet light while almost entirely blocking visible light. The use of the Corning filter reduces the loss of sharpness in contours between high and low densities, termed halation, which is a problem associated with the large density ranges in Landsat negatives. This filter is very effective when used for contact printing, but is very inefficient for optical printing. The P-3 is processed to a 1.0 system gamma in a Model 11CM Versamat with MX-885 developer at 85°F (29.4°C).

The 9.5 inch (241 mm) fourth generation negative (N-4) is printed from the 70 mm P-3. Tests have shown that the halation introduced by enlargement can be best controlled when the enlargements are made from a positive rather than a negative. For this reason, the 70 mm P-3 is printed to a 9.5 inch (241 mm) N-4 on an enlarger with a fixed magnification of 3.369 which results in an image scale of 1:1,000,000. The N-4 exposure is determined using a density analyzer with a light integrating head which measures the integrated scene density of the P-3 image of band 5. The objective of this step in the composite production is to prepare an N-4 from a P-3 which will have an average density near 1.0 density units. Exposure adjustments are made for only band 5. Bands 4, 5, and 7 of the same scene are printed with the same exposure as band 5. The N-4 enlargement is printed on Kodak 2421 film and is processed in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).

The 9.5 inch (241 mm) N-4 is roll-to-roll contact printed on a modified Colorado printer to produce a 9.5 inch (241 mm) fifth generation positive transparency (P-5). A Corning 5970 filter is also used to reduce the halation on the P-5 (or UVP-5) transparency. The P-5 film is Kodak type 2421 and is processed in a 11CM Versamat with MX-885 developer at 85°F (29.4°C). A system gamma of 1.5 is achieved for the fifth generation positive. Increased contrast of the P-5 enhances both the color contrast and color saturation on false-color film positives and false-color prints.

Before a color composite can be printed, the positive transparencies must be registered as a set by using the tick marks in the four corners on each Landsat image. Only bands 4, 5, and 7 are used for making a standard false-color composite; band 6 is not registered. The equipment required for registering transparencies consists of a light table, registration punch, and magnifying eyepiece. One P-5 transparency, usually band 4, is taped to the light box with the emulsion side down. A second P-5 transparency is placed over the taped image and is aligned with the diagonal tick marks by using the magnifying eyepiece. The second transparency is then taped into position and both transparencies are simultaneously punched. After the second transparency is unfastened and removed, the third transparency is placed over the first, aligned, and punched. The registration of the transparencies is checked by mounting the punched images on registration pins and viewing the aligned scenes over a light table.

The printing of the P-5 black and white transparencies onto color film to produce a false-color composite utilizes a vacuum easel with registration pins mounted on the bed, a point light source with a filter wheel, three primary filters and a filter selector, a timer for the light source, and a registration punch for the color film. Before the color composite printing is executed, however, the enlarger light source is calibrated for color balance. To do this, a test exposure is made through each filter to a neutral step tablet on the color film. The three filters used in the production of the color composite are adjusted with neutral density filters until equal exposure produces neutral densities near the 1.0 step on the color film. When using a 21 step gray scale, the eighth step of increasing density (about 1.06 density units) is used to check the color balance.

To determine the exposures for each band to be used in printing the false-color composite, the input densities from the P-5 transparencies are read by a transmission densitometer from the step annotation gray scale nearest (but not exceeding) the 1.0 density step. These density values, from bands 4, 5, and 7, are used to adjust the exposures so a neutral density of about 1.0 will be reproduced on the color transparency. The actual adjustments in printing times for each band, however, are determined by a density/exposure chart. By making the annotation scale neutral at the 1.0 step, the relationships of the image densities of bands 4, 5, and 7 are retained, thereby ensuring that the same general color is always reproduced without the need for subjective visual evaluation. The variations in the relative densities of the black and white transparencies are also partially corrected by this process.

Once the exposures and color balance have been determined, the color film positive (CFP-6) can be printed. This process begins with the previously registered and punched band 7 placed over a sheet of unexposed Kodak Aerochrome color reversal film type 2447. The film and transparency are exposed for a predetermined time to red light through a Wratten #29 red filter. Band 7 (infrared spectral band) is removed from the easel and replaced by band 5 (red spectral band) which is then registered and exposed to green light through a Wratten #58 green filter. Band 5 is then removed and replaced by band 4 (green spectral band), which is registered and exposed to blue light through a Wratten #47 blue filter. When this procedure is completed, the exposed 2447 film is processed in a Versamat model 1811 with EA-5 chemistry to form a sixth generation film-positive color transparency.

The CFP-6 is first inspected and then entered into the data base file at the EROS Data Center. Color standard product (CSP-7) film copies of this composite are produced by contact printing the CFP-6 on a modified Mark II printer using Kodak 2447 color-reversal film. Before printing, however, the light source is color balanced by test printing, developing, and evaluating a 21 step tablet to ensure that all densities on the wedge have as neutral a gray tone as possible. The exposure for the color transparency is determined by measuring the integrated scene density of the composite. After printing, the CSP-7 is processed in a Versamat model 1811 with EA-5 chemistry to form a film positive color transparency.

Paper prints at 1:1,000,000 scale are contact printed from the CFP-6 transparency. Color balancing of the light source is accomplished by test printing and processing a 21 step tablet. Exposure is determined from the integrated scene density of the color composite. The color reversal paper used for printing is Kodak 2212 which is processed in a color Simplex processor with R-5 chemistry.

A summary of the EDC process for producing Landsat color composites is found on Table 1. The false-color

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Table 1 near here.

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composite print (CSP-7) of the Landsat-1, August 29, 1972 subscene is displayed on Figure 8.

Figure 8 near here.

PHOTO-OPTICAL ENHANCEMENT PROCESS FOR LANDSAT COLOR COMPOSITES

To provide better color saturation and color contrast, a photo-optical enhancement (POE) procedure has been experimentally introduced for the August 29, 1972 Landsat-1 scene. This work has been conducted at the EROS Data Center by Darrell C. Ramerth under the supervision of Richard L. Nelson, Assistant Supervisor of the EDC Custom Color Laboratory.

Table 1. EROS Data Center process for the production of Landsat standard product color composites[1]

Step #	Film Production Generation	
1	N-2 70 mm	The N-2 is furnished by the Goddard Space Flight Center. It is a contact print made from the first generation positive (P-1) produced on the Electron Beam Recorder. The N-2 is an unsprocketed 70 mm film, type SO-467, which has been processed to a system gamma of 1.0.
2		The N-2 is contact printed on Kodak 2421 film using a Corning 5970 filter which is transparent to ultraviolet light to produce the third generation positive (P-3).
3	P-3 or UVP-3 70 mm	The P-3 is processed to a system gamma of 1.0 in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).

Table 1. EROS Data Center process for the production of Landsat standard product color composites--Continued

Step #	Film Production Generation	
4		The P-3 is printed on Kodak 2421 film at a fixed enlargement scale of 3.369 to produce a 9.5 inch fourth generation negative (N-4). The exposure for the N-4 is determined by taking an integrated scene density of band 5.
5	N-4 9.5 inch (241 mm)	The N-4 is processed to a system gamma of <u>1.0</u> in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).
6		The N-4 is contact printed on Kodak 2421 film using a Corning 5970 filter to produce a fifth generation positive (P-5).
7	P-5 or UVP-5 9.5 inch (241 mm)	The P-5 is processed to a system gamma of <u>1.5</u> in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).

Table 1. EROS Data Center process for the production of Landsat standard product color composites--Continued

Step #	Film Production Generation	
8		Bands 4, 5, and 7 of the P-5's are registered, punched, and contact printed on Kodak Aerochrome 2447 to produce a color film positive (CFP-6)-/. The multiple exposures for the composite are calculated from the annotation grey scale of each band so the 1.0 step will be neutral.
9	CFP-6 9.5 inch (241 mm)	The CFP-6 is processed in a Versamat 1811 with EA-5 chemistry.
10		The CFP-6 is entered into the EDC data base file to act as the master from which the standard product color transparency and color paper products are printed.

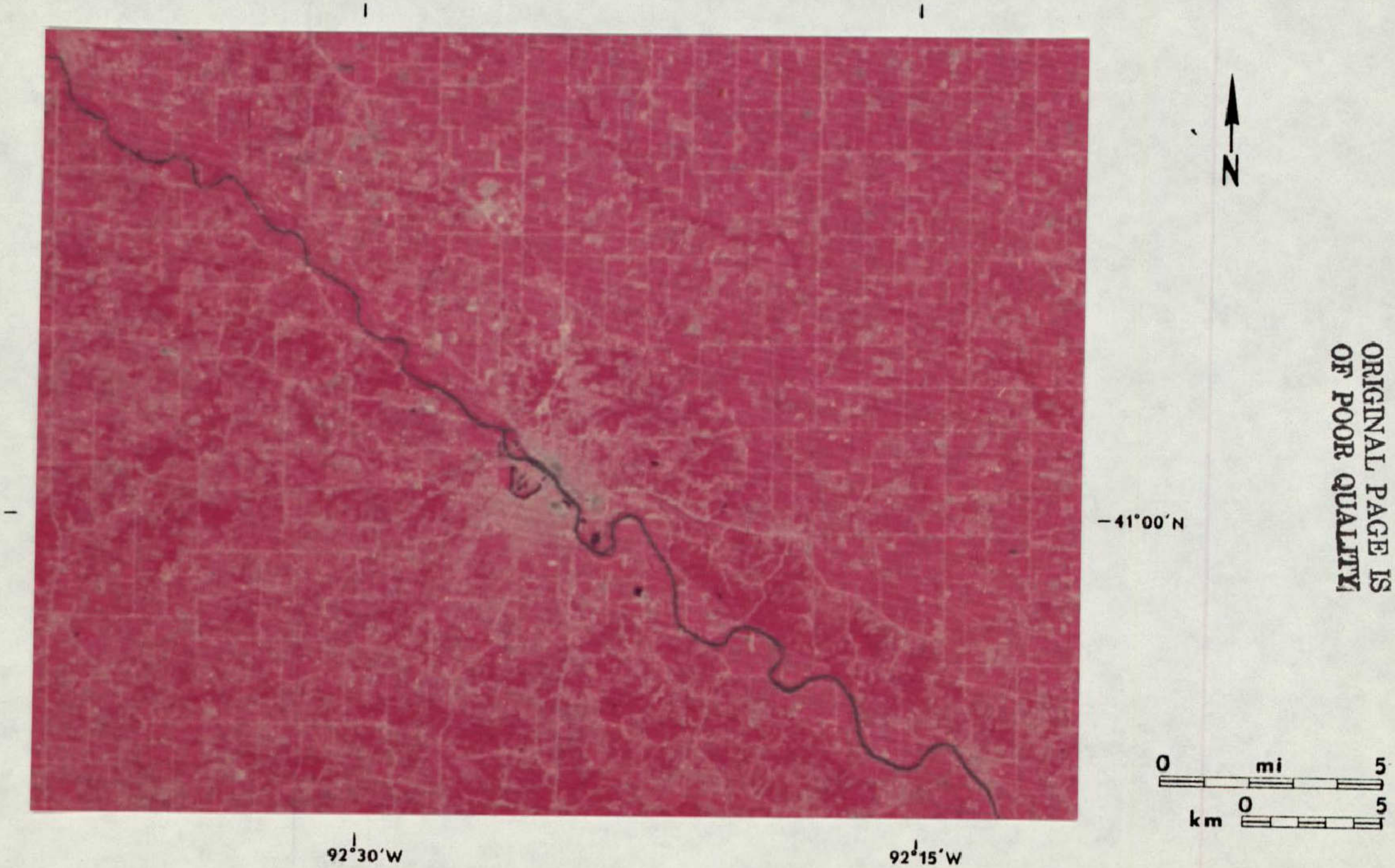
Table 1. EROS Data Center process for the production of Landsat standard product color composites--Continued

Step #	Film Production Generation	
11	CSP-7 9.5 inch (241 mm)	The color standard products (CSP-7) are contact printed from the CFP-6 on Kodak 2447 film and 2212 paper. The Kodak color reversal film is processed in a 1811 Versamat with EA-5 chemistry. The 2212 color reversal paper is processed in a Simplex Color Processor with R-5 chemistry.

_/ The data for this figure were extracted in part from the "Production Procedures for Preparation of Landsat Color Products," EROS Data Center, Sioux Falls, South Dakota, April 28, 1977. This reference is an EDC interoffice memorandum written by Keith Maas of Technicolor Graphic Services, Inc.

_/ Cibachrome Type D (CCT-D661) color reversal film processed with a modified P-10 process in an Autopan color automat may be substituted at a future date in place of Kodak 2447.

Figure 8. Landsat standard product (CSP-7) of the August 29, 1972 Wapello County subscene



Landsat image identification number: 1037-16213

Scale: 1:250,000

upper density ranges for the bands before they were contact printed on the film. The amount of flash exposure for band 5 was determined from the POE P-5 (band 5) average scene density (ASD = $D_{min.} + D_{max.} / 2$) which was input to the exposure calculation to produce a 1.0 ± 0.20 ASD on the POE P-6. For band 7, however, the average scene density was determined for areas containing no water. This strategy was followed for band 7 because image densities associated with water are very high in comparison to other scene densities. Table 2 lists the POE scene output densities

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Table 2 near here

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for the August 29, 1972 scene. For band 7, two $D_{max.}$ values are listed--one value for areas excluding water bodies and one for water bodies. The average scene density for the POE P-5 band 7 excluding water is 0.54, while the ASD including water is 1.26. If the 1.26 ASD is used to produce a 1.0 ASD on the P-6, the land areas would possess a much lower contrast than if the 0.54 ASD is used. Because this contract's objective is land classification in Iowa, the subtle density variations in water bodies are not critical. For this reason, the lower average scene density was used as the input to the P-6. To produce the optimal scene contrast results, band 5 had a gamma of 1.1 and band 7 had

Table 2_/. POE scene output densities for the P-3, P-5, and P-6 film positives of the August 29, 1972 scene (1037-16213)

Band	P-3 Scene Output Densities		P-5 Scene Output Densities		P-6 Scene Output Densities	
	$D_{min.}$	$D_{max.}$	$D_{min.}$	$D_{max.}$	$D_{min.}$	$D_{max.}$
4	0.59	0.71	0.65	0.90	0.30	0.97
5	0.67	1.01	0.83	1.65	0.48	1.30
7	0.43	0.56	0.45	0.62	0.45	1.40
		1.22 (water)		2.07 (water)		3.20 (water)

_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

a gamma of 2.5 on the SS-7 film. Tone reproduction curves for this film have been generated from a calibrated step wedge for each band of the POE P-6 (Figure 9). The

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Figure 9 near here.

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exposure aim point of the P-6 bands was a $D_{min.}$ of 0.40 ± 0.10. The Kodak SS-7 film used in this enhancement step was processed in a Kodak 242 film processor using Kodak Supermatic developer.

Densities from calibrated step tablet

Band 4

Gamma approx. = 6.8

Band 5

Flash exposed before contact printing.

Gamma approx. = 1.1

Band 7

Flash exposed before contact printing.

Gamma approx. = 2.5

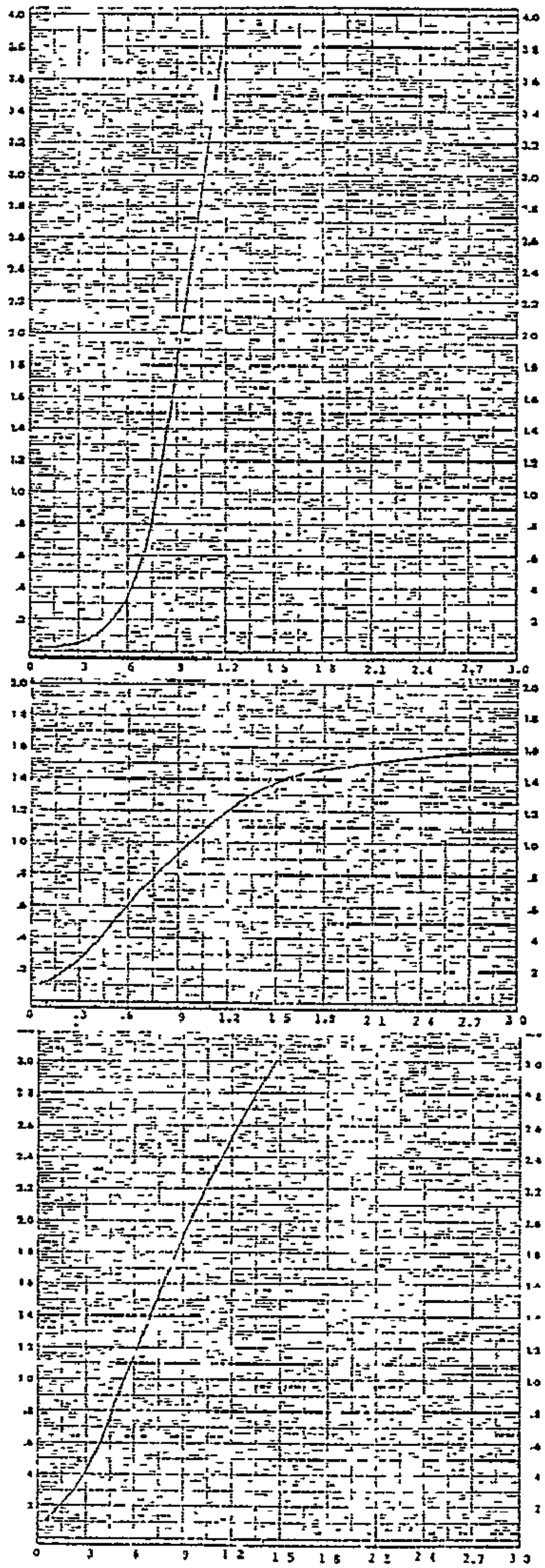

Figure 9. Tone reproduction curves for POE (P-6) Kodak SS-7 film for bands 4, 5, and 7 of the August 29, 1972 scene (1037-16213)

A summary of the exposure strategy for the POE P-6 Kodak Super Speed-7 film is listed below:

1. The $D_{min.}$ aim point for all bands was 0.40 ± 0.10.

2. The $D_{max.}$ aim point was limited to 1.60 ± 0.20. These $D_{min.}$ and $D_{max.}$ aim points are within the densities that can be recorded on the color film and color paper products used at EDC. In addition, these aim points provide optimal color saturation.

3. Band 4 P-6 film was processed to produce the maximum scene output density range on the SS-7 film.

4. Band 5 was flash exposed based on the POE P-5 average scene density to produce an ASD of 1.0 ± 0.20 on the POE P-6.

5. Band 7 was flash exposed based on the POE P-5 ASD (excluding water) to produce an ASD of 1.00 ± 0.20 on the POE P-6.

Bands 4, 5, and 7 of the POE P-6 generation were registered, punched, and contact printed on Kodak Aerochrome 2447 film. The exposures used to print the POE color composite were determined from the average scene densities for the individual bands. The enhanced color film positive (ECFP-7) was processed in a Versamat 1811 with EA-5 chemistry. Tone reproduction curves for both the standard product and POE color composite emulsion layers are shown on Figure 10 (data on Table 3) and Figure 11 (data on Table 4). Enhanced false-color paper products (ECP-8) were

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Figure 10, Table 3, Figure 11, and Table 4 near here.

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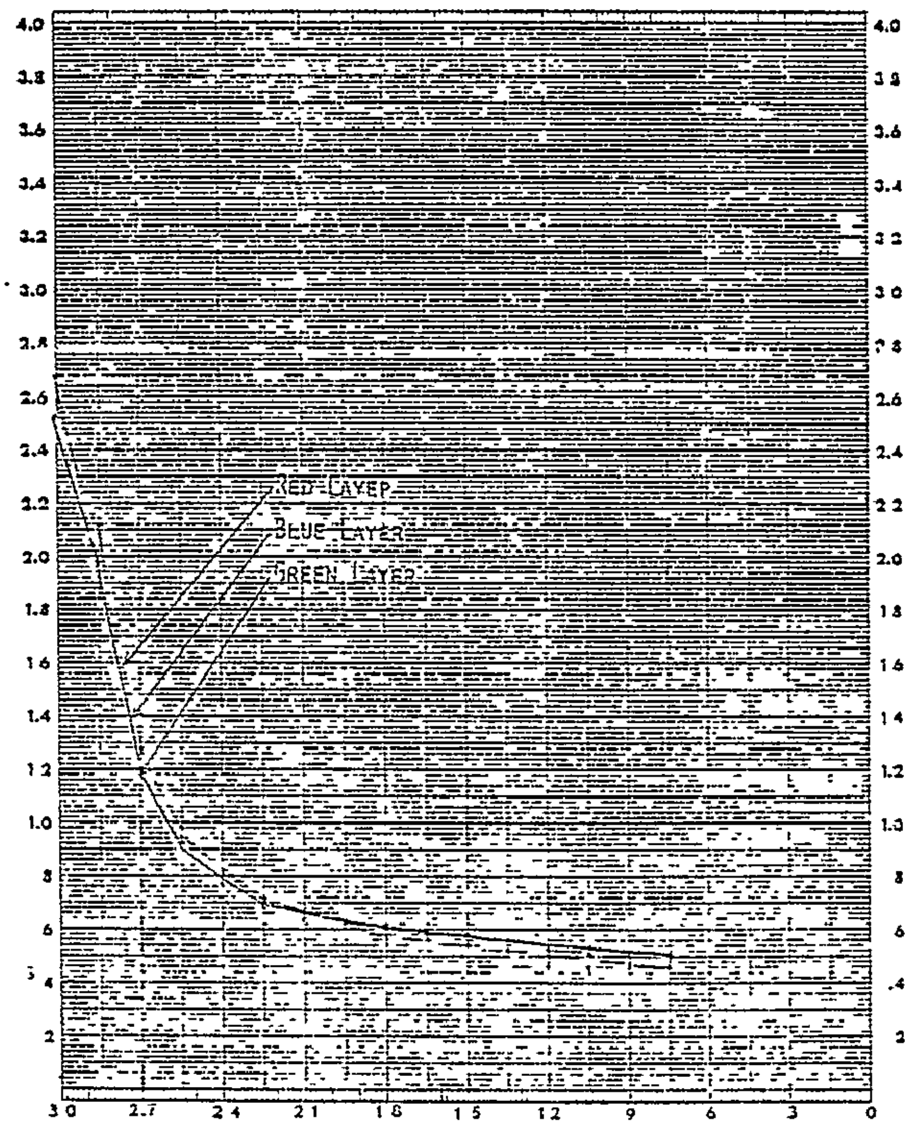
printed from the composite on Kodak 2212 color reversal paper and processed in a color Simplex processor.

C-2

Figure 10-/. Tone reproduction curves for the standard product color composite transparency for the August 29, 1972 scene (1037-16213)



_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

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Table 3[1]. Optical transmission density readings for the calibrated step wedge of the August 29, 1972 standard product color composite (1037-16213)

Step #	Green Filter	Blue Filter	Red Filter
1	2.67	2.52	2.59
2	1.98	1.99	2.11
3	1.19	1.20	1.27
4	0.94	0.92	0.98
5	0.80	0.77	0.81
6	0.71	0.69	0.72
7	0.66	0.66	0.66
8	0.62	0.63	0.62
9	0.60	0.62	0.59
10	0.58	0.59	0.56
11	0.56	0.58	0.54
12	0.53	0.56	0.52
13	0.50	0.53	0.47
14	0.50	0.53	0.47
15	0.50	0.53	0.47

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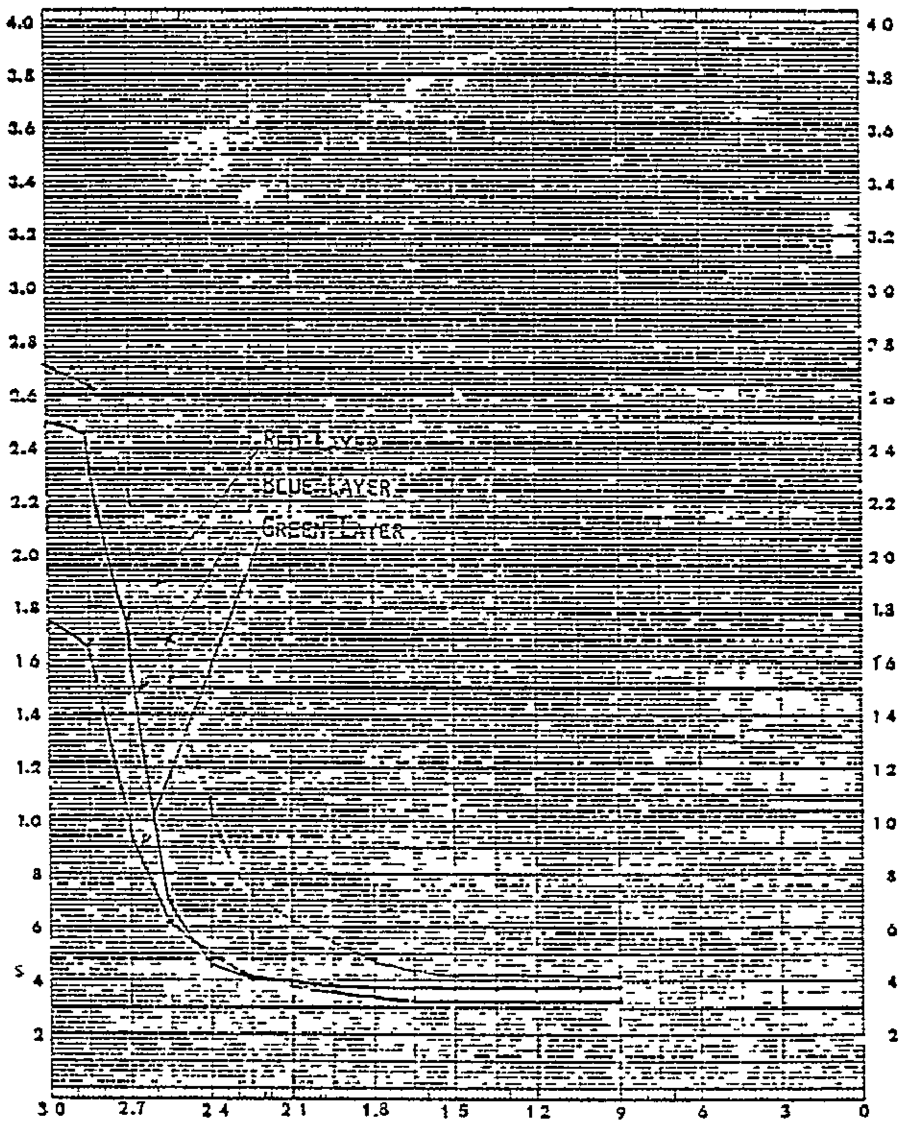
[1] Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 11-/. Tone reproduction curves for the POE color composite transparency of the August 29, 1972 scene (1037-16213)



_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Table 4-/. Optical transmission density readings for the calibrated step wedge of the August 29, 1972 photo-optically enhanced color composite (1037-16213)

Step #	Green Filter	Blue Filter	Red Filter
1	1.74	2.49	2.69
2	1.67	2.47	2.66
3	0.96	1.77	2.19
4	0.62	0.68	1.54
5	0.49	0.45	1.09
6	0.41	0.40	0.75
7	0.38	0.39	0.62
8	0.36	0.38	0.54
9	0.34	0.37	0.48
10	0.33	0.37	0.43
11	0.32	0.37	0.42
12	0.32	0.37	0.42
13	0.32	0.37	0.42
14	0.32	0.37	0.42
15	0.32	0.37	0.42

_/ Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

A summary diagram outlining the EDC photo-optical enhancement process for Landsat false-color composites is found in Table 5. The POE color composite print of the

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Table 5 near here.

Wapello County subscene is displayed on Figure 12. When

Figure 12 near here.

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compared to the standard product false-color composite print (Figure 7), the enhanced color contrast and better color saturation of the POE image are evident.

Table 5. EROS Data Center photo-optically enhanced color composite process for Landsat images

Procedure Step	Film Production Generation	
1 through 4		These steps are the same as those used to produce the EDC standard Landsat color composite.
5	N-4 9.5 inch (241 mm)	The N-4 is processed to a system gamma of <u>1.5</u> in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).
6		The N-4 is contact printed on Kodak 2421 using a Corning 5970 filter which is transparent to ultraviolet light to produce the P-5.
7	P-5 or UVP-5 9.5 inch (241 mm)	The P-5 is processed to a system gamma of <u>1.5</u> in a 11CM Versamat with MX-885 developer at 85°F (29.4°C).

Table 5. EROS Data Center photo-optically enhanced color composite process for Landsat images--Continued

Procedure Step	Film Production Generation	
8		The P-5 is contact printed onto a direct positive super speed graphic arts film (Kodak type SS-7) to produce the P-6. Band 4 is contact printed directly on the SS-7 film using an exposure calculated to give a $D_{min.}$ aim point of 0.4 $\pm$ 0.10 on the P-6. Bands 7 and 5 requires that the SS-7 film be flash exposed to burn off high densities (see Table 5). The P-5 transparencies are then printed using an exposure to give a 1.0 ASD on the P-6.

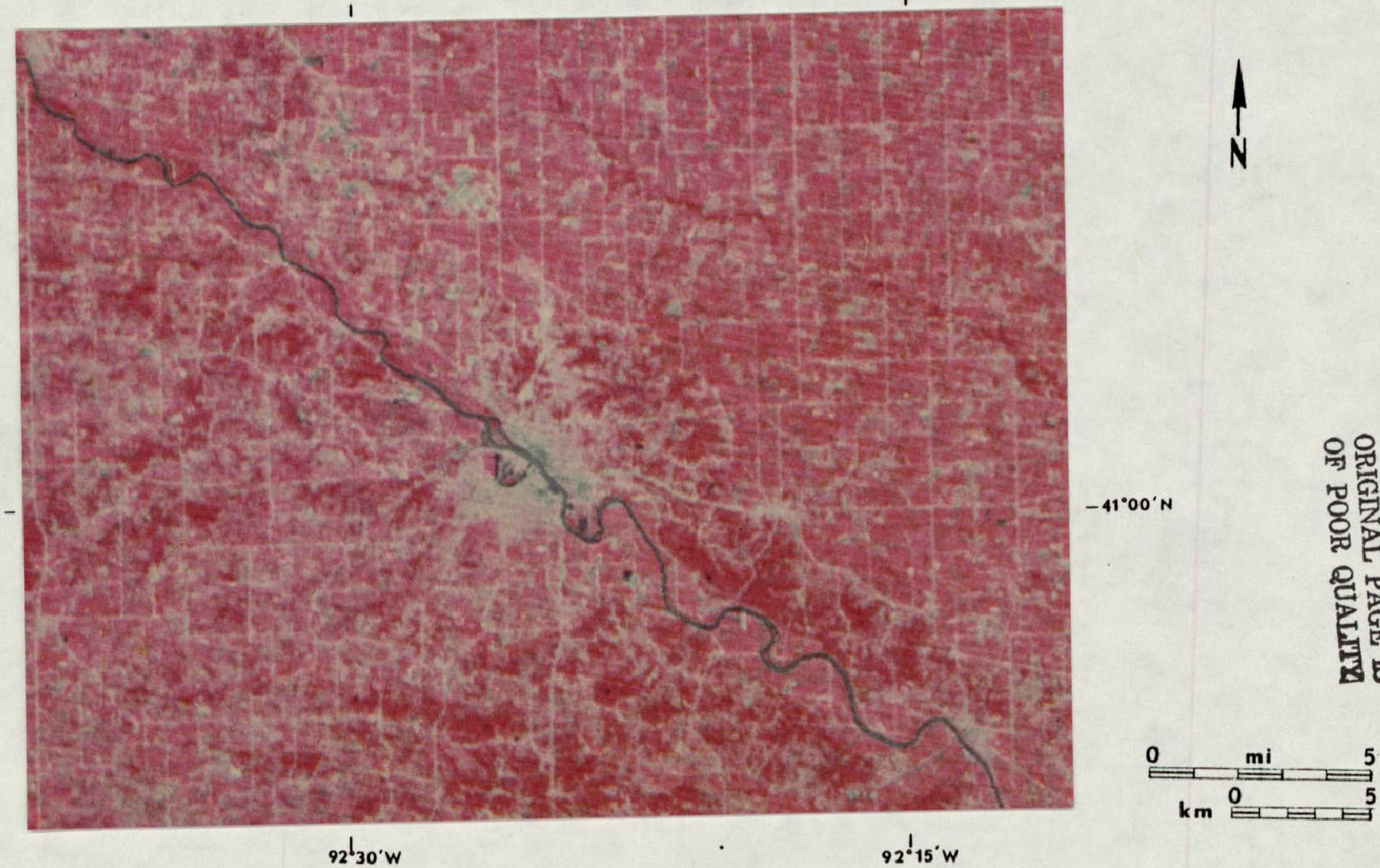
Table 5. EROS Data Center photo-optically enhanced color composite process for Landsat images--Continued

Procedure Step	Film Production Generation	
9	P-6 9.5 inch (241 mm)	The P-6 film is processed in a Kodak 242 film processor with Kodak Supermatic developer. The system gammas for the P-6 bands vary with the input densities and exposure: band 4's gamma--6.8; band 5's gamma--1.1; band 7's gamma--2.5.
10		Bands 4, 5, and 7 of the P-6's are registered, punched, and contact printed on Kodak Aerochrome 2447 using multiple exposures calculated from the average scene density to produce the enhanced color film positive (ECFP-7).

Table 5. EROS Data Center photo-optically enhanced color composite process for Landsat images--Continued

Procedure Step	Film Production Generation	
11	ECFP-7 9.5 inch (241 mm)	The enhanced color film positive (ECFP-7) is processed in a Versamat 1811 with EA-5 chemistry.
12		The ECFP-7 is printed on Kodak 2212 color reversal paper to produce the enhanced color paper product (ECPP-8). The exposure for the color print is determined from the ECFP-7 integrated scene density.
13	ECPP-8 9.5 inch (241 mm)	The enhanced color paper product (ECPP-8) is processed in a Simplex Color Processor.

Figure 12. Photo-optically enhanced false-color print (ECPP-8) of the August 29, 1972 Wapello County subscene



Landsat image identification number: 1037-16213

Scale: 1:250,000

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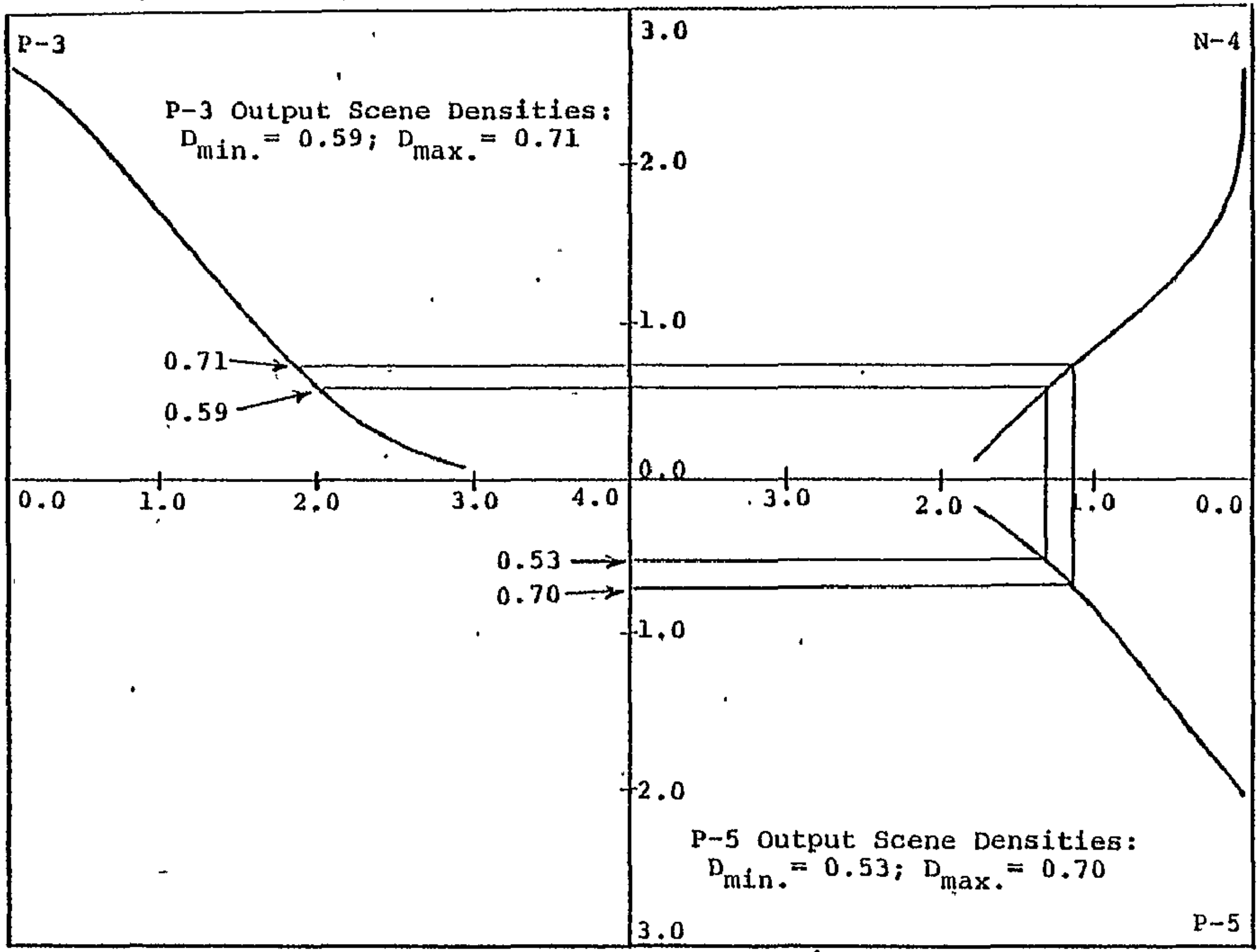
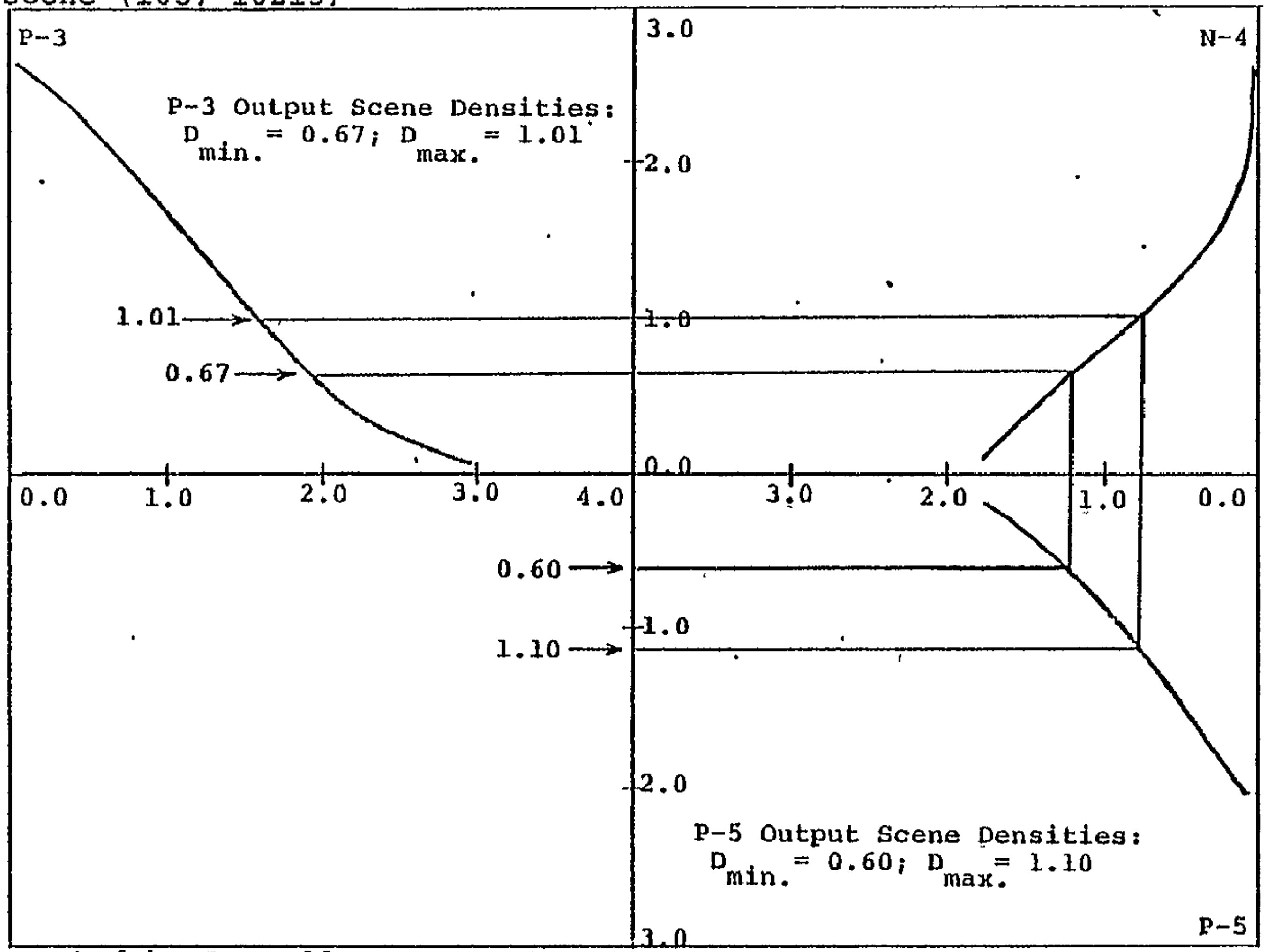
Figure 13-/. Tone reproduction diagram for band 4 of the standard product August 29, 1972 scene (1037-16213)



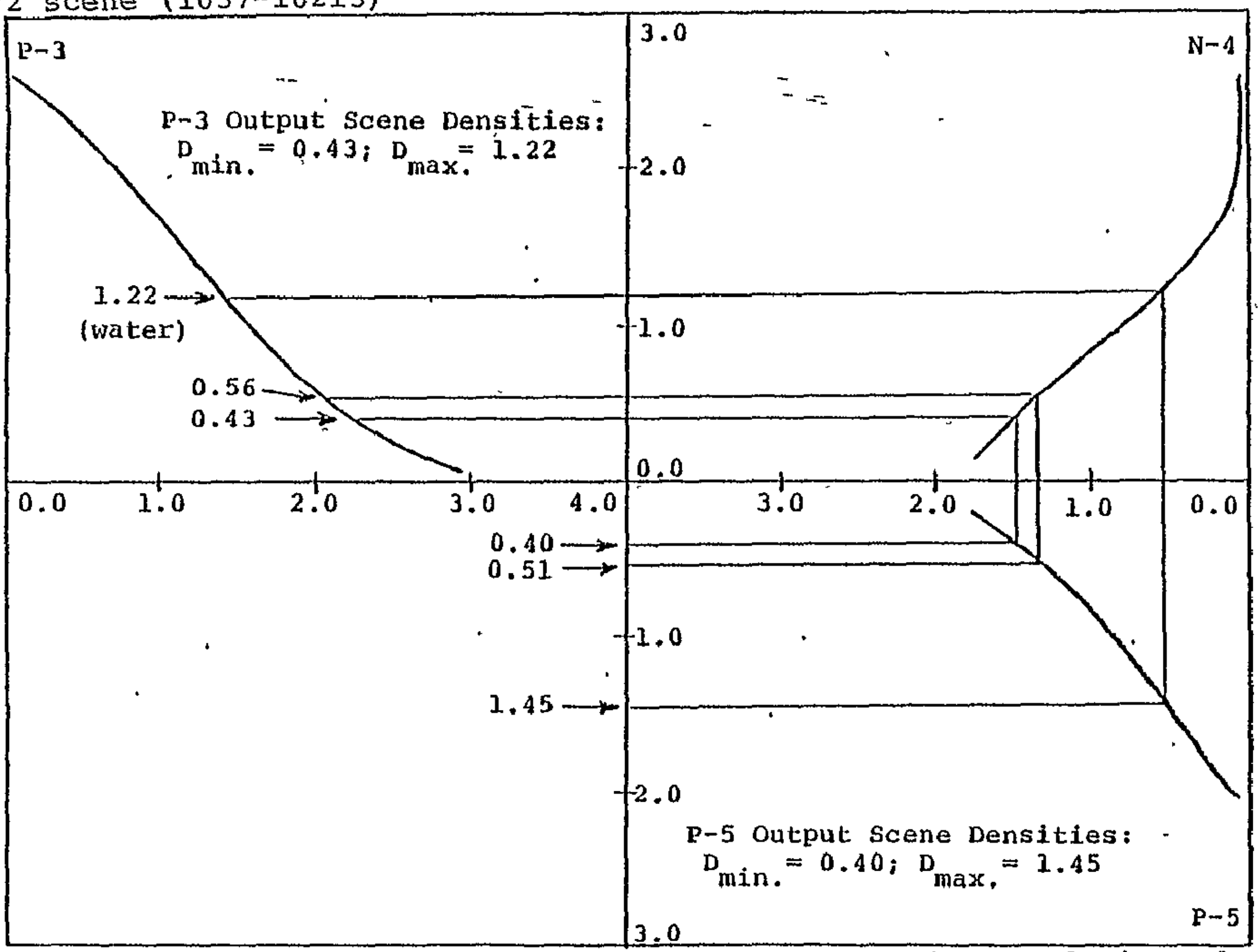
_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 14-/. Tone reproduction diagram for band 5 of the standard product August 29, 1972 scene (1037-16213)



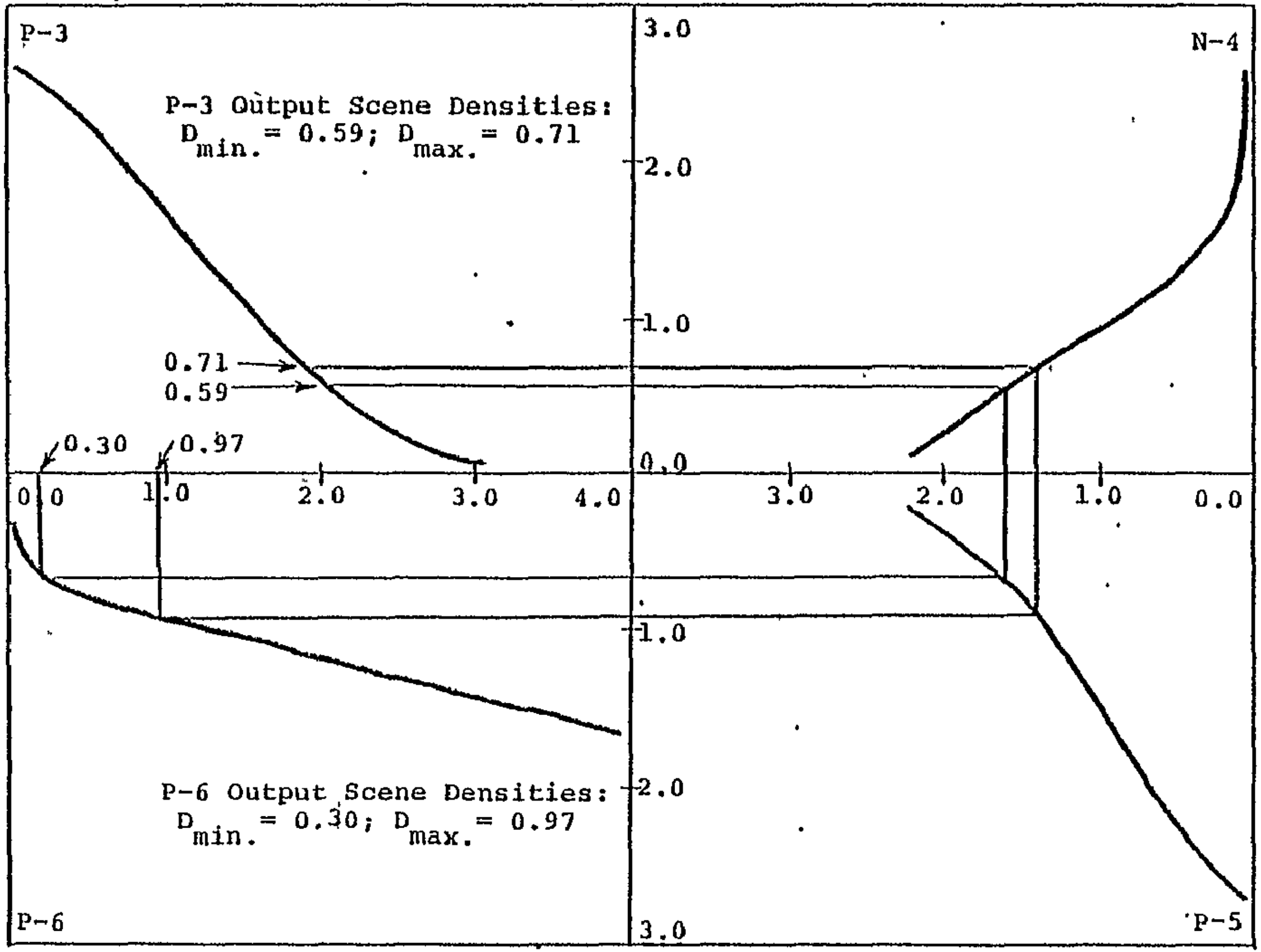
_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 15_/. Tone reproduction diagram for band 7 of the standard product August 29, 1972 scene (1037-16213)



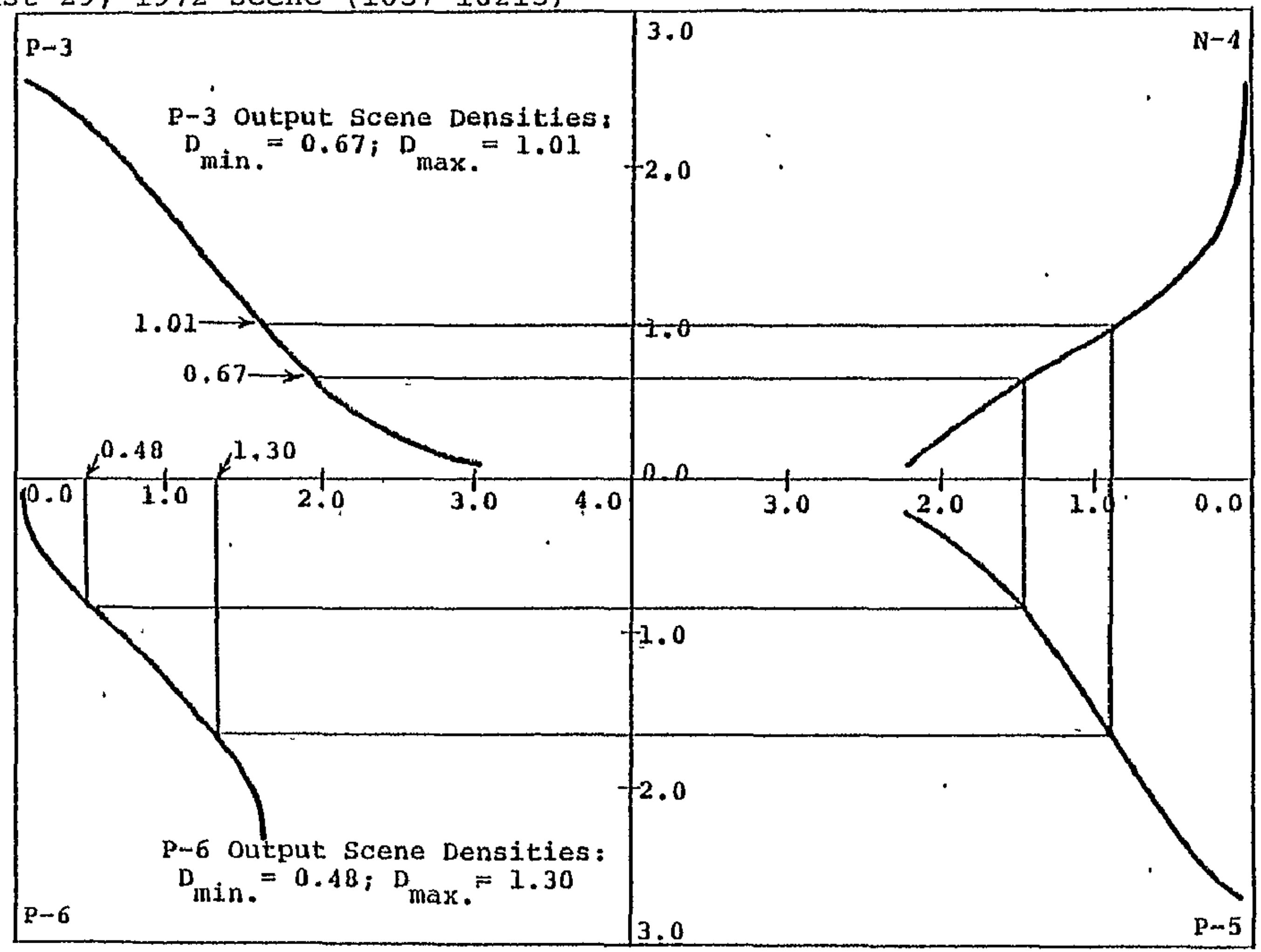
_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 16-/. Tone reproduction diagram for band 4 of the photo-optically enhanced August 29, 1972 scene (1037-16213)



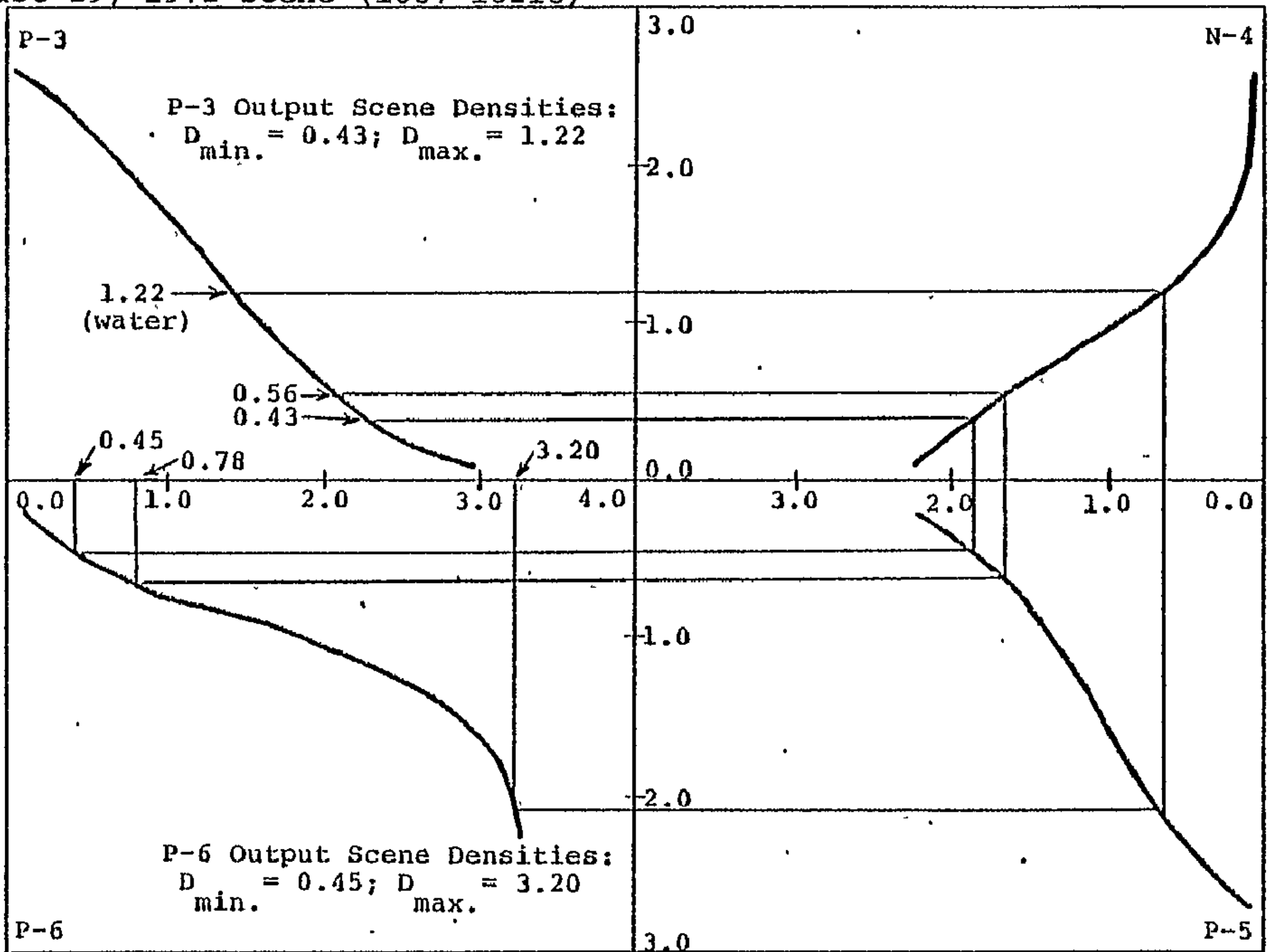
_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 17-/. Tone reproduction diagram for band 5 of the photo-optically enhanced August 29, 1972 scene (1037-16213)



_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Figure 18[/]. Tone reproduction diagram for band 7 of the photo-optically enhanced August 29, 1972 scene (1037-16213)



_/ Data generated by Darrell C. Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Table 6-/. Data for tone reproduction curves of the August 29, 1972 standard product scene (1037-16213)

Step #	N-2	P-3	N-4	P-5
	Film Product Generation			
1	0.04	2.61	0.04	2.11
2	0.20	2.52	0.04	2.11
3	0.35	2.40	0.05	2.11
4	0.51	2.27	0.06	2.09
5	0.66	2.11	0.08	2.07
6	0.81	1.94	0.11	2.04
7	0.95	1.77	0.16	1.99
8	1.11	1.58	0.26	1.86
9	1.26	1.41	0.40	1.68
10	1.41	1.24	0.57	1.46
11	1.56	1.04	0.75	1.20
12	1.67	0.93	0.90	1.01
13	1.80	0.79	1.09	0.79
14	1.96	0.65	1.26	0.62
15	2.10	0.53	1.40	0.49
16	2.25	0.43	1.52	0.39
17	2.40	0.32	1.62	0.30
18	2.53	0.25	1.70	0.25
19	2.68	0.19	1.75	0.23

Table 6. Data for tone reproduction curves of the August 29, 1972 standard product scene (1037-16213)--Continued

Step #	Film Product Generation N-2	P-3	N-4	P-5
20	2.82	0.15	1.77	0.21
21	2.97	0.12	1.80	0.19

Density readings taken from a 21 step tablet for the black and white film products used to produce the Landsat color composite.

_/ Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

Table 7–/. Data for tone reproduction curves of the August 29, 1972 photo-optically enhanced scene (1037-16213)

	Film Product Generation						
Step #	N-2	P-3	N-4	P-5	P-6 Band 4	P-6 Band 5	P-6 Band 7
1	0.04	2.61	0.04	2.70	4.00	1.59	3.27
2	0.20	2.52	0.04	2.70	4.00	1.59	3.27
3	0.35	2.40	0.04	2.70	4.00	1.59	3.27
4	0.51	2.27	0.05	2.70	4.00	1.59	3.27
5	0.66	2.11	0.07	2.70	4.00	1.59	3.27
6	0.81	1.94	0.10	2.70	4.00	1.59	3.27
7	0.95	1.77	0.16	2.60	4.00	1.59	3.27
8	1.11	1.58	0.26	2.50	4.00	1.59	3.27
9	1.26	1.41	0.41	2.34	4.00	1.59	3.27
10	1.41	1.24	0.62	2.06	4.00	1.58	3.25
11	1.56	1.04	0.85	1.71	4.00	1.38	3.09
12	1.67	0.93	1.03	1.42	3.27	1.09	2.64
13	1.80	0.79	1.29	1.08	1.70	0.78	2.06
14	1.96	0.65	1.50	0.78	0.47	0.45	1.29
15	2.10	0.53	1.69	0.60	0.12	0.25	0.75
16	2.25	0.43	1.85	0.45	0.06	0.15	0.44
17	2.40	0.32	1.98	0.36	0.04	0.11	0.27
18	2.53	0.25	2.08	0.30	0.04	0.09	0.20
19	2.68	0.19	2.15	0.26	0.04	0.08	0.15

Table 7. Data for tone reproduction curves of the August 29, 1972 photo-optically enhanced scene (1037-16213)--Continued

Film Product Generation

Step #	N-2	P-3	N-4	P-5	P-6 Band 4	P-6 Band 5	P-6 Band 7
20	2.82	0.15	2.20	0.23	0.04	0.07	0.13
21	2.97	0.12	2.22	0.21	0.04	0.07	0.12

Density readings taken from a 21 step tablet for the black and white film products used to produce the Landsat color composite.

_/ Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

product color composite, are $D_{min.}$ = 0.53 and $D_{max.}$ = 0.70. This diagram illustrates that very little change in contrast is introduced in this standard product band from the P-3 image. The tone reproduction diagram for the POE band 4 (Figure 16), however, starts with the same P-3 scene output densities, but the P-6 scene output densities ($D_{min.}$ = 0.30; $D_{max.}$ = 0.97) have been increased by the POE process. This increased scene contrast is the objective of the photo-optically enhanced P-6 film product. A summary of the standard product P-5 and POE P-6 output densities is listed on Table 8.

Table 8 near here.

Table 8_/. Summary of scene density ranges as traced through tone reproduction diagrams on Figures 13 through 18

Band	P-3 Scene Output Densities		P-5 Standard Product Output Densities		P-6 POE Product Output Densities	
	$D_{min.}$	$D_{max.}$	$D_{min.}$	$D_{max.}$	$D_{min.}$	$D_{max.}$
4	0.59	0.71	0.53	0.70	0.20	0.97
5	0.67	1.01	0.60	1.10	0.48	1.30
7	0.43	0.56	0.40	0.51	0.45	0.78
		1.22 (water)		1.45 (water)		3.20 (water)

_/ Data generated by Darrell Ramerth under the supervision of Richard L. Nelson, Custom Color Laboratory, EROS Data Center.

COLOR COMPOSITE EVALUATION

The higher scene contrast of the P-6 film generation transparencies is in turn printed through to the composite and thereby produces better color contrast and color saturation. For land classification purposes, the photo-optically enhanced color composite was judged to be a better photo interpretation product for all land classification categories. The bases for this statement are summarized in Table 9.

Table 9 near here.

COST COMPARISON OF THE POE VERSUS STANDARD PRODUCT COLOR COMPOSITE

If no standard product color composite exists in the EDC data base file, a $50.00 charge is made for the printing of a color transparency. A copy of this color film positive transparency costs $15.00; a 1:1,000,000 scale color paper print costs the user $12.00. To produce a photo-optically enhanced false-color composite, the EDC Custom Color Laboratory must be utilized. The cost of generating a POE color transparency is $150.00 (Richard L. Nelson, Personal Communication, 1977) which is three times the amount charged for the EDC standard false-color composite.

Table 9. Comparison of the photo-optically enhanced and standard product color composites

Land Category	Comments on Interpretation
1. Urban Commercial/ Industrial	The higher contrast in the urban area tends to make the commercial/industrial district a darker blue-green color and therefore more easily interpretable on the POE color composite.
2. Urban Residential	The higher contrast of the POE composite makes the residential areas more distinct from the surrounding agricultural lands.
3. Forest	The forested areas are deeper red on the POE composite than on the standard product composite. In areas where the forest cover is not very dense, the POE is easier to interpret because of the better color contrast.
4. Water	Water bodies have better color saturation thereby appearing darker blue on the POE composite. For

Table 9. Comparison of the photo-optically enhanced and standard product color composites--continued

Land Category	Comments on Interpretation
	image analysis purposes, the POE print is not significantly different from the standard product.
5. Transportation Network	Roads are brighter and therefore more distinct on the POE composite.
6. Extractive	Strip mines are slightly more distinct on the POE composite, but remain difficult to delineate.

EDC DIGITAL IMAGE ENHANCEMENT SYSTEM (EDIES) PRODUCTS

Computer enhanced Landsat scenes also may be obtained from the EROS Data Center. The image enhancement procedure begins with a computer compatible tape (CCT) received from NASA/Goddard. An interactive multispectral analysis system is utilized to assess the tape quality and also to determine contrast enhancement parameters. A general purpose computer system performs geometric corrections, contrast enhancement, destriping, and replacement of bad lines. Edge enhancement may also be included in the procedure if desired.

To produce EDIES products, systematic geometric correction functions are used to remove distortions introduced from earth rotation. Geometric corrections are also made for variations in line length resulting from non-uniform mirror velocity in the multispectral scanner. Systematic radiometric correction functions are used to remove striping caused by variations in detector response. If a line of missing data occurs in a Landsat band, synthetic lines are created to replace the line.

Contrast enhancement is performed to expand the distribution of brightness values in the Landsat bands to cover the full digital range. This operation increases scene contrast which in turn accentuates land cover features and minimizes the effects of atmospheric scattering. An optional edge enhancement algorithm may be used to emphasize boundaries between landscape characteristics that exhibit subtle differences in brightness values along their margins. Picture elements in an edge enhanced scene are modified so that the pixels brighter than the local average are reassigned brighter DN (digital number) values and pixels darker than the local average are given darker DN values.

The corrected and enhanced Landsat data of an EDIES scene are stored on a magnetic tape which is used on the EDC laser beam recorder (LBR) to produce a film product. The digital numbers that represent scene brightness values are recorded linearly with density over a preselected density range on the recording film (Figure 19). First

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Figure 19 near here.

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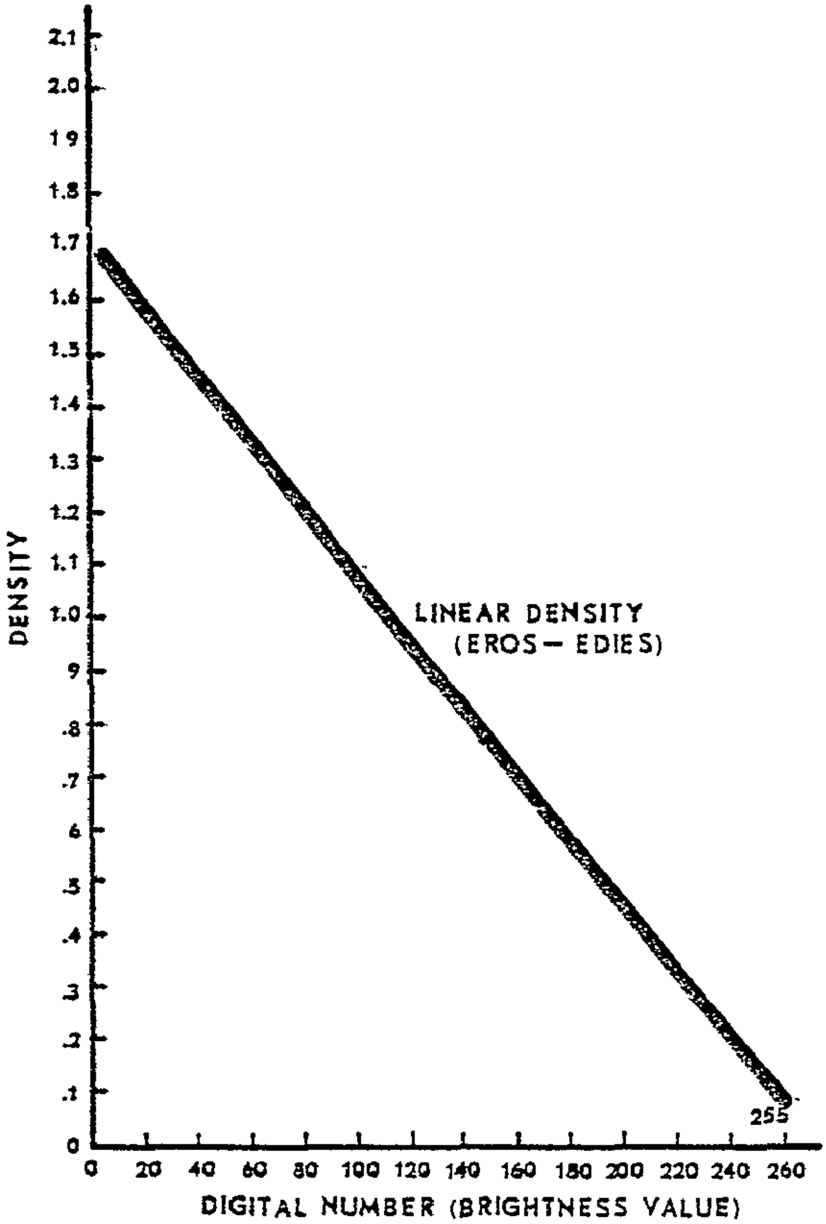
generation negatives (N-1) and positives (P-1) at 1:1,000,000 scale (241 mm) are produced on the laser beam recorder. The P-1 transparencies can be composited into a second generation false-color transparency.

Figure 19. Laser beam recorder fılm recordıng function at EDC



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CUSTOM COMPUTER ENHANCEMENT PROCESSING OFFERED OUTSIDE OF THE DEPARTMENT OF INTERIOR

Computer enhancement of Landsat data is conducted on a routine basis by several private businesses and on a limited basis by governmental organizations. The Jet Propulsion Laboratory's Image Processing Laboratory (IPL) utilizes a data handling system called VICAR (Video Image Communication and Retrieval) for recording, processing, and displaying Landsat images. The fundamental philosophy of the VICAR system is that the analyst, in accomplishing his image processing, may call for the execution of one or more of a group of programs from a system library. Because all the image data are in VICAR format, the data may be passed from one applications program to another without the worry of incompatibility. These application programs are accessed through the VICAR language by a series of English statements entered on computer cards. When all necessary processing has been performed on an image, the data are written on magnetic tape for playback on a film recording device. The cost of such computer processing is dependent upon the type of data manipulation and required data products. A summary of digital image processing at the Jet Propulsion Laboratory is presented on Table 10.

Table 10 near here.

Table 10. Flow chart of digital image processing at the Jet Propulsion Laboratory (JPL)

Computer compatible tapes (CCT's) received from the EROS Data Center

↓

CCT's copies and saved at JPL in Goddard Space Flight Center format

↓

Computer processing at JPL using an IBM 360 Model 65 System

↓

Utilization of VICAR (Video Image Communication and Retrieval System)

↓

CCT data VERTS logged

CCT data in VICAR format

CCT data are corrected for:

a. Skew

b. Panoramic distortion

c. Mirror scan velocity profile

d. Synthetic pixels

e. Aspect ratio

Master VICAR tape saved ←

↓

Image ERTSFIXED

↓ Line drops "fixed"

Image Optimization Programs

Contrast stretching

a. Linear

b. Ramp CDF

c. Gaussian

Table 10. Flow chart of digital image processing at the Jet Propulsion Laboratory (JPL)--Continued

Image annotation

↓ Image is masked and titled

Production of film copies

Transparencies are produced on an Optronics P-1500

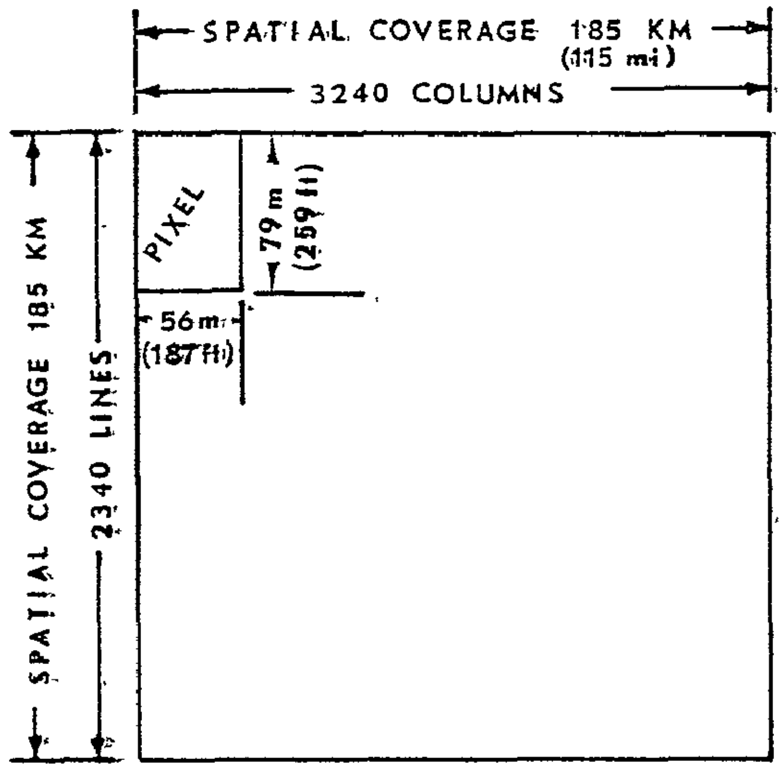
DISCUSSION OF JPL IMAGE PROCESSING

VICAR system

The standard Landsat image has its picture elements arranged in a matrix of 2340 lines by 3240 columns. Each MSS detector has an instantaneous field of view (IFOV) of 79 by 79 meters. Every picture element in the line direction of the image is overscanned which results in pixel-to-pixel center spacing of only 56 meters. Due to this oversampling of the detector analog signal, each pixel sample overlaps the previous sample by 23 meters. The sampled pixel value is not due to the 56 by 79 meter IFOV alone, but contains, in addition, the integrated reflectance from the 23 meter overlap. The pixel arrangement of a standard Landsat imaged scene is illustrated on Figure 20.

Figure 20 near here.

Figure 20. Picture element arrangement of a Landsat standard product imaged scene



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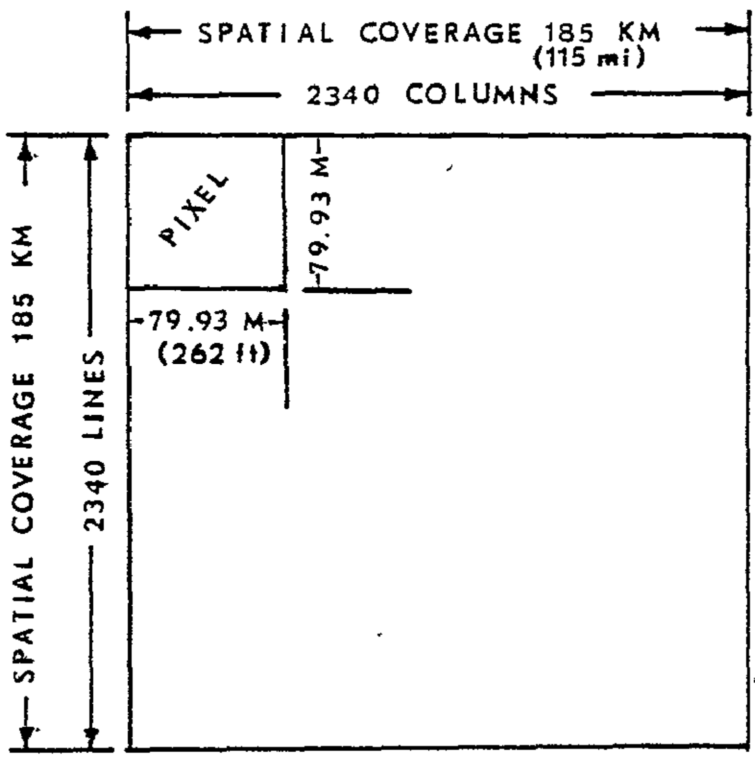
When a computer compatible tape is translated into VICAR format by the VERTSLOG program, the picture elements are resampled to produce square pixels. This resampling (called aspect ratio correction) is accomplished by linear interpolation between the "over-sampled" picture elements in the column direction (spectral integration over 56 meters) to produce new picture elements that correspond to the spectral reflectance integrated over approximately 79 meters. The resulting matrix of pixture elements is 2340 lines by 2340 columns. Each pixel in the VICAR format integrates reflectance over 79.93 meters square (Figure 21).

Figure 21 near here.

Aspect ratio correction is necessary because the film recording device used at JPL can only produce a picture element that is square.

Figure 21. Picture element arrangement on a Jet Propulsion Laboratory computer enhanced VICAR product scene



In addition to the aspect ratio correction, other image corrections are made for skew, panoramic distortion, and mirror scan velocity profile. The correction for image skew is necessary to compensate for the Earth's movement relative to Landsat as the scene is being recorded by the multispectral scanner. Another geometric adjustment corrects the panoramic image distortion resulting from the image being tangent to the Earth's spherical surface at only one point. Because the MSS mirror velocity is not constant, the length of the image lines vary slightly. Synthetic picture elements are produced by the computer at the NASA Goddard Data Processing Facility to adjust all image lines to the same length. Landsat image scan lines are lengthened by inserting these pixels at regularly determined intervals to obtain the desired line length. Synthetic pixels are duplicates of pixel DN values located at predetermined positions on the scan line. Because VICAR format requires a resampling to square pixels, thereby adjusting the line lengths, these synthetic pixels are not needed and are consequently removed from the Goddard data.

If lines of missing or random data occur in a Landsat band, synthetic lines may be created by linear interpolation between the digital numbers in the lines surrounding the bad line data. This VICAR program is called ERTSFIX. The advantage of "ERTSFIXing" a scene is that an image is created which is free from the distraction of missing scan lines. For visual interpretation purposes this cosmetic operation is very effective.

Data transformation and display

On a standard CCT, bands 4, 5, and 6 have seven-bit precision. Seven computer bits determine the digital number value assigned to a pixel. The dynamic range for seven-bit precision is 0 to 127 ($2^7 = 128$). Dynamic range in this context is defined as the possible values that a set of digital data can take, which is dependent upon the level of precision used. This, in turn, means that the data base for pixels in bands 4, 5, and 6 has 128 possible levels of gray. Band 7, however, has a six-bit precision giving a dynamic range of 0 to 63 ($2^6 = 64$) and hence 64 possible gray levels. Image processing techniques used at the Jet Propulsion Laboratory "scale up" both the six and seven-bit data to an eight-bit precision. The dynamic range for eight-bit precision is 0 to 255 ($2^8 = 256$). With this expansion, more discrete levels are available for the DN values which are computed in the resampling process. The greater the number of gray levels, the more levels of contrast an image will possess. Contrast is defined here as the amount of visible differences between the darkest and lightest tones on a film positive or print. Scaling up of CCT data does not transform the relationships between reflectance values assigned to the picture elements. It does, however, create a greater range of values between digital numbers so that more gradations exist within the expanded dynamic range.

When scaling up of CCT data is performed on the VICAR system, a bit shift occurs which gives bands 4, 5, and 6 a dynamic range of 0 to 254. Band 7 has a data range of 0 to 252. For practical purposes, these range losses are insignificant.

Optronics P-1500 film recorder characteristics

The Optronics Photowrite Model P-1500 Film Recorder is a precision digital film recording system which is designed to produce hard copy photographic prints from digital data. In the film recorder, a beam of light is modulated by the digital data to expose a sheet of Kodak Linograph Shellburst 2474 film that has been clamped to the outside of a circular drum. Kodak 2474 is a thin, mylar-based, high contrast, red sensitive film. The optical system, consisting of a red-light emitting diode (LED) source, an adjustable aperture, and a lens complex, focuses the light beam onto the film. As the LED source travels across the rotating sheet of Kodak 2474 film, picture elements are exposed relative to the assigned digital numbers. The light proof canister which encloses the film and drum can then be removed from the film recording system and taken to a darkroom for processing.

JPL false-color negatives

Before a false-color negative can be printed, the Optronics black and white positive transparencies must be registered as a set. To facilitate registration, images are processed by a VICAR applications program, called MASK, to add a scene border with registration tick marks gray scale and annotation. Because only bands 4, 5, and 7 were used to produce the false color composites in this report (except for the composite shown on Figure 4), band 6 was not registered. The equipment for registering transparencies consists of a light table, a registration punch, and a magnifying eyepiece. The black and white positive transparencies are individually registered to the VICAR generated mask, punched, and removed from the light table.

The printing of the black and white transparencies onto color negative film is accomplished at JPL by using a contact frame with registration pins mounted on the bed, a point-light source with a filter wheel, three primary filters and filter selector, and a timer for the light source. The first step in producing a false-color negative requires the registration of MSS band 4 (green spectral band) to the contact frame via the mounting pins on top of a sheet of Kodak 4108 Vericolor II--Type L film. The film and the black and white transparency are exposed for a predetermined time to blue light through a Wratten #47B primary filter. Band 4 is removed from the contact frame and is replaced by band 5 (red spectral band) which is registered and exposed to green light through a Wratten #61 green filter. Band 5 is then replaced by band 6 or 7 (infrared spectral bands), which is registered and exposed to red light through a Wratten #29 red filter. When this procedure is completed, the exposed Vericolor II film is removed and processed in a Kreonite C-41 roller transport processor with C-41 chemistry to form a false-color negative transparency. Vericolor II negatives are printed on Kodak Ektacolor RC-37 photographic paper.

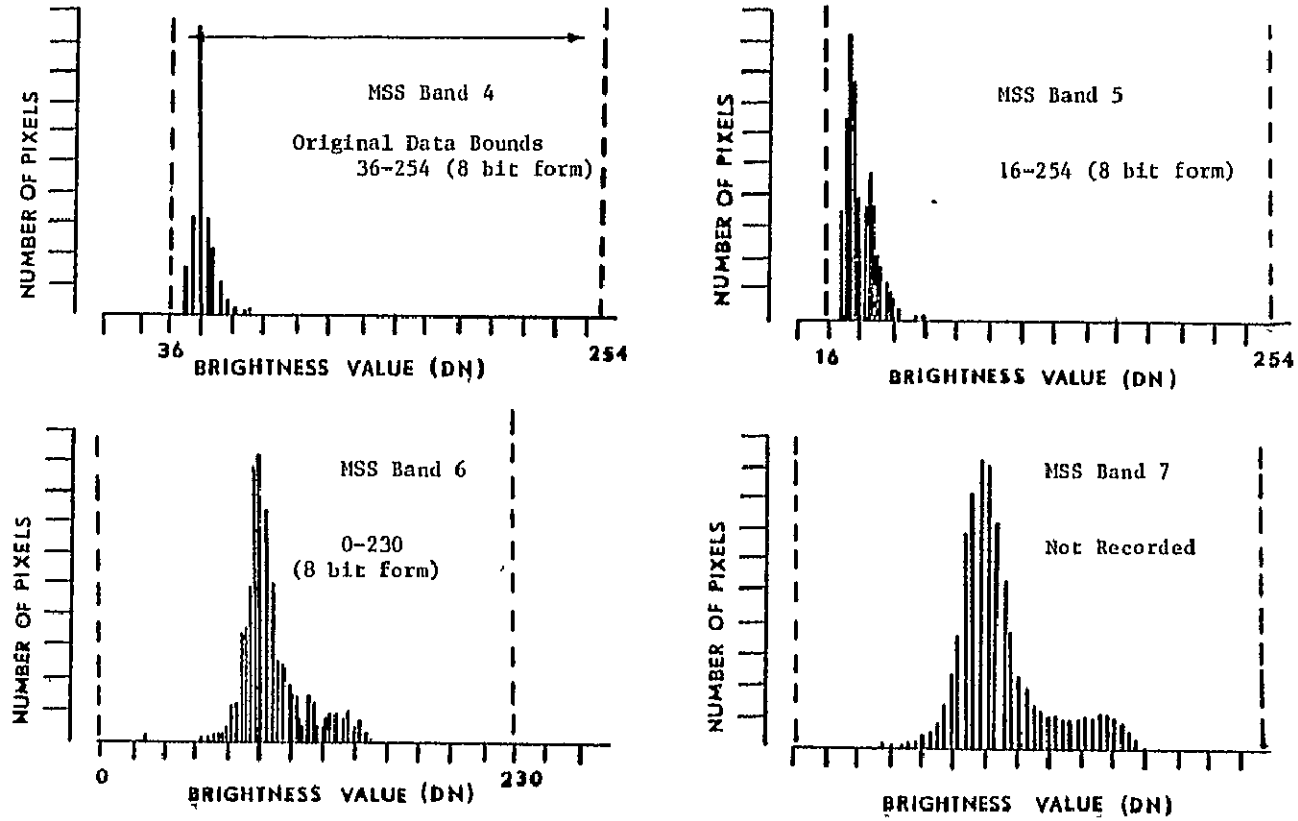
Contrast stretching of image data

Reflectance characteristics of Landsat scenes can be displayed by the construction of histograms which illustrate the relationship between pixel brightness values (digital numbers) and their frequency of occurrence. Examples of histograms produced on the IMAGE 100 for each MSS band of the Wapello County subscene are displayed on Figure 22.

Figure 22 near here.

Dashed lines on each graph indicate the spectral range of the data within that band. The subscene from which these data were derived is displayed by the JPL print on Figure 4. Band 6 seemed to possess greater detail in the urban area on the subscene than band 7 and therefore was selected for the infrared band to be used in the compositing process. All other false color composites discussed in this report were produced from bands 4, 5, and 7. The raw data of the subscene are shown on the histograms to be clustered within relatively limited brightness value ranges. To expand the distribution of digital numbers across the total eight-bit range of 0 to 255, a method called contrast stretching is employed. Mathematical algorithms are implemented to transform original brightness values into new digital numbers that fill the entire eight-bit range. To maximize

Figure 22. Raw data histograms for the JPL Wapello County subscene (August 29, 1972, 1037-16213) area shown on Figure 4. Data processed by the IMAGE 100 at EDC.



the extent over which brightness values may be expanded, the data at the end portions of the spectral histograms can be reassigned to the digital numbers of 0 and 255 (corresponding to black and white, respectively, on a positive image). The percentage of the total picture elements saturated to white or black is controlled by the computer analyst. This reassigned data has been "truncated" from the end portions of the histograms. The points at which truncation has occurred are termed "stretch bounds". The result of truncating the histogram and thereby saturating portions of the data to white and black is the creation of a greater range of gray levels on the contrast stretched scene.

Histograms showing linearly contrast stretched data for the Wapello County subscene are displayed on Figure 23.

Figure 23 near here.

The original spectral data ranges are indicated as well as the assigned stretch bounds. MSS band 4, for example, originally possessed an eight-bit data range of DN 36 to DN 254. Stretch bounds of DN 40 and DN 67 were chosen by the computer analyst. These truncation points were determined by arbitrarily assessing the upper and lower bounds of the major portion of the data. According to the specified contrast parameters, brightness values below 40 have been reassigned to a DN value of 0 (black), and brightness values greater than 67 have been reassigned to DN 255 (white). The percentage of picture elements saturated to black and white is noted on the stretched data histograms. The remaining gray levels (41 to 66) were linearly stretched to cover the brightness range from 1 to 254. The original and contrast stretch bounds for each of the MSS bands composited, as well as the percents of pixels saturated by the truncation process, are summarized in Tables 11 and 12.

Tables 11 and 12 near here.

Figure 23. Histograms after a JPL linear contrast stretch for the Wapello County subscene (August 29, 1972, 1037-16213) area shown on Figure 4. Data extracted by the IMAGE 100 at EDC.

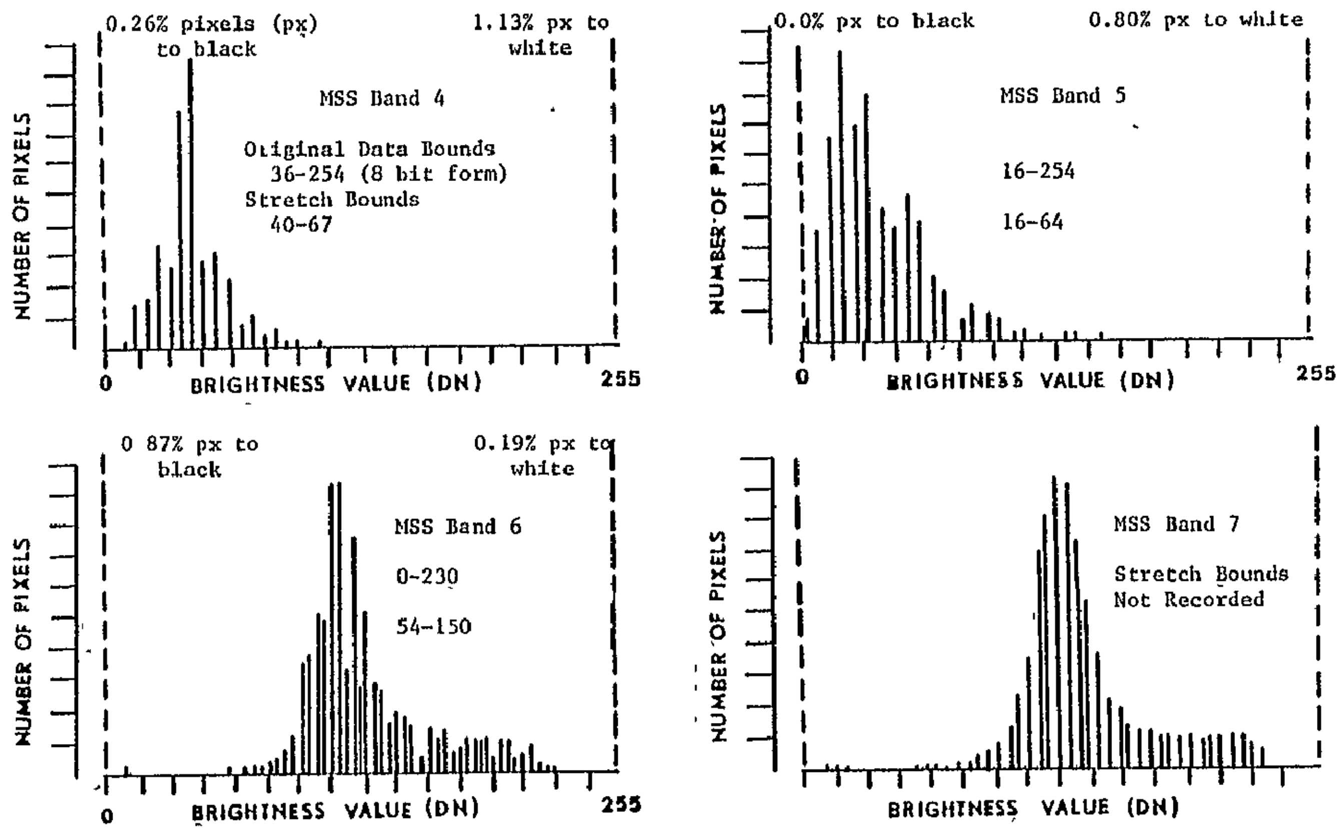


Table 11. Spectral data range for histograms shown on Figure 23

Band	Lower Data Bound	Upper Data Bound
	August 29, 1972 scene (1037-16213)	
#4	36	254
#5	16	254
#6	0	230

Table 12. Contrast stretch bounds and percents of pixels saturated for the histograms shown on Figure 23

Band	Lower Stretch Bound	% Pixels Sat.	Upper Stretch Bound	% Pixels Sat.
	August 29, 1972 scene (1037-16213)			
#4	40	0.26	67	1.13
#5	16	0.00	64	0.80
#6	54	0.87	150	0.19

Image evaluation

Initially, prints of the August 29, 1972 JPL computer enhanced false-color composite (produced from MSS bands 4, 5, and 6) showed similar blue-green colors in several land classes, including water, urban areas, extractive sites, and agricultural areas. In Ottumwa, for example, the blue-green color of the commercial and industrial areas resembled the hue of the water in the Des Moines River. Strip mines located a few miles northwest of Ottumwa also appeared similar in color to the runways of Ottumwa International Airport. This hue also characterized occasional agricultural fields and pasture lands throughout Wapello County. Differentiation of these blue-green land cover features based solely on the August Landsat false-color composite proved to be difficult or impossible.

To determine if greater detail existed in the CCT data for the separation of these land use categories than portrayed on the JPL false-color prints, the IMAGE 100 system at the EROS Data Center was employed to process the Wapello County subscene. When the data was displayed on the television screen as a false-color composite, more variations in hues could be discerned which permitted easier delineation of all land cover categories. Attempts to improve the appearance of the land use categories on the JPL products were made by utilizing three contrast programs (linear, ramp cumulative distribution function [CDF], and Gaussian) with varying amounts of data truncation. The resultant JPL false-color prints still possessed the characteristic blue-green color in several of the land use classes. This situation led to the initial hypothesis that photographic processing was the cause of blue-green color domination.

A 32 step density wedge was produced on Kodak 2474 Shellburst film in the Optronics recorder to test this hypothesis. Densities corresponding to every eighth DN value from 0 to 255 were used to expose a positive step wedge. After the film was developed, a transmission densitometer was used to read the photographic densities on the gray scale. A graph displaying the digital number versus transmission density is shown on Figure 24. The photo-

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Figure 24 near here.

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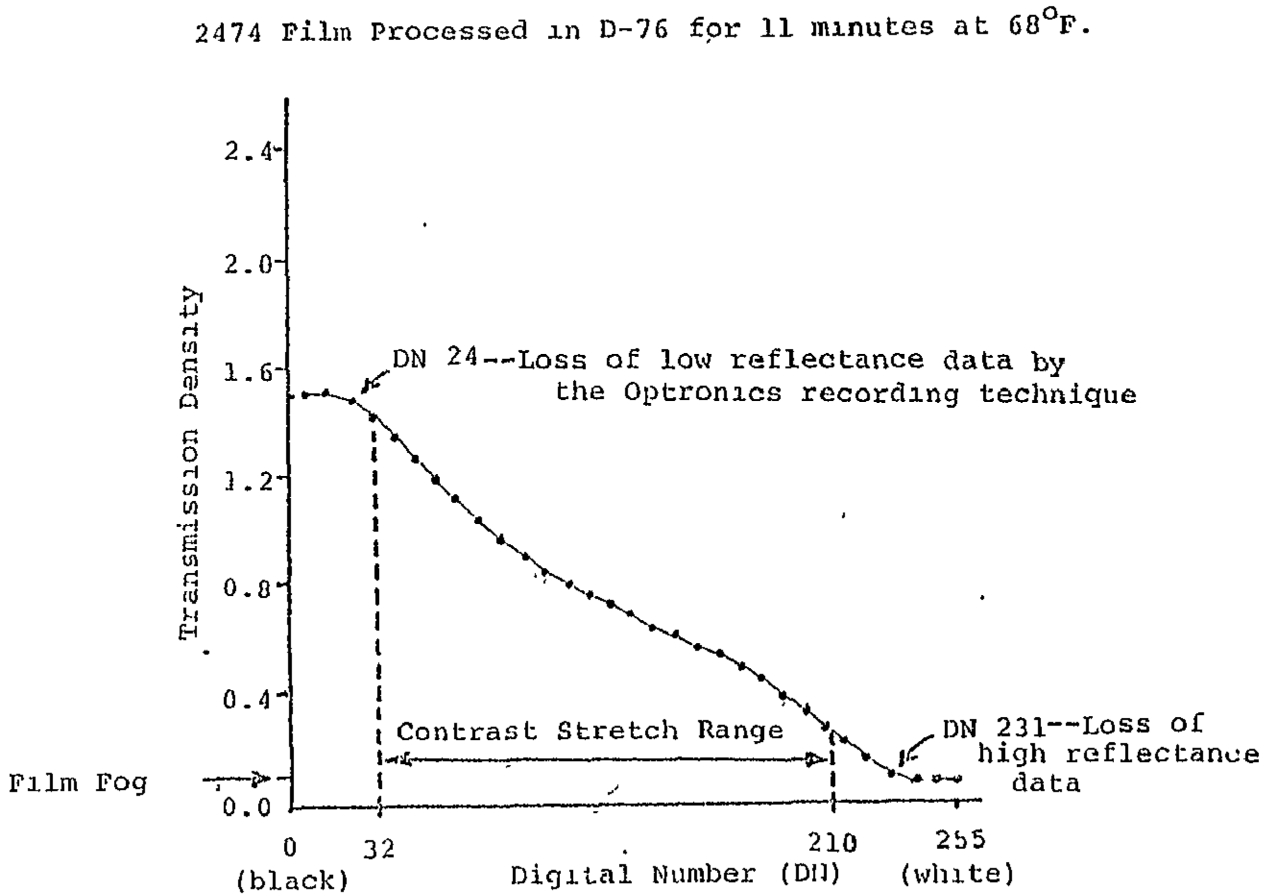
graphic density range of Kodak 2474 film is approximately 2.5 optical density units with an associated fog level of 0.11 to 0.19. The term "fog" is defined as the optical density on a film after development without exposure. The density/digital number relationship as recorded for the Optronics film indicated that the LED could not record unique densities associated with digital numbers from DN 0 to 24. In addition, the density/DN curve showed that film densities corresponding to approximately DN of 232 to 255 could not be uniquely recorded on the Kodak 2474 film. Because of the limitations in the Optronics recording system, only 207 of the 256 possible gray levels could be recorded on film.

Figure 24_/. Digital number versus transmission density for linograph Shellburst film 2474 for positive step wedge exposed on an Optronics P-1500 at the Jet Propulsion Laboratory



Data Used for Curve

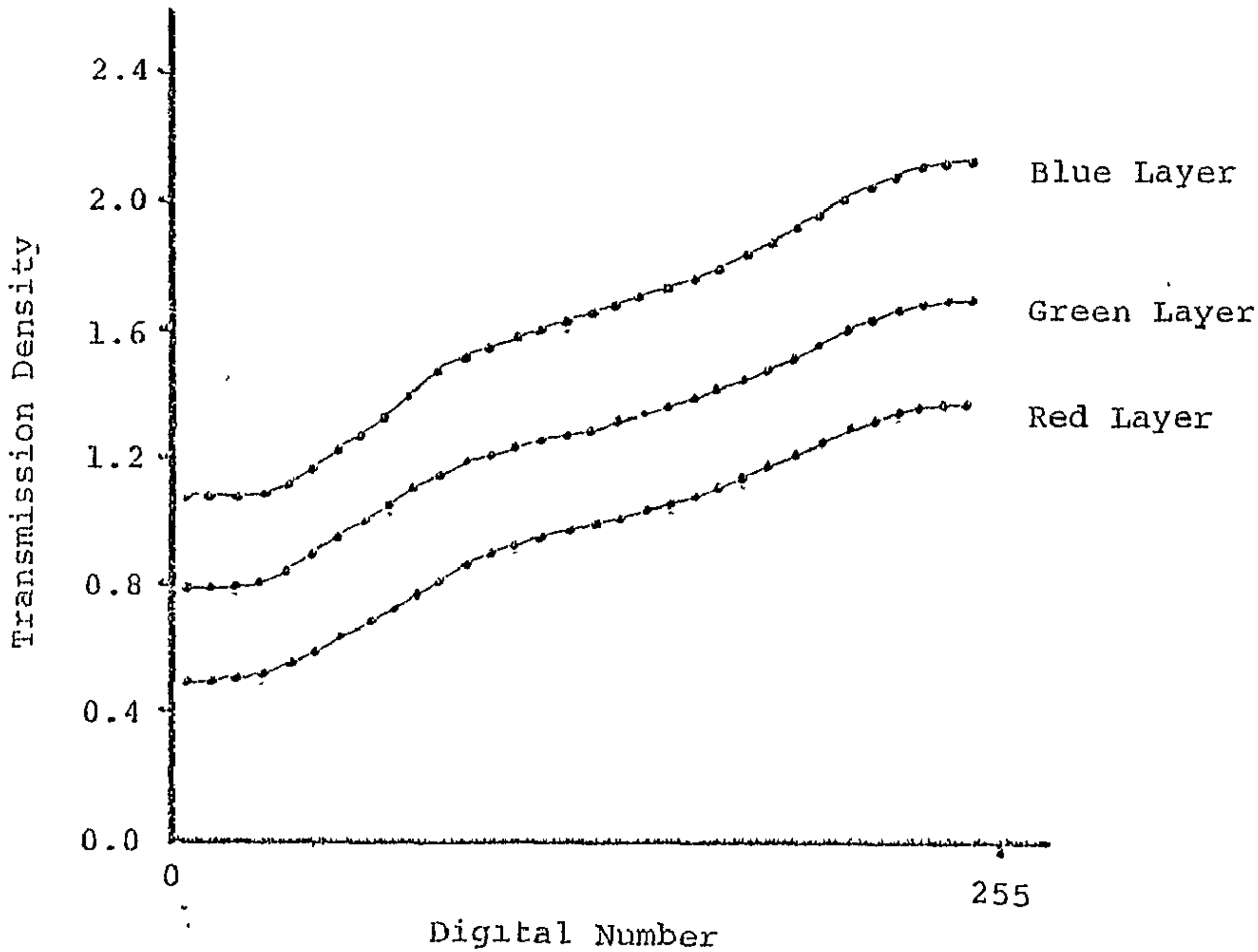
DN	Density
0	1.49
8	1.50
16	1.50
24	1.47
32	1.41
40	1.34
48	1.26
56	1.18
64	1.11
72	1.03
80	0.96
88	0.89
96	0.84
104	0.79
112	0.76
120	0.72
128	0.68
136	0.64
144	0.61
152	0.57
160	0.53
168	0.49
176	0.44
184	0.39
192	0.34
200	0.27
208	0.21
216	0.15
224	0.10
232	0.07
240	0.05
248	0.05
255	0.05

_/ Data for photographic curves produced by Ron Wichelman at JPL.

To determine the ability of the Kodak Vericolor II--Type L film to record the densities on the Shellburst 2474 film, the 32 step density wedge produced on the Optronics was printed onto this color negative film. A neutral wedge was printed by exposing the black and white Optronics gray scale to red, green, and blue light in a manner similar to that used at JPL to produce a false-color negative. After processing, the densities on the Vericolor II black and white wedge were read with a transmission densitometer for each dye layer. The transmission density versus DN relationship shown on Figure 25 (data on Table 13) illustrates that the densities associated with digital numbers from about 0 to 24 and 232 to 255 could not be differentiated.

Figure 25 and Table 13 near here.

Figure 25[/]. Digital number versus transmission density for the Optronics P-1500 positive step wedge printed onto Vericolor II, Type L color negative film



_/ Data for photographic curves produced by Ron Wichelman at JPL.

Table 13-/. Data for Figure 25, digital number (DN) versus transmission density for the Optronics P-1500 positive step wedge printed onto Vericolor II, Type L color negative film

Digital Number	Transmission Density: Red Wratten #29	Transmission Density: Green Wratten #61	Transmission Density: Blue Wratten #47B
(Base + Fog)	0.10	0.38	0.67
8	0.49	0.79	1.08
16	0.50	0.79	1.09
24	0.50	0.79	1.08
32	0.52	0.81	1.08
40	0.54	0.84	1.12
48	0.58	0.89	1.17
56	0.63	0.95	1.23
64	0.67	0.98	1.27
72	0.73	1.05	1.34
80	0.78	1.10	1.42

Table 13. Data for Figure 25, digital number (DN) versus transmission density for the Optronics P-1500 positive step wedge printed onto Vericolor II, Type L color negative film--Continued

Digital Number	Transmission Density		
	Red	Green	Blue
	Wratten #29	Wratten #61	Wratten #47B
88	0.83	1.14	1.48
96	0.86	1.18	1.52
104	0.90	1.20	1.55
112	0.92	1.23	1.59
120	0.95	1.25	1.61
128	0.97	1.27	1.63
136	0.99	1.29	1.66
144	1.01	1.32	1.69
152	1.03	1.33	1.71
160	1.06	1.36	1.74
168	1.08	1.39	1.77

Table 13. Data for Figure 25, digital number (DN) versus transmission density for the Optronics P-1500 positive step wedge printed onto Vericolor II, Type L color negative film--Continued

Digital Number	Transmission Density		
	Red	Green	Blue
	Wratten #29	Wratten #61	Wratten #47B
176	1.10	1.41	1.80
184	1.14	1.44	1.84
192	1.17	1.47	1.87
200	1.20	1.50	1.91
208	1.25	1.55	1.96
216	1.29	1.59	2.01
224	1.32	1.63	2.04
232	1.35	1.66	2.08
240	1.36	1.67	2.11
248	1.37	1.68	2.12
255	1.37	1.69	2.12

_/ Data produced by Ron Wichelman at JPL.

The 32 step density wedge developed on the Vericolor II negative was printed onto Kodak Ektacolor 37 RC color photographic paper. The reflection density/DN graph that is shown on Figure 26 (data on Table 14) displays no discernable

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Figure 26 and Table 14 near here.

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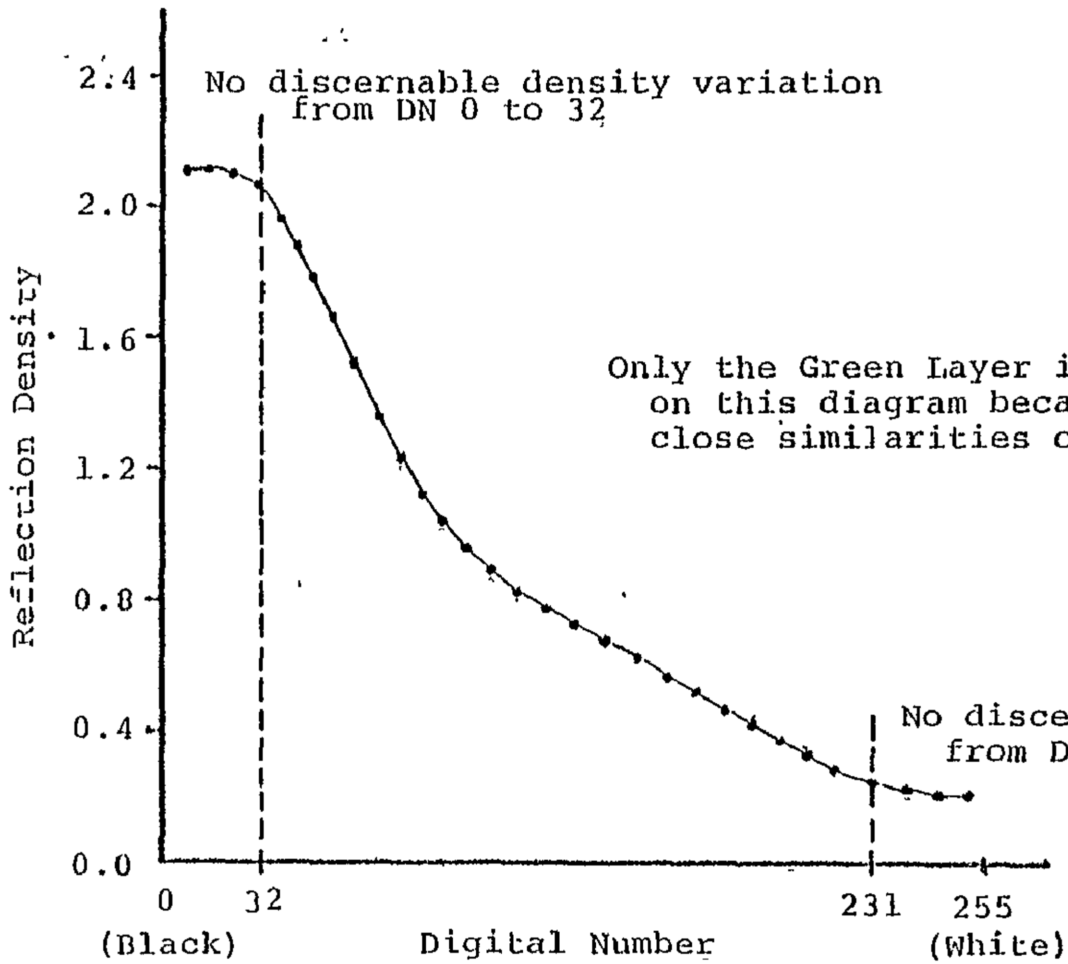
change in photographic density from DN 0 to 32. In addition, no differentiation of densities can be determined from approximately DN 232 to 255. The change in slope of the curve at approximately DN 120 shows the 37 RC paper to have a greater contrast for low reflectance digital numbers than for high reflectance values. Lower reflectance land cover should consequently possess slightly greater tonal variations than high reflectance cover.

Figure 26-/. Digital number versus reflection density for the Vericolor II, Type L 32 step wedge printed onto Ektacolor 37 RC photographic paper



_/ Data for photographic curves produced by Ron Wichelman at JPL.

Table 14—/. Data for Figure 26, digital number (DN) versus reflection density for the Vericolor II, Type L 32 step wedge printed onto Ektacolor 37 RC photographic paper

<u>Digital Number</u>	<u>Reflection Density</u>		
	Red Wratten #29	Green Wratten #61	Blue Wratten #47B
8	2.00	2.14	2.21
16	2.00	2.12	2.21
24	1.98	2.10	2.21
32	1.96	2.07	2.20
40	1.86	1.95	2.10
48	1.72	1.79	1.95
56	1.58	1.64	1.77
64	1.46	1.50	1.63
72	1.31	1.34	1.44
80	1.14	1.17	1.24
88	1.01	1.04	1.09

Table 14. Data for Figure 26, digital number (DN) versus reflection density for the Vericolor II, Type L 32 step wedge printed onto Ektacolor 37 RC photographic paper--Continued

Digital Number	Reflection Density		
	Red Wratten #29	Green Wratten #61	Blue Wratten #47B
96	0.91	0.96	0.98
104	0.83	0.90	0.92
112	0.75	0.83	0.83
120	0.70	0.78	0.79
128	0.66	0.75	0.74
136	0.59	0.69	0.69
144	0.55	0.65	0.63
152	0.51	0.61	0.59
160	0.46	0.57	0.55
168	0.42	0.53	0.51
176	0.38	0.48	0.44

Table 14. Data for Figure 26, digital number (DN) versus reflection density for the Vericolor II, Type L 32 step wedge printed onto Ektacolor 37 RC photographic paper--Continued

Digital Number	Reflection Density		
	Red Wratten #29	Green Wratten #61	Blue Wratten #47B
184	0.33	0.44	0.40
192	0.30	0.40	0.36
200	0.26	0.35	0.32
208	0.22	0.31	0.29
216	0.19	0.28	0.26
224	0.18	0.25	0.24
232	0.17	0.23	0.23
240	0.17	0.22	0.22
248	0.16	0.21	0.21
255	0.16	0.22	0.22

_/ Data produced by Ron Wichelman at JPL.

The results of printing the 32 step density wedge onto the various photographic products showed that losses of tonal detail introduced on the Optronics film were duplicated on the 37 RC paper from the Vericolor II negative. The limitation in the Optronics system at JPL to uniquely record densities for upper and lower DN values led to the development of a film recording strategy to solve this problem. Through a table look-up procedure, contrast stretched data which normally could not be recorded on the 2474 film were reassigned to a range of image densities corresponding to the DN values of 32 to 210. This digital number range with its associated film densities was conservatively selected to ensure that all DN tonal values could be uniquely recorded on the 2474 film. After contrast stretching, the JPL table look-up procedure reassigned the DN value of 0 to the DN value of 32, and the DN value of 255 was reassigned to a DN value of 210. The full range (256 levels) of contrast stretched data was compressed to "fit" within this range of 178 gray levels. The amended image data was then stored on a file tape for subsequent film recorder input. The advantage of having the ability to uniquely display all of the DN values in a scene outweighs the disadvantage of assigning a limited gray level range to the image data. The use of this smaller range could be avoided by the implementation of a table look-up program in the mini-computer of the Optronics film recorder. A table look-up program in the film recorder's computer could assign the 256 gray levels only to film densities that the Optronics is capable of recording on film. This procedure would eliminate the need for amending the contrast stretch data before it is stored on magnetic tape. A table look-up program is routinely used on the Optronics film recorder in the Data Analysis Laboratory at EDC (F. A. Waltz, personal communication, 1976).

A JPL enhanced false-color print of the Wapello County subscene that has been linearly stretched and compressed using the table look-up procedure to fit all of the image data within the Optronics recording range of DN 32 to 210 is shown on Figure 27. This scene has also been geometri-

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Figure 27 near here.

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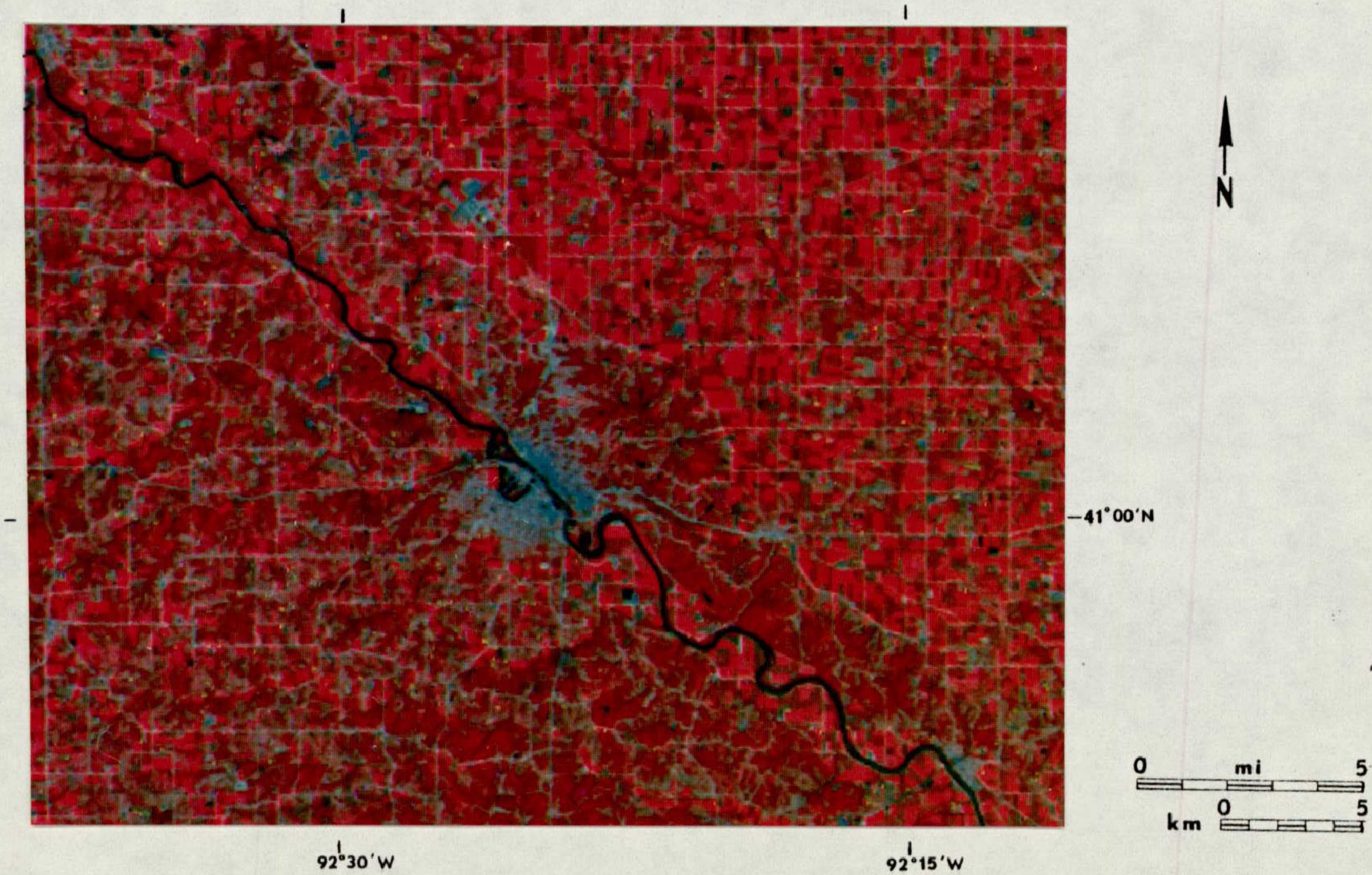
cally rotated by computer techniques from the satellite track orientation to true north. Many land cover features in this image possess blue-green hues similar to the earlier JPL false-color print (Figure 4). The commercial-industrial area of Ottumwa still resembles the hue of strip mines and some agricultural lands. Even though this scene was produced to minimize the loss of tonal variations from the Optronics film recorder, the domination of the blue-green color in certain land cover classes continued to prevail.

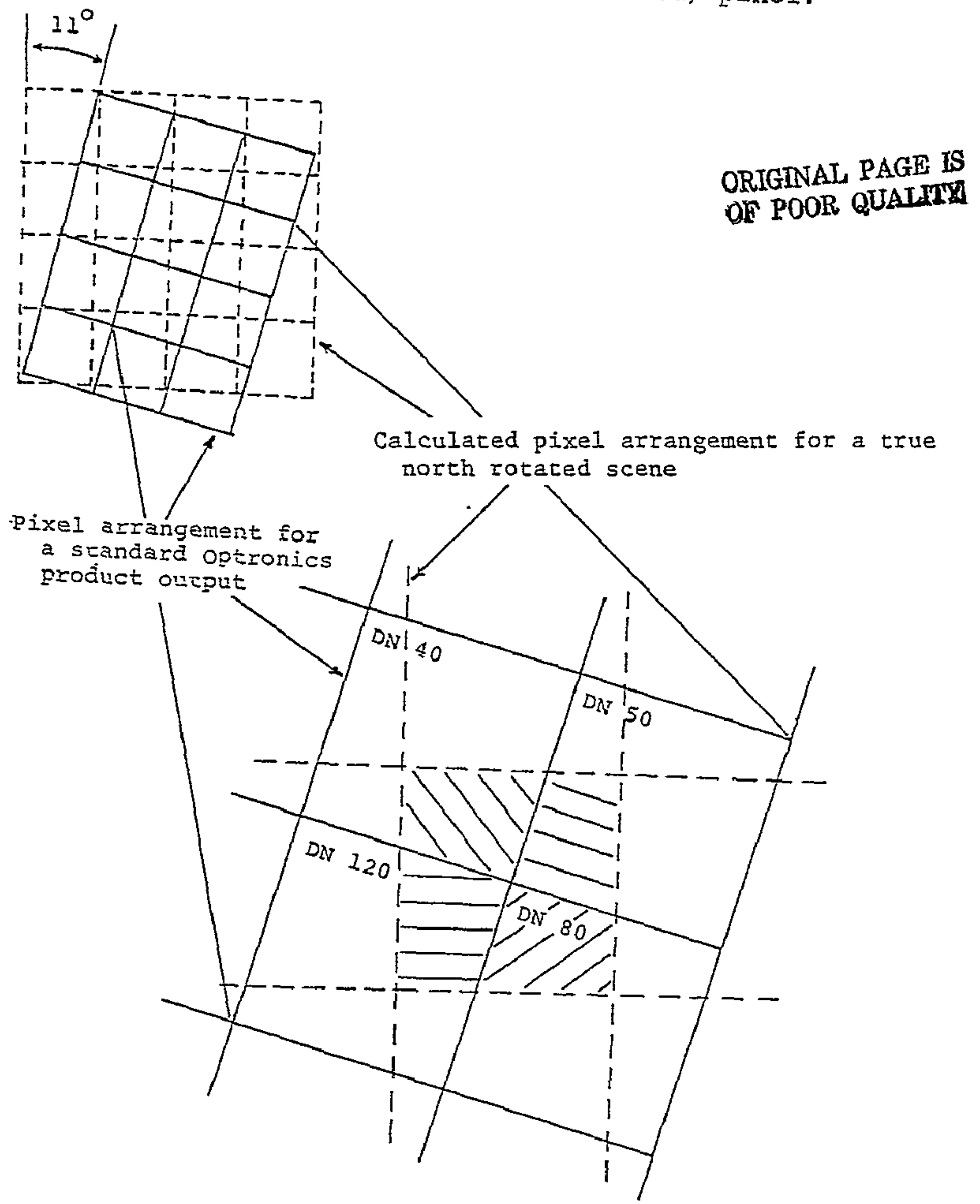
Figure 27. Landsat JPL subscene of Wapello County which has been contrast stretched and rotated to true north



Subscene from August 29, 1972 image (1037-16213)

Scale: 1:250,000

Figure 28. Pixel arrangements for a true north rotated Landsat scene. The bilinear interpolation process weights by area the contribution of the four surrounding pixel's DN values in order to calculate the DN value for the rotated (cross-hatched) pixel.



weights, by area, the contribution of these four pixels (DN 40, 50, 120, and 80) to calculate the DN value for the rotated pixel (DN 75). To accomplish this rotation for a full frame JPL scene, the operation of utilizing four pixel values to calculate one rotated value pixel value must be carried out on a 2340 by 2340 matrix for each spectral band.

Although the true north rotated scenes are aesthetically pleasing, there are disadvantages which must be considered. (1) The recalculation of all DN values through the bilinear interpolation process consumes much computer time and makes this operation relatively expensive. (2) The bilinear interpolation process causes road networks to become less distinct than on a non-rotated JPL enhanced product. (3) Pixel drops (small yellow dots on Figure 27) are enlarged by the recalculation process to cover 2 to 4 pixels instead of one. (4) The regional planners at the Area XV Regional Planning Commission in Ottumwa, Iowa indicated that a photographically oriented true north scene was just as useful for their purposes as a computer rotated scene.

COLOR PHOTOGRAPHIC PROCESSING AT THE IOWA GEOLOGICAL SURVEY

Attempts were made to minimize the blue-green domination in portions of the digitally enhanced scenes through photographic processing techniques. Photographic technicians at JPL found it difficult to determine the optimal exposure, color balance, and image scale for land classification purposes in south central Iowa. For this reason, color photographic processing was implemented at the Iowa Geological Survey so that persons trained in image analysis could judge the quality and usefulness of the color products in the photographic laboratory. Because the printing and processing of both JPL color film negatives and EDC color film positives was desired, the Unicolor processing system was identified as the most practical and inexpensive method to meet these capabilities. The initial investment was surprisingly small--about $115.00. Below is a list with prices for the equipment (beyond the standard black and white photographic paraphernalia) needed for color processing:

1.	Unicolor processor drum	$ 29.00
2.	Color compensating filters	30.00
3.	Unicolor drum roller	41.00
4.	Unicolor thermometer	15.00
	Total	$115.00 (1976 prices)

The color photographic papers used at IGS in the Unicolor system were Kodak RC-37 for printing color negatives and Ciba-Geigy Cibachrome Type A for printing color positives. The chemical processing cycle for either paper takes about 12 to 15 minutes. Varying processor drum sizes allowed as many as two 11x14-inch prints or four 8x10-inch prints to be developed simultaneously. The chemical temperature requirements for both of these color papers were not extremely critical. A range of 75°F ± 3°F is permitted for Cibachrome chemicals, while RC-37 paper processing allows a 5°F range (72½°F ± 2½°F) for the developer and a 10°F range (75°F ± 5°F) for all other chemicals. Processing costs incurred per picture (chemical + paper) are listed below:

	Print Size	
Photo Paper Type	8" x 10"	11" x 14"
RC-37	$ 0.87/print	$ 1.34
Cibachrome Type A	$ 1.89	$ 3.89 (1976 prices)

Although the blue-green domination problem could not be eliminated through photographic techniques, high quality prints were inexpensively processed by persons with minimal photographic experience from readily available color processing systems. This ability to print color composite prints allows the image user to:

1. project the prints at the exact scale desired,
2. expose for optimal color contrast and saturation,
3. adjust for suitable color balance, and
4. quickly judge the usefulness of the products for photographic analysis and interpretation.

DATA TRUNCATION AND THE BLUE-GREEN

DOMINATION OF FALSE-COLOR COMPOSITES

Careful evaluation of the JPL false-color composite led to the analysis that the blue-green appearance of several landscape features was related to either very high or very low reflectance phenomena. Upon contrast stretching of the image data, extreme tonal values were saturated to white and black. The amount of data to be truncated prior to linear stretching of the scene was arbitrarily determined from spectral histograms. The percentage of saturated pixel elements could be easily ascertained but the location of these pixels within the scene could not be specified from the histogram data. The IMAGE 100 system at JPL was used to determine the percent and location of pixels truncated in order to investigate the suspected relationship between the blue-green color dominance in the JPL enhanced scene (Figure 4) and the amount of data truncated during contrast stretching. The Wapello County subscene was processed from the CCT data of the August 29, 1972 scene, stored in memory, and displayed on the IMAGE 100 television monitor (Figure 29). The cursor in rectangular

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Figure 29 near here.

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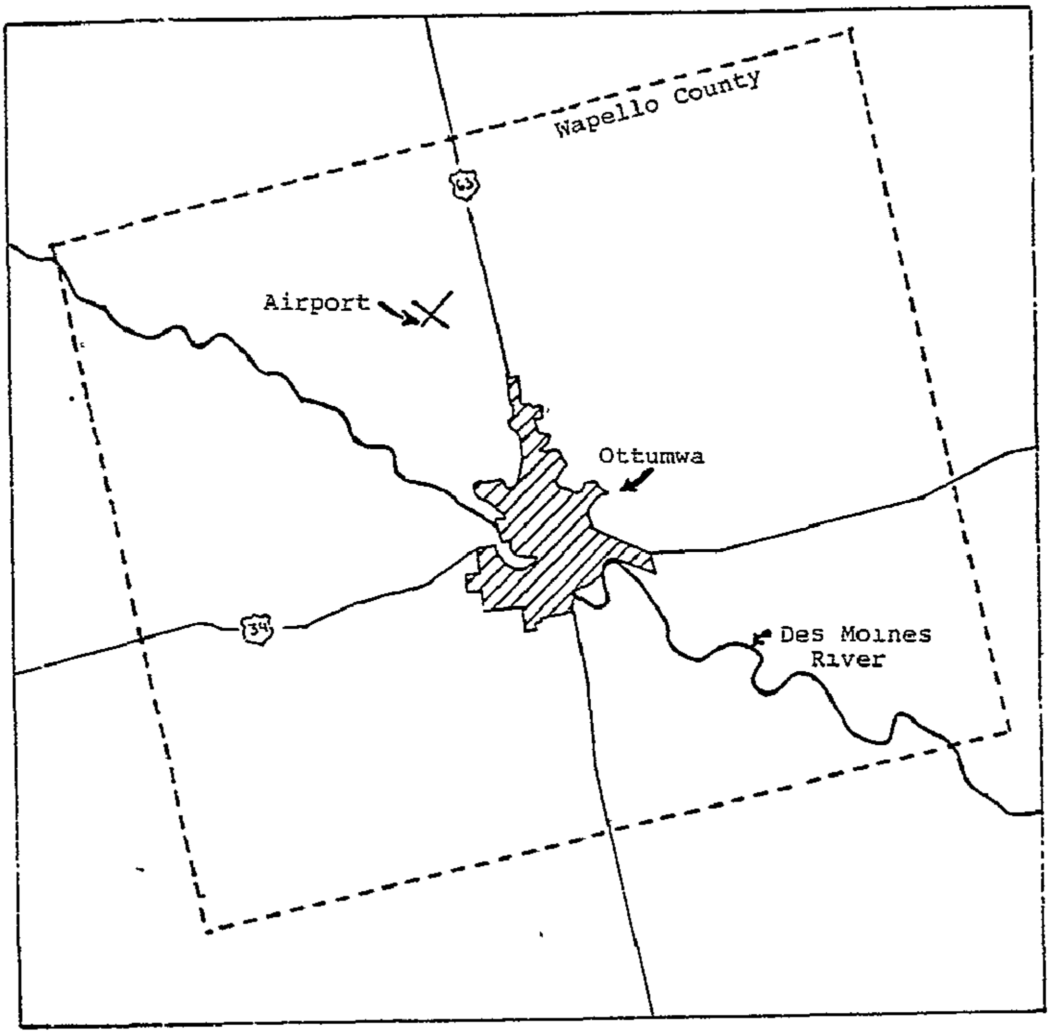
mode was positioned to enclose the entire image on the

Figure 29. Location of Wapello County as displayed on the IMAGE 100 television monitor. This sketch map is used in conjunction with Figures 30 through 34 to show the location of picture elements saturated either to white or black during contrast stretching of image data.

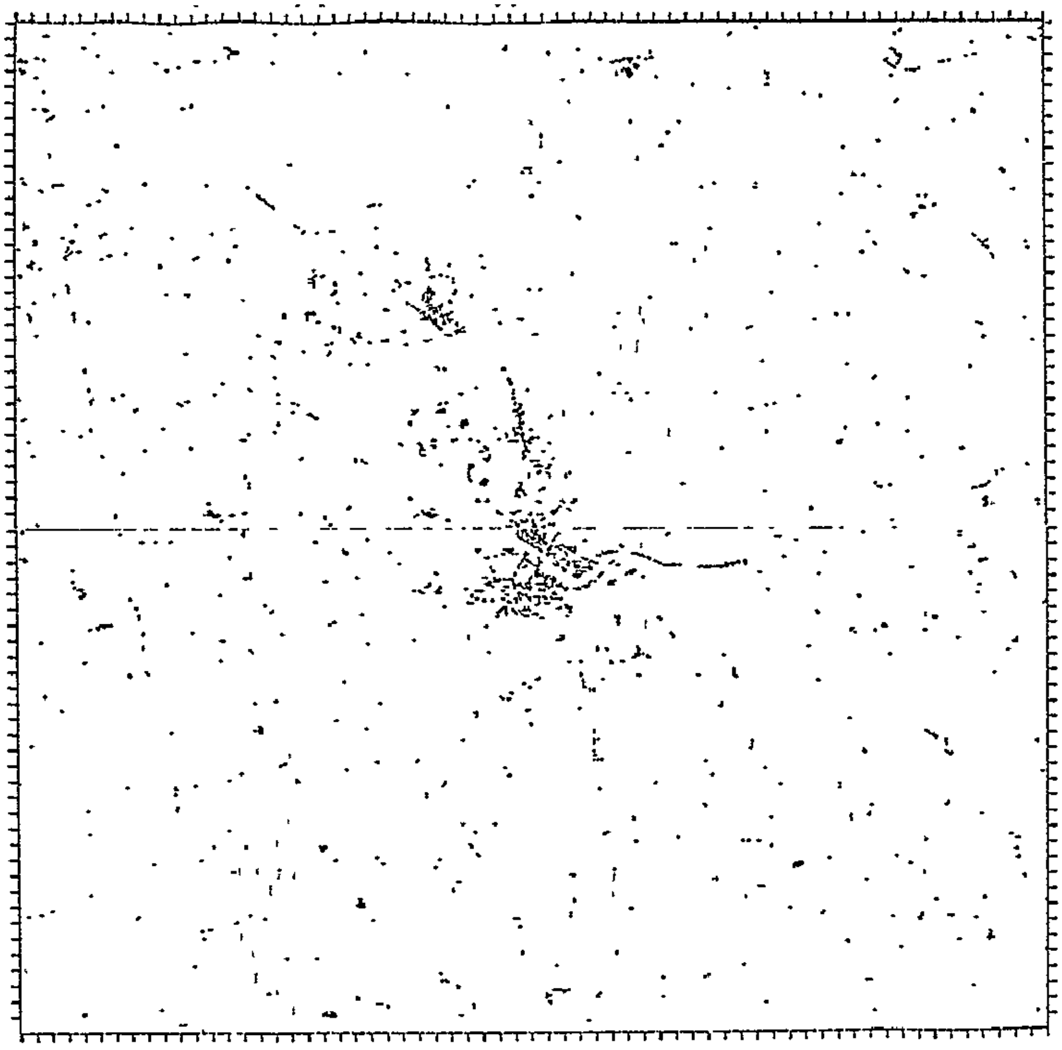


screen. The single-cell signature acquisition and histogram overlay programs were used to determine the spectral histograms for the MSS data in memory. The upper and lower stretch bounds for each band used to produce the JPL false-color composite (MSS bands 4, 5, and 6) were read from the VICAR system annotation on the black and white film positives. The raw data in the memory for band 4 was produced on the terminal screen by the histogram display program. Using the thumbwheel located on the terminal keyboard, the vertical crosshair which originally designated the upper raw data bound of 254 was repositioned to DN 67 on the histogram abcissia, thereby reassigning the upper bound value for band 4 (Tables 11 and 12). The amount of pixels truncated by this reassignment of the upper data bound was 1.13 percent. Distribution of the affected picture elements was shown on the television monitor by "alarming" (assigning a color for identification purposes) these pixels in green. The location of the pixels saturated to white or black within each band of the scene was represented on paper by using the Gould printer interfaced with the IMAGE 100 (Figures 30 through 34). These prints illustrate that

Figures 30 through 34 near here.

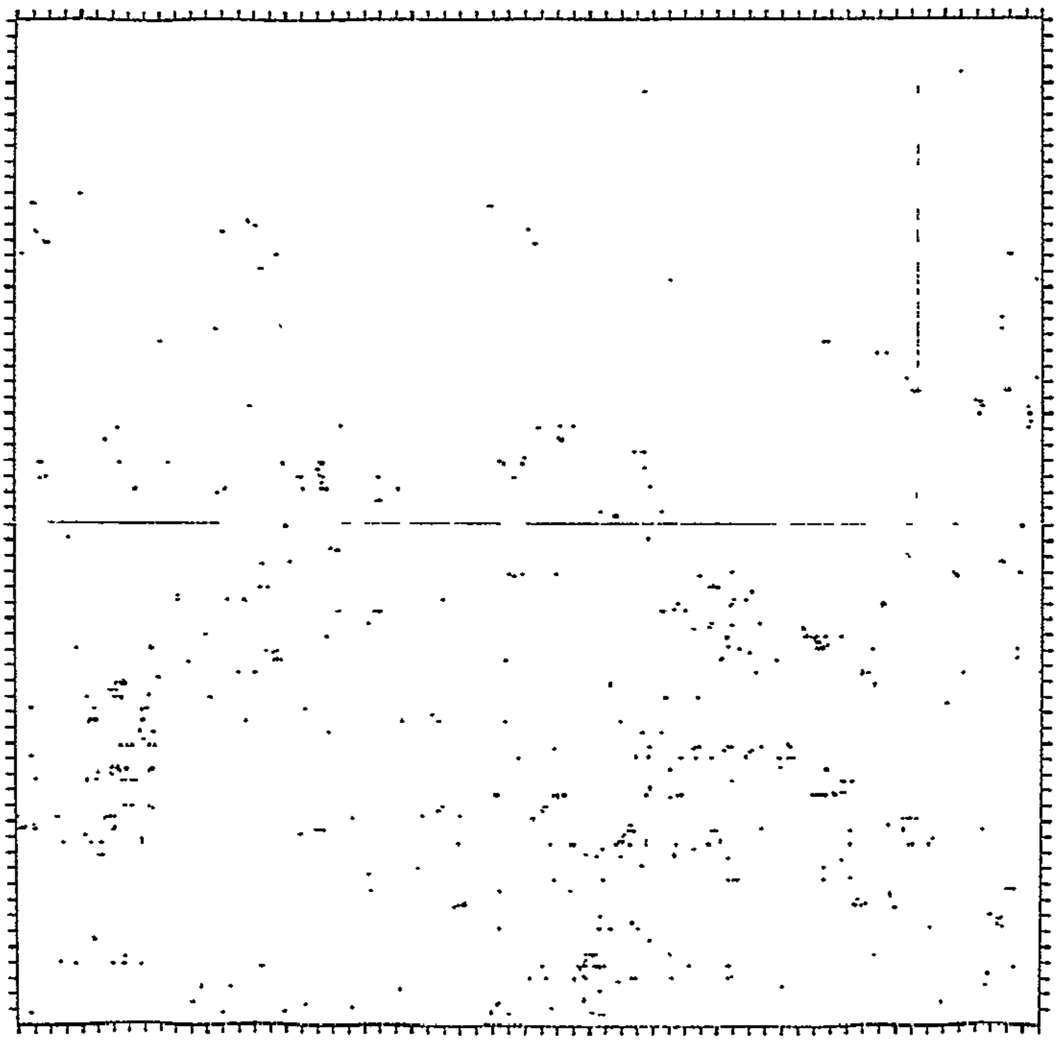
even when very small percentages of the raw data are truncated, the tonal variations that are lost tend to

Figure 30. Pixels saturated to white (displayed in black) by contrast stretching using DN 67 as the upper stretch limit for band 4 of the August 29, 1972 Wapello County subscene (1037-16213) display produced on the IMAGE 100 system at JPL



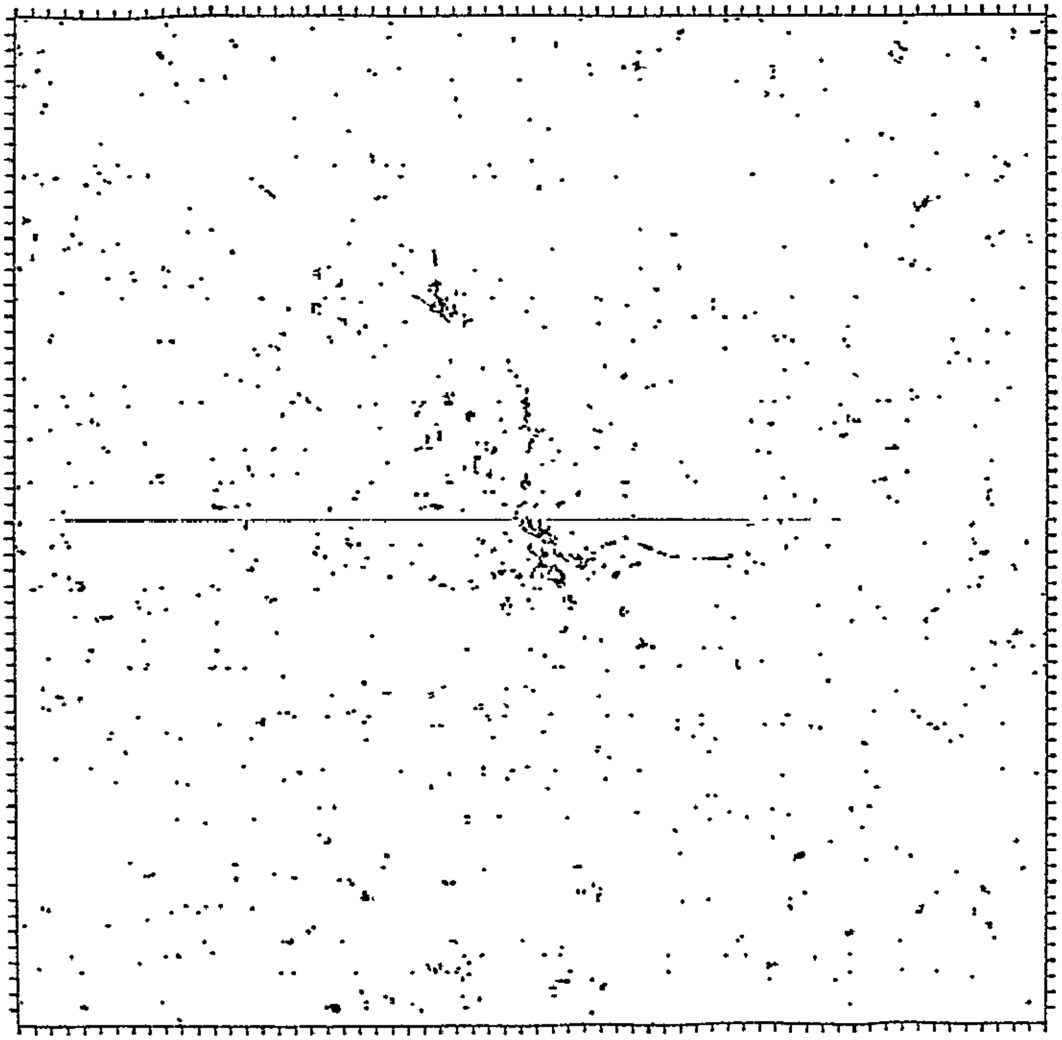
MSS Band 4: Upper Data Bound--DN 254.
Upper Stretch Bound--DN 67; Reassigned to DN 255.
DN 67 to 254 Saturated to White (1.13% of Total Pixels).

Figure 31. Pixels saturated to black by contrast stretching using DN 40 as the lower stretch limit for band 4 of the August 29, 1972 Wapello County subscene (1037-16213). Display produced on the IMAGE 100 system at JPL.



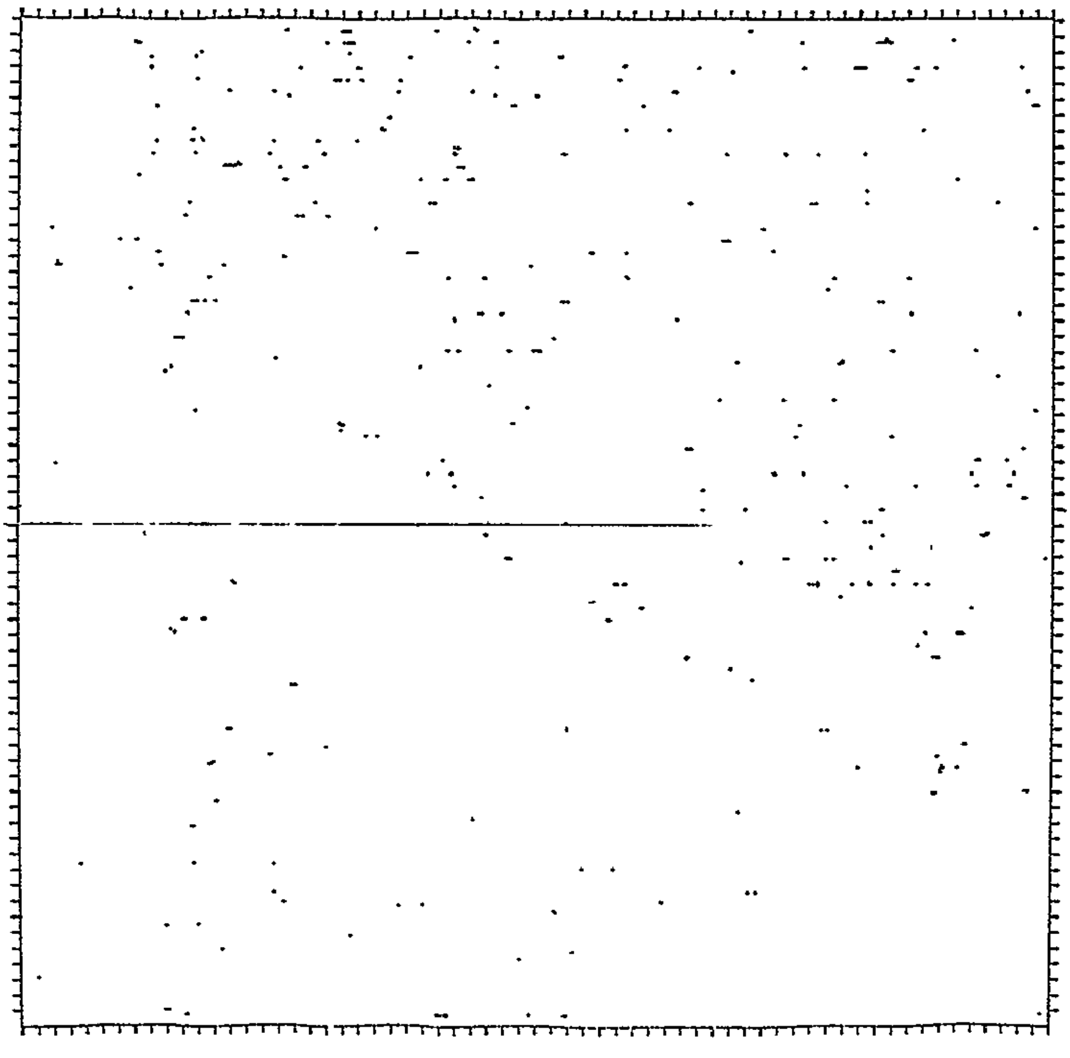
MSS Band 4: Lower Date Bound--DN 6.
Lower Stretch Bound--DN 40; Reassigned to DN 0.
DN 6 to 40 Saturated to Black (0.26% of Total Pixels).

Figure 32. Pixels saturated to white (displayed in black) by contrast stretching using DN 150 as the upper stretch limit for band 5 of the August 29, 1972 Wapello County subscene (1037-16213). Display produced on the IMAGE 100 system at JPL.



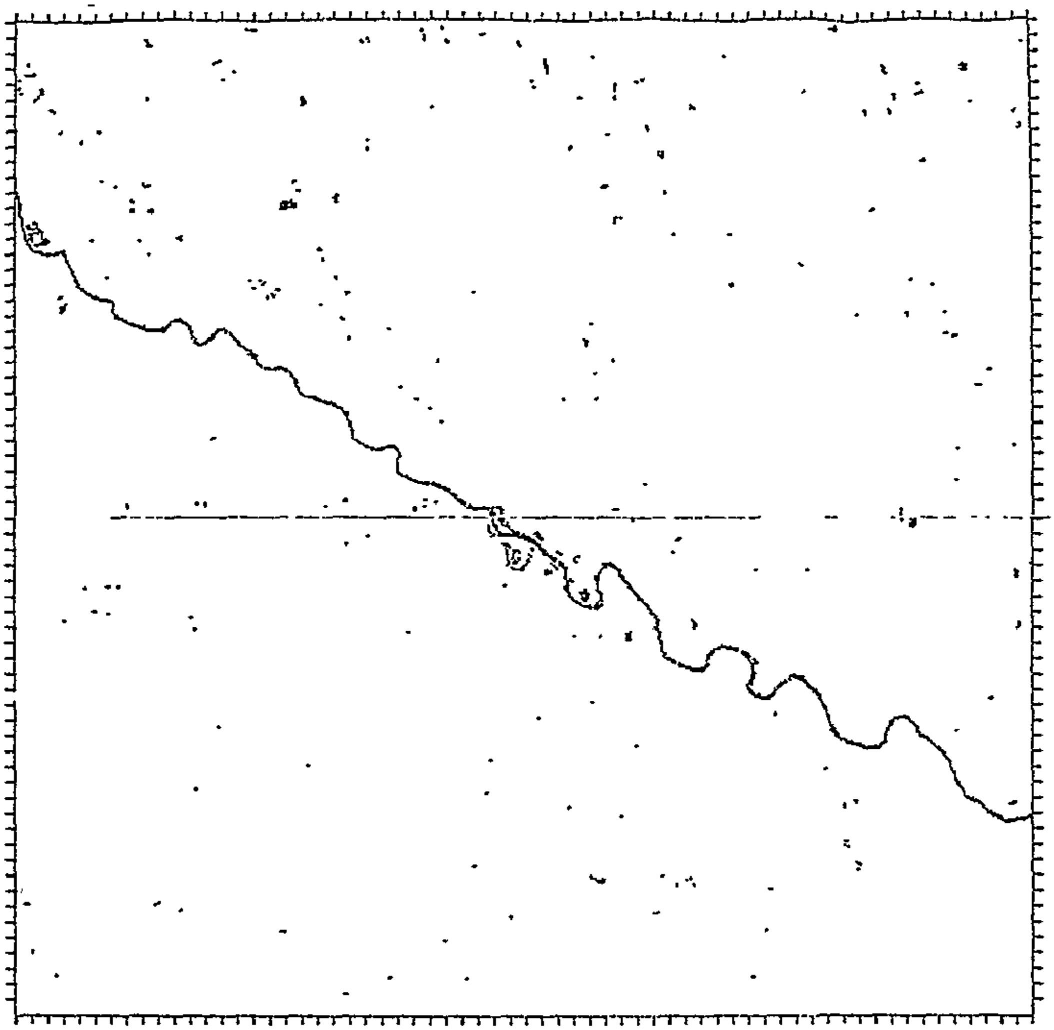
MSS Band 5: Upper Data Bound--DN 254.
Upper Stretch Bound--DN 150; Reassigned to DN 255.
DN 150 to 254 Saturated to White (0.80% of Total Pixels).

Figure 33. Pixels saturated to white (displayed in black) by contrast stretching using DN 150 as the upper stretch limit for band 6 of the August 29, 1972 Wapello County subscene (1037-16213). Display produced on the IMAGE 100 system at JPL.



MSS Band 6: Upper Data Bound--DN 230.
Upper Stretch Bound--DN 150; Reassigned to 255.
DN 150 to 230 Saturated to White (0.19% of Total Pixels).

Figure 34. Pixels saturated to black by contrast stretching using DN 54 as the lower stretch limit for band 6 of the August 29, 1972 Wapello County subscene (1037-16213). Display produced on the IMAGE 100 system at JPL.



MSS Band 6: Lower Data Bound--DN 0.
Lower Stretch Bound--DN 54: Reassigned to DN 0.
DN 0 to 54 Saturated to Black (0.87% of Total Pixels).

cluster in various land classes such as urban areas and water. The upper truncation limits for bands 4 and 5, for example, (Figures 30 and 32) show approximately one percent of the upper reflectance pixels saturated to white when the scenes are contrast stretched. The urban area of Ottumwa, the airport, and sections of roads can be delineated by the location of the truncated pixels. Randomly located pixels on the upper stretch limit saturation prints are often related to pixel drops and not to land cover phenomena. The assignment of a lower stretch bound of DN 54 to band 6 resulted in the loss of tonal variations in low reflectance scene elements, such as water bodies (Figure 34). The pixels (less than one percent) outlining the meandering course of the Des Moines River as well as the oxbow lakes near Ottumwa all possessed the same tone (black) after contrast stretching. When the contrast stretched bands were composited into a false-color product, the tones resulting from data truncation on all three bands had a cumulative effect on the print in terms of loss of variations in tonal detail. The associated high and low optical densities of these saturated pixels on the individual band film products was determined to have created the blue-green color dominance in certain land cover classes on the false-color composite. For example, when bands 4 and 5 are contrast stretched with upper reflectance values truncated to white, the resultant black and white film products display urban areas as low optical density land cover. Concrete and light colored roof tops account for the high reflectance nature of cultural features. Bands 6 and 7, however, record low reflectance values for these features, which results in much higher optical film densities for the same urban areas. When a false-color composite is printed from these black and white positives, the bands are registered and individually printed onto a sheet of color film. Band 4 is printed with blue light, band 5 is printed with green light, and band 6 (or 7) is printed with red light. When bands 4 and 5 are severely stretched, the black and white film positives have low optical density in urban areas. During the printing of a false-color composite, much silver halide will be activated in the corresponding emulsion layers causing little yellow or magenta dyes to be formed. Band 6 (or 7), which displays urban areas as dark tones, prevents red light from reaching the "red emulsion layer". Consequently little silver halide is activated and much cyan dye is produced. Because little yellow and magenta dyes are produced for the urban areas, much blue and green light will be reflected from a color print. The cyan dye for band 6 (or 7) will absorb the red light being reflected from the print, and hence cause the urban areas to be dominated by blue-green colors. A summary of this discussion is outlined on Figure 35.

Figure 35 near here

Figure 35. Illustration of the blue-green color domination for urban areas on a computer enhanced satellite image

Landsat Spectral Band	Urban Scene Characteristics on enhanced Landsat black and white film products	Colors Produced on color film dye layers for urban areas when a color composite is generated from black & white film products	Light Reflected from color print for urban areas
#4	Light (little density)	Little Yellow Dye Formed	Much Blue Light Reflected
#5	Light (little density)	Little Magenta Dye Formed	Much Green Light Reflected
#6 (or 7)	Dark (much density)	Much Cyan Dye Formed	Little Red Light Reflected

RESULT: BLUE-GREEN DOMINATION IN URBAN AREAS

VARIATIONS IN DIGITAL IMAGE PROCESSING FOR THE WAPELLO COUNTY SUBSCENE

Three versions of the Wapello County subscene have been produced on the IMAGE 100 and recorded on film by the Optronics system to illustrate the effects of data truncation resulting from contrast stretching of a scene. One subscene was produced with raw data from the standard EDC computer compatible tape, another with 2% data truncation on each end of the spectral histograms (4% total), and the third with limited contrast stretch bounds that were interactively determined on the IMAGE 100 to minimize the loss of scene detail due to data truncation. The image data extracted by the IMAGE 100 for these subscenes were stored in memory on magnetic tape for film recording on the Optronics P-1700 system at EDC. A table look-up program was employed to ensure that the spectral bands produced on the recorder were linear with density. Hence, only densities that were capable of being recorded on Kodak 2447 film were assigned to the digital number range of each band. The black and white film positives produced for bands 4, 5, and 7 were registered as a set and composited on Kodak 2447 in the same manner as Landsat standard product false-color film positives. These false-color composites were printed on Kodak 2212 paper.

Wapello County subscene recorded from raw data

The first Wapello County subscene recorded on film by the Optronics system was produced from the raw data of a standard EDC computer compatible tape. Densitometer readings from the 22 step density wedge on the black and white film positives showed the digital numbers to be linear with transmission (Figure 36 with data on Table 15).

Figure 36 and Table 15 near here.

The plotted film recording relationship demonstrated that all digital number values were assigned densities that were capable of being recorded on Kodak 2447 film. These raw data film positives were found to be characteristically low in contrast. Spectral histograms showed most of the data to be concentrated in a small digital number range within the data bounds for each MSS band (Figure 37). The false

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Figure 37 near here.

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color composite transparency produced from the black and white positives displayed low color contrast (color print on Figure 38).

Figure 38 near here.

Figure 36. Transmission density versus digital number for the 22 step density wedge recorded on the Optronics film of the raw data Wapello County subscene processed by the IMAGE 100

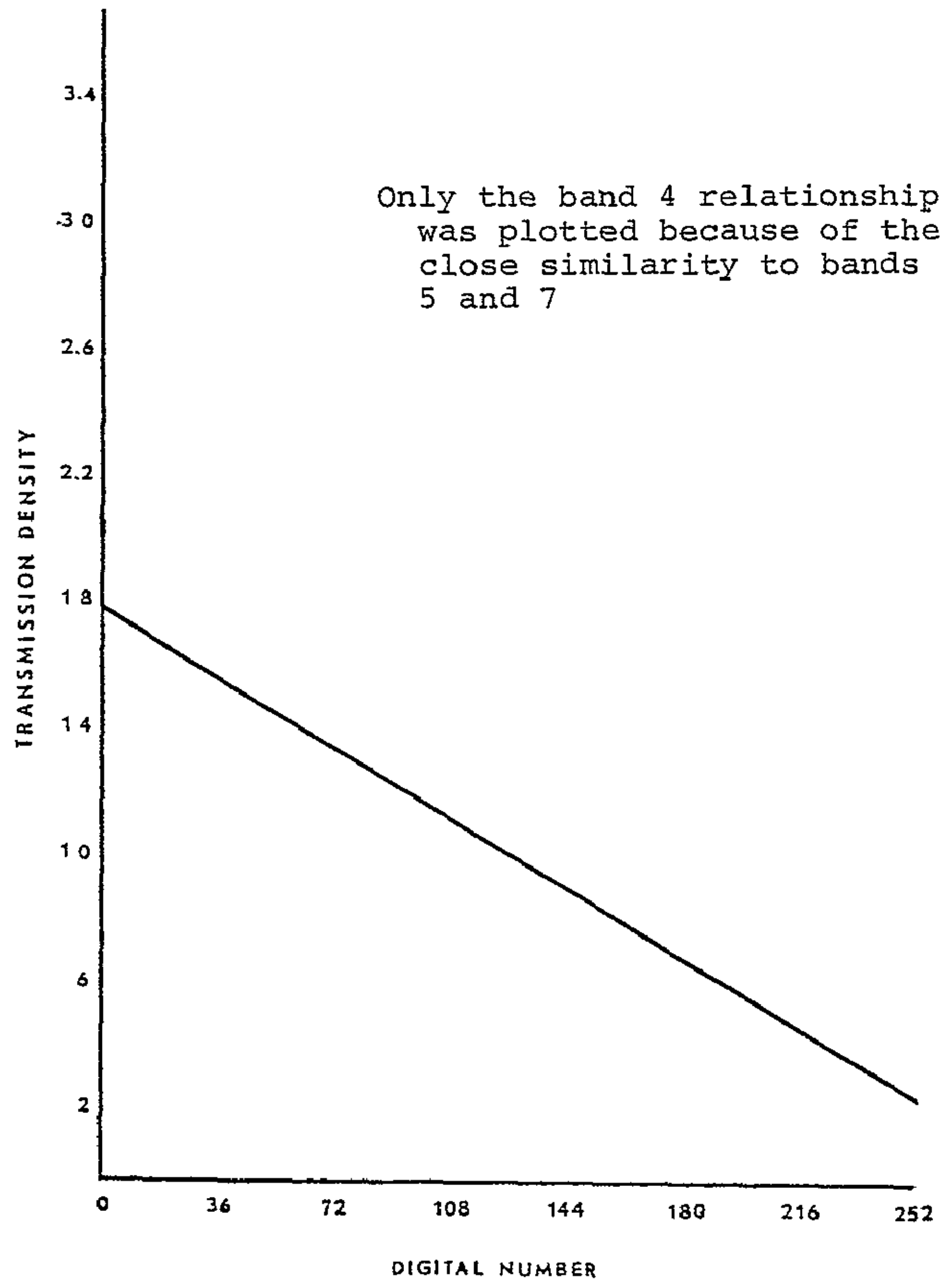


Table 15. Step wedge densities from Optronics film positives for raw data of the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Band 4	Band 5	Band 7
1	252	.22	.22	.22
2	240	.29	.29	.29
3	228	.38	.38	.38
4	216	.47	.47	.46
5	204	.52	.52	.52
6	192	.60	.60	.60
7	180	.65	.66	.67
8	168	.73	.73	.74
9	156	.80	.80	.81
10	144	.88	.88	.89
11	132	.95	.94	.96
12	120	1.03	1.03	1.05
13	108	1.11	1.11	1.12

Table 15. Step wedge densities from Optronics film positives for raw data of the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Band 4	Band 5	Band 7
14	96	1.20	1.20	1.21
15	84	1.27	1.27	1.27
16	72	1.35	1.35	1.36
17	60	1.41	1.41	1.41
18	48	1.48	1.48	1.48
19	36	1.56	1.56	1.56
20	24	1.62	1.63	1.63
21	12	1.70	1.71	1.72
22	0	1.78	1.79	1.79

Figure 37. Spectral histograms of the raw data for the Wapello County subscene processed by the IMAGE 100 for the August 29, 1972 Landsat scene (1037-16213)

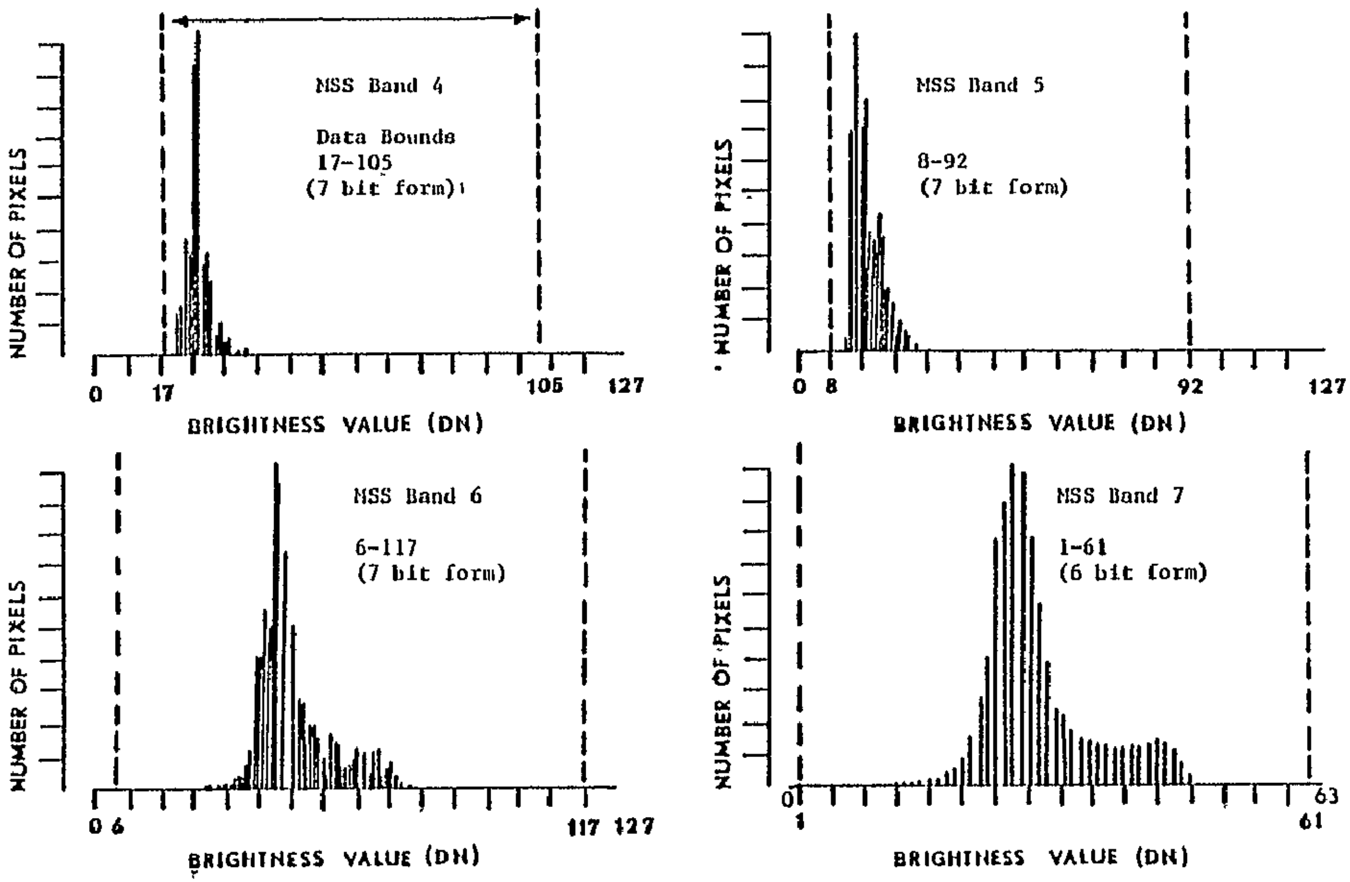
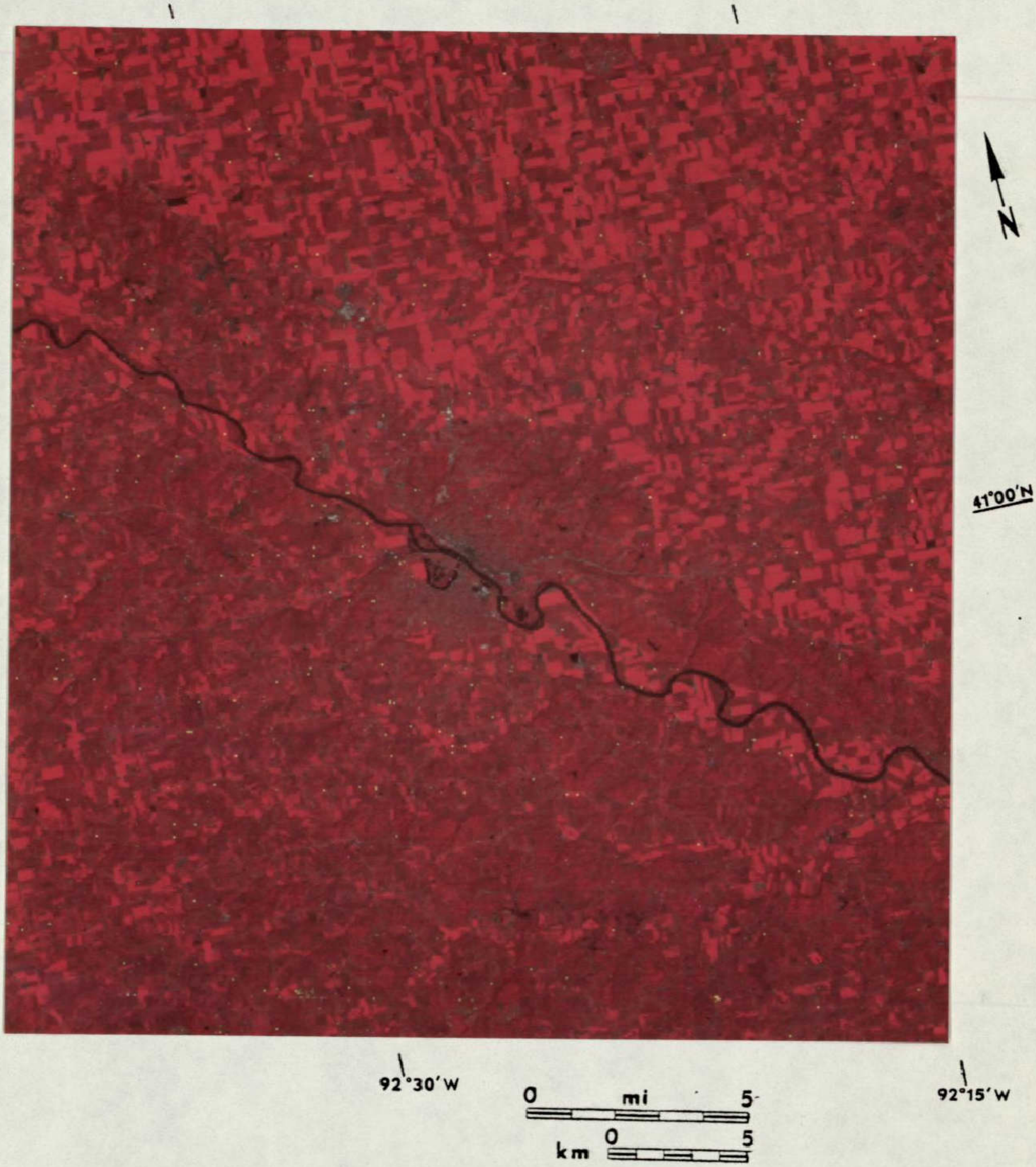


Figure 38. False-color print of the Wapello County subscene produced from raw data. Subscene processed by the IMAGE 100 and recorded on the Optronics system.



Subscene from Landsat image taken on August 29, 1972 (1037-16213). Scale: approximately 1:250,000

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A graph of transmission density versus digital number for the dye layers on the false-color film positive is shown on Figure 39 (data on Table 16). These data have indicated

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Figure 39 and Table 16 near here.

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that all digital numbers assigned to densities have been uniquely recorded on each dye layer of the color film. Little detail can be established on this subscene in the urban area of Ottumwa or in the forested lands in southwestern Wapello County. In addition, transportation networks are very faint on the image and hence difficult to delineate.

Figure 39. Transmission density versus digital number for the dye layers on the 22 step density wedge of the color film positive produced from Optronics film positives of raw data for the Wapello County subscene

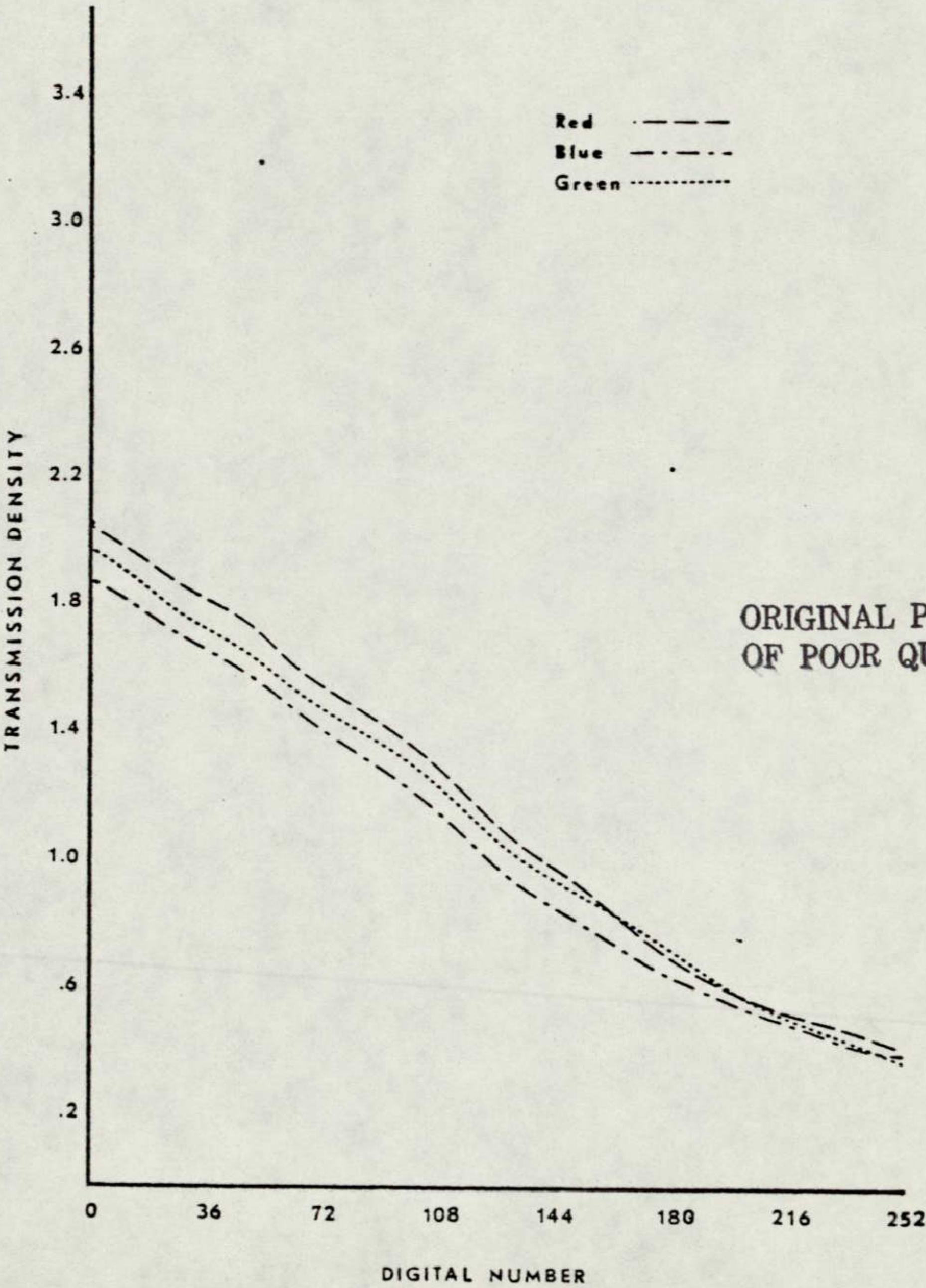

Table 16. Step wedge densities of the color film positive printed from raw data recorded on the Optronics system for the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density Red	Transmission Density Green	Transmission Density Blue
1	252	.39	.35	.37
2	240	.43	.40	.40
3	228	.47	.45	.44
4	216	.52	.51	.48
5	204	.56	.56	.52
6	192	.63	.64	.59
7	180	.69	.70	.63
8	168	.77	.78	.70
9	156	.87	.87	.78
10	144	.97	.96	.86
11	132	1.06	1.03	.94
12	120	1.17	1.14	1.05
13	108	1.28	1.23	1.14

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Table 16. Step wedge densities of the color film positive printed from raw data recorded on the Optronics system for the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Red	Green	Blue
14	96	1.39	1.34	1.25
15	84	1.47	1.41	1.33
16	72	1.56	1.49	1.42
17	60	1.63	1.55	1.49
18	48	1.73	1.65	1.58
19	36	1.82	1.72	1.66
20	24	1.89	1.80	1.72
21	12	1.98	1.90	1.81
22	0	2.05	1.98	1.88

Wapello County subscene recorded from linearly contrast stretched data with 2% truncation limits

The second version of the Wapello County subscene was contrast stretched with 2% data truncation on each end of the histograms (4% of total pixels) for each spectral band. Histograms displaying the stretch bounds used for the production of the black and white film positives are found on Figure 40. Ninety-six percent of the spectral data for

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Figure 40 near here.

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each MSS band falls between the dashed lines indicated on each histogram. These data were linearly stretched by the IMAGE 100 computer (histograms on Figure 41) and stored on

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Figure 41 near here.

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magnetic tape. Black and white positives were produced from this stored data with the digital numbers recorded linearly with transmission on the Optronics film recorder (data on Table 17). The step wedge densities on the composited

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Table 17 near here.

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false-color film positive have also demonstrated a general

Figure 40. Spectral histograms for the Wapello County subscene processed by the IMAGE 100 showing the contrast stretch bounds for 2% data truncation on each end of the histogram. Subscene from the August 29, 1972 Landsat scene (1037-16213).

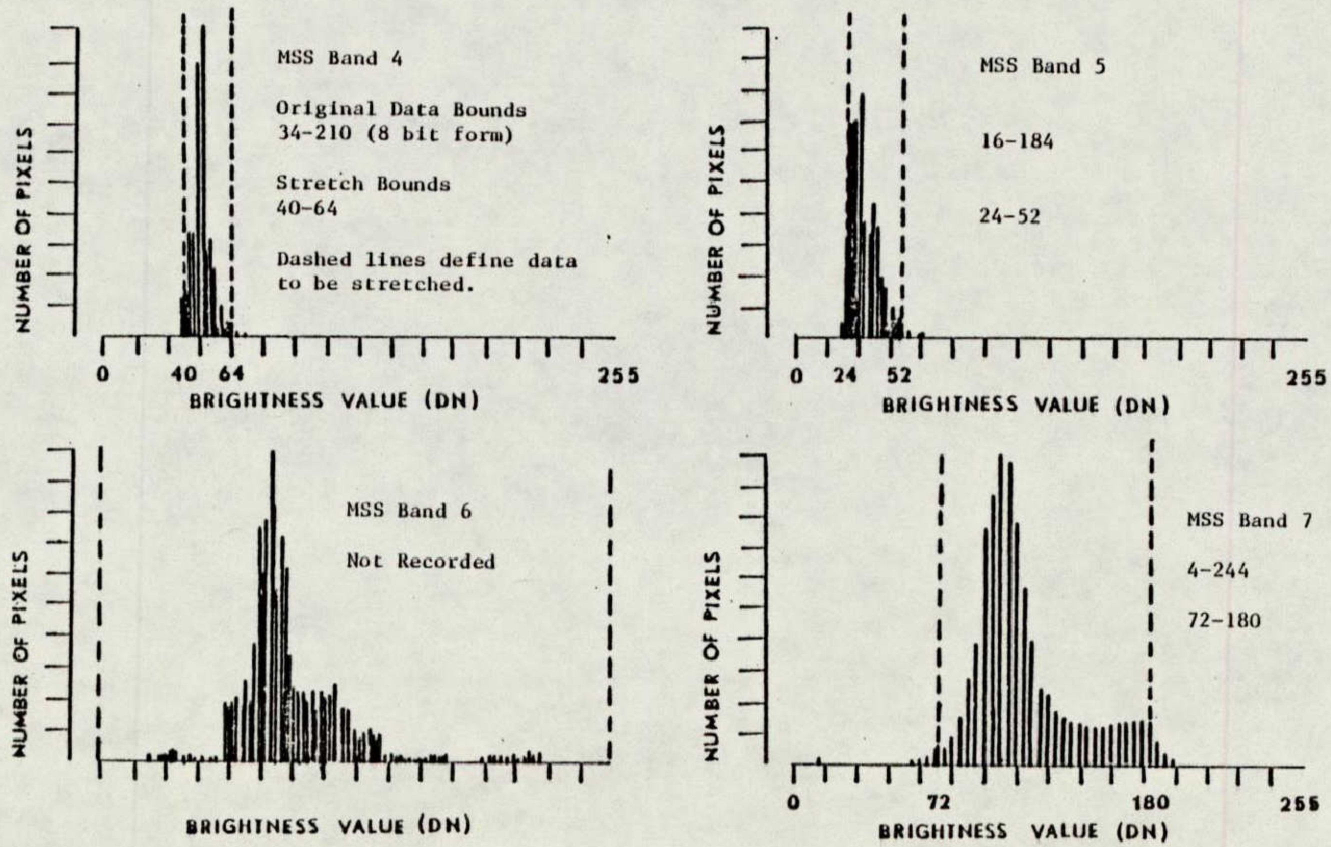

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Figure 41. Spectral histograms for the Wapello County subscene processed by the Image 100 showing the 4% total truncated data after linear contrast stretching. Subscene from the August 29, 1972 Landsat scene (1037-16213).

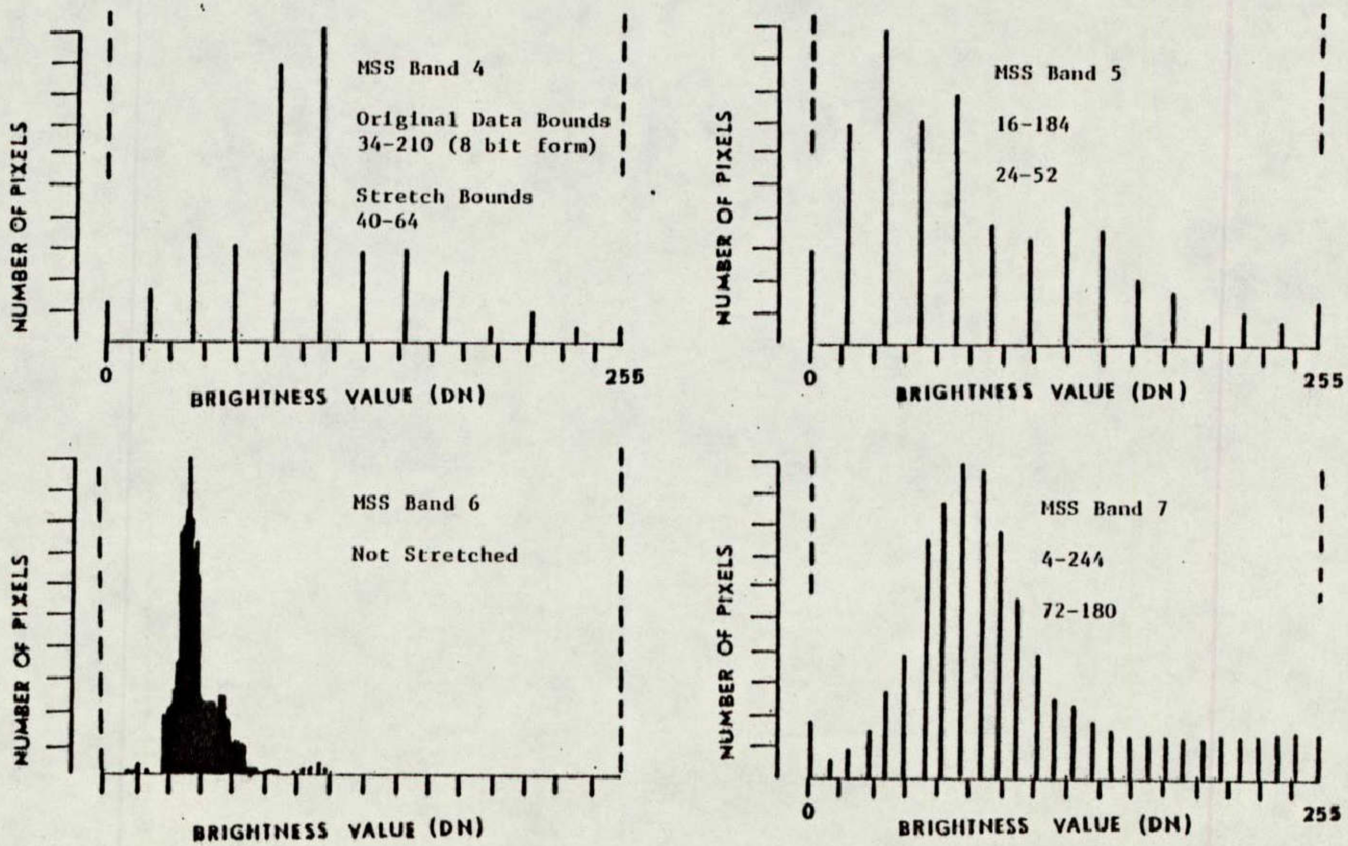

Table 17. Step wedge densities from Optronics film positives for truncated data (2% on each end of the histogram) of the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Band 4	Band 5	Band 7
1	252	.21	.22	.22
2	240	.27	.29	.30
3	228	.35	.38	.39
4	216	.44	.47	.48
5	204	.50	.53	.53
6	192	.59	.62	.61
7	180	.65	.68	.67
8	168	.72	.75	.75
9	156	.79	.83	.82
10	144	.87	.91	.90
11	132	.93	.98	.97
12	120	1.01	1.06	1.06
13	108	1.09	1.14	1.13

Table 17. Step wedge densities from Optronics film positives for truncated data (2% on each end of the histogram) of the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density Band 4	Transmission Density Band 5	Transmission Density Band 7
14	96	1.18	1.23	1.23
15	84	1.24	1.29	1.29
16	72	1.33	1.38	1.35
17	60	1.39	1.44	1.43
18	48	1.46	1.52	1.50
19	36	1.54	1.60	1.58
20	24	1.60	1.67	1.66
21	12	1.69	1.75	1.76
22	0	1.77	1.82	1.84

linear relationship between digital number and film density, thereby indicating that all digital number densities were uniquely recorded (Figure 42 with data on Table 18).

Figure 42 and Table 18 near here.

Figure 42. Transmission density versus digital number for the dye layers on the 22 step density wedge of the color film positive produced from Optronics film positives of the 4% truncated data for the Wapello County subscene

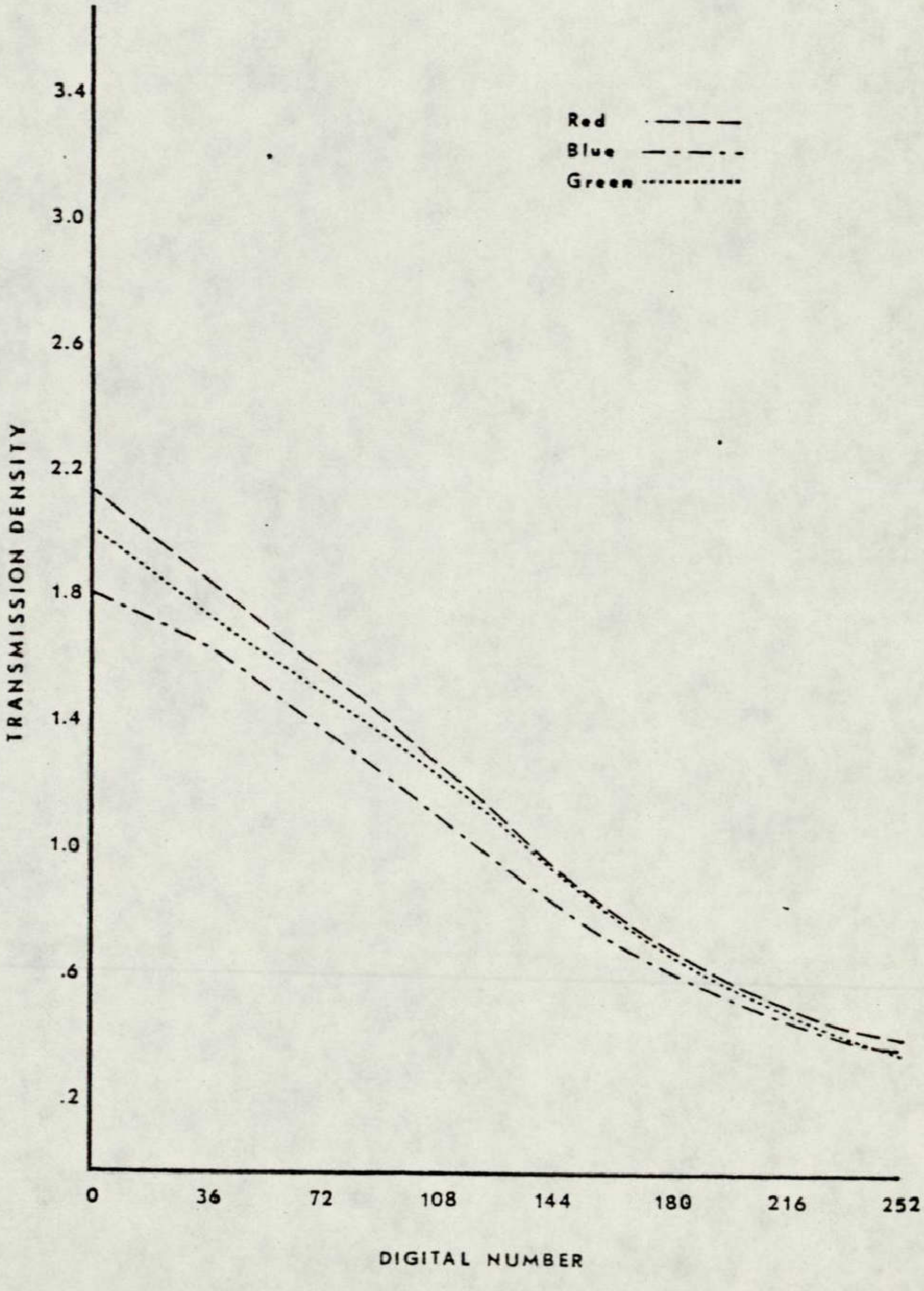

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Table 18. Step wedge densities of the color film positive printed from 4% truncated data (2% on each end of histogram) recorded on the Optronics system for the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density Red	Transmission Density Green	Transmission Density Blue
1	252	.38	.33	.35
2	240	.40	.37	.37
3	228	.44	.42	.41
4	216	.50	.49	.46
5	204	.54	.54	.50
6	192	.61	.61	.55
7	180	.66	.67	.60
8	168	.75	.76	.67
9	156	.85	.84	.74
10	144	.95	.94	.83
11	132	1.05	1.03	.91
12	120	1.16	1.12	1.00

Table 18. Step wedge densities of the color film positive printed from 4% truncated data (2% on each end of histogram) recorded on the Optronics system for the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Red	Green	Blue
13	108	1.22	1.21	1.09
14	96	1.29	1.33	1.21
15	84	1.46	1.39	1.27
16	72	1.56	1.48	1.36
17	60	1.64	1.55	1.44
18	48	1.73	1.63	1.53
19	36	1.83	1.72	1.62
20	24	1.91	1.79	1.66
21	12	2.01	1.88	1.71
22	0	2.12	1.98	1.80

The false-color print produced from the 4% truncated data composite (Figure 43) shows an extreme blue-green

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Figure 43 near here.

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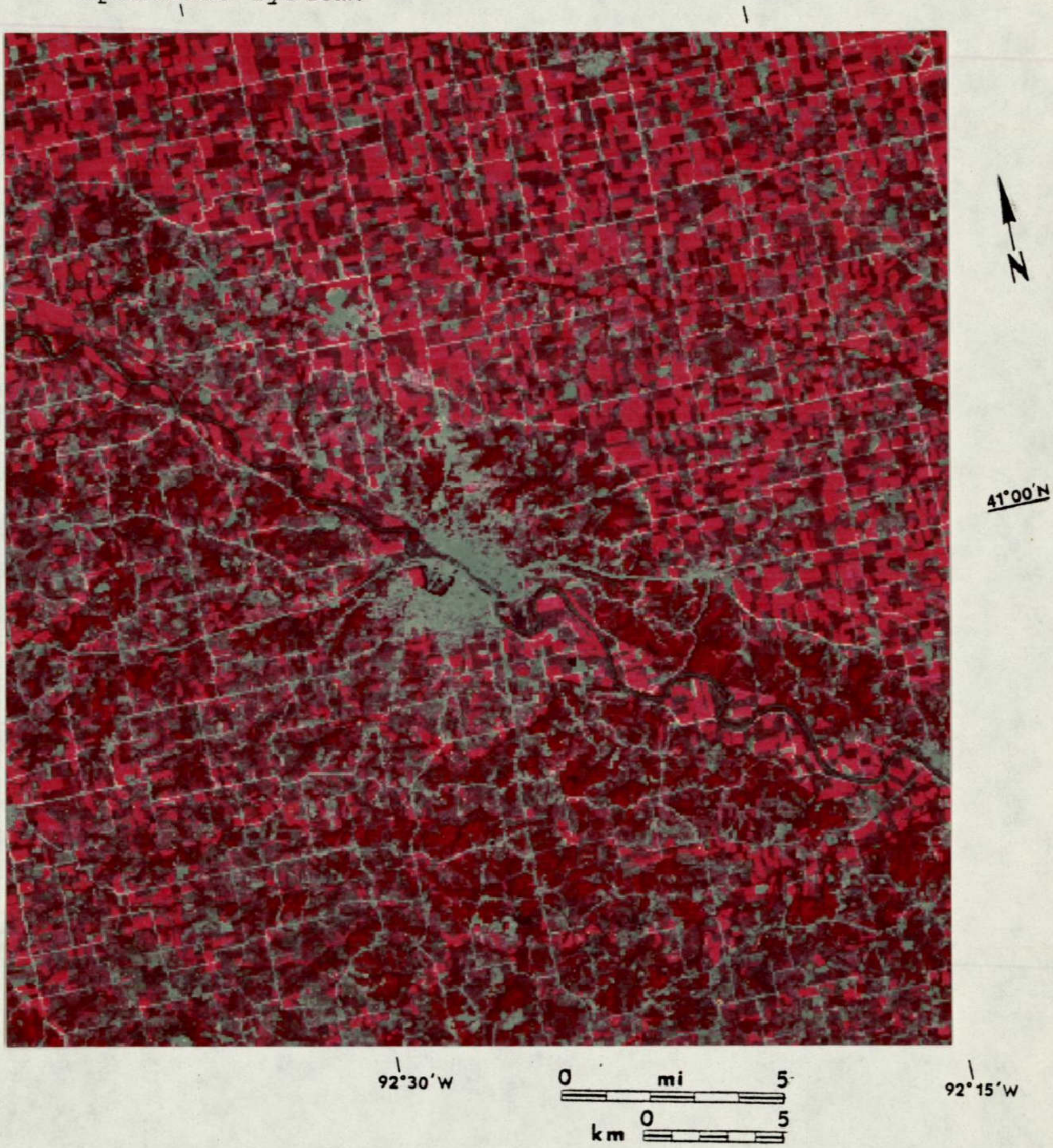
dominance within the scene. Ottumwa especially possesses an overall blue-green hue. This homogeneous appearance has generally eliminated the differentiation between the commercial/industrial and residential sections of the urban area. Strip mines northwest of Ottumwa also appear blue-green and are similar in color to selected agricultural fields. The road network, especially in the southwestern portion of Wapello County, also is dominated by this hue. The extent of the blue-green color is of greater proportions on this scene than on the JPL enhanced prints shown on Figures 4 and 27. This blue-green dominance in the various land classes has been found to be directly related to the amount of data truncated during the process of contrast stretching.

Figure 43. False-color print of the contrast stretched Wapello County subscene with 4 percent data truncation. Subscene processed by the IMAGE 100 and recorded on the Optronics system.



Subscene from Landsat image taken on August 29, 1972 (1037-16213). Scale: approximately 1:250,000

(saturated) pixels thereby causing significant losses of tonal detail in specific land classes, the bound was reassigned until only a random pattern of saturated picture elements occurred. The truncation limits for each MSS band of the third version of the Wapello County subscene were determined in this interactive manner to identify the greatest digital range over which the image data could be expanded without sacrificing significant scene detail. Histograms illustrating the selected stretch bounds are shown on Figure 44. Data from the 22 step density wedge

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Figure 44 near here.

(Table 19) on each of the black and white Optronics

Table 19 near here.

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transparencies of this linearly contrast stretched scene portrays a linear film recording function. The plotted relationship of transmission density and digital number for the false-color composite produced from the Optronics transparencies is displayed on Figure 45 with data on Table 20.

Figure 45 and Table 20 near here.

Figure 44. Spectral histograms for the Wapello County subscene processed by the IMAGE 100 showing original data bounds and interactively determined stretch bounds used to produce the Optronics composite print shown on Figure 46

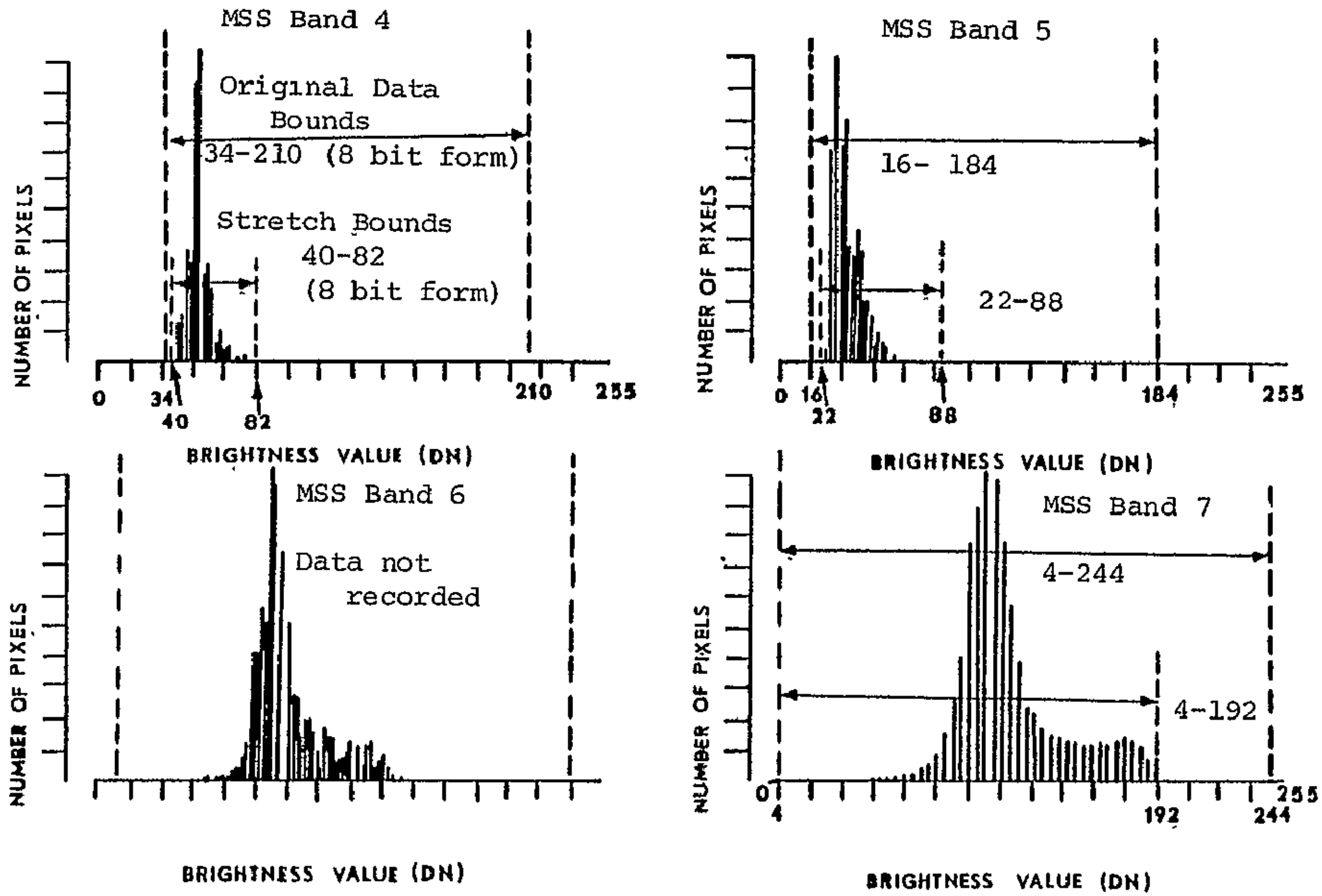

Table 19. Step wedge densities from Optronics film positives for linearly stretched data of the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Band 4	Band 5	Band 7
1	252	.22	.22	.21
2	240	.31	.31	.29
3	228	.41	.41	.37
4	216	.51	.50	.46
5	204	.56	.56	.51
6	192	.65	.64	.59
7	180	.71	.70	.65
8	168	.79	.77	.72
9	156	.86	.84	.79
10	144	.95	.93	.88
11	132	1.02	.99	.94
12	120	1.10	1.07	1.02
13	108	1.17	1.13	1.09

Table 19. Step wedge densities from Optronics film positives for linearly stretched data of the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density Band 4	Band 5	Band 7
14	96	1.25	1.23	1.18
15	84	1.32	1.31	1.24
16	72	1.40	1.38	1.33
17	60	1.46	1.44	1.39
18	48	1.53	1.51	1.45
19	36	1.61	1.59	1.52
20	24	1.67	1.65	1.59
21	12	1.74	1.73	1.68
22	0	1.82	1.81	1.75

Figure 45. Transmission density versus digital number for the dye layers on the 22 step density wedge on the color film positive produced from the Optronics film positives of the linearly stretched data for the Wapello County subscene

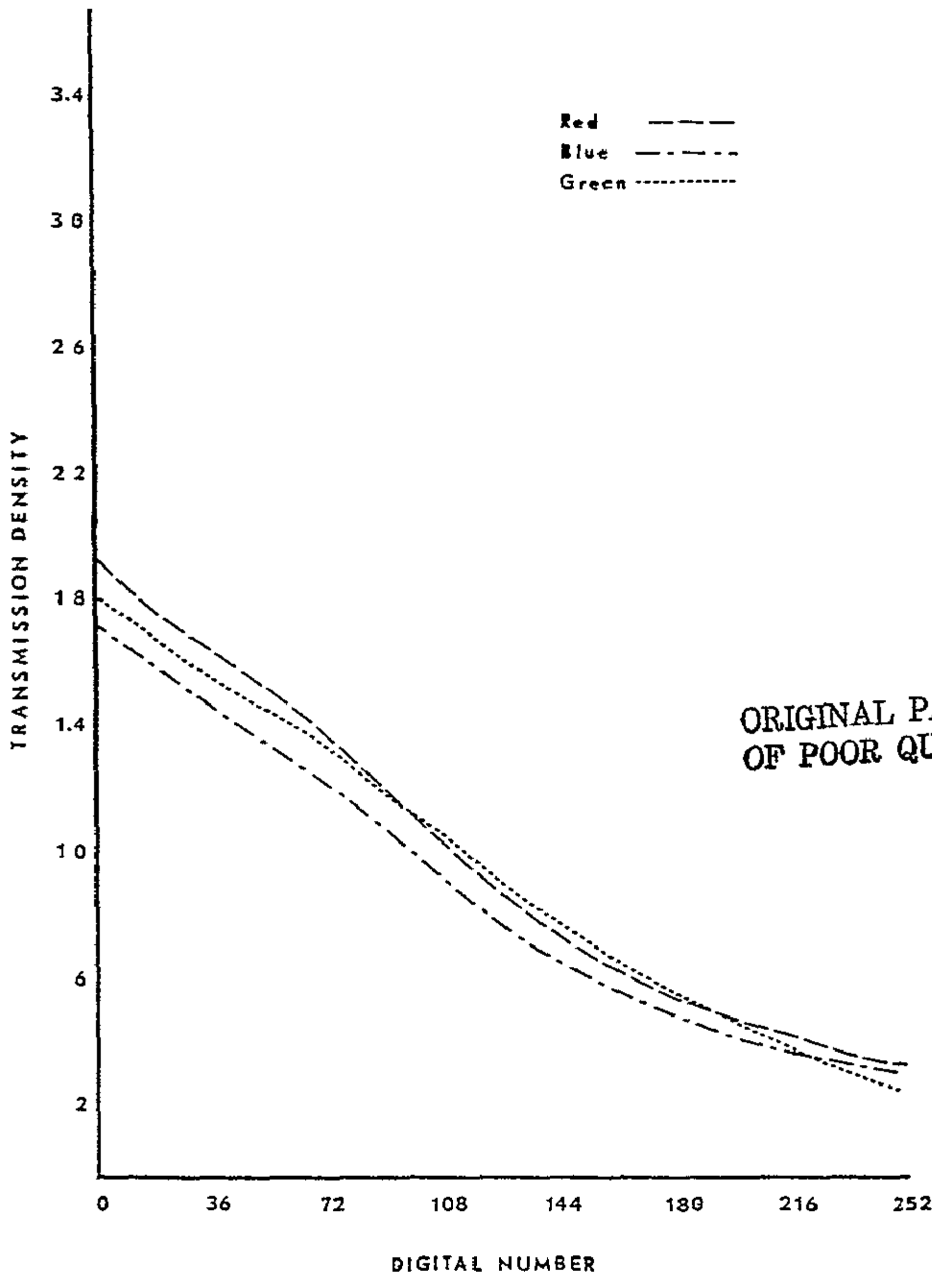

Table 20. Step wedge densities of the color film positive printed from linearly stretched data recorded on the Optronics system for the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Red	Green	Blue
1	252	.33	.25	.31
2	240	.35	.29	.32
3	228	.39	.34	.36
4	216	.43	.40	.39
5	204	.46	.44	.41
6	192	.51	.50	.46
7	180	.55	.55	.49
8	168	.61	.63	.55
9	156	.67	.70	.60
10	144	.76	.79	.67
11	132	.84	.88	.74
12	120	.95	.98	.84

Table 20. Step wedge densities of the color film positive printed from linearly stretched data recorded on the Optronics system for the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Red	Green	Blue
13	108	1.04	1.04	.92
14	96	1.19	1.17	1.04
15	84	1.29	1.28	1.15
16	72	1.40	1.36	1.23
17	60	1.46	1.42	1.31
18	48	1.54	1.48	1.37
19	36	1.64	1.57	1.47
20	24	1.73	1.64	1.55
21	12	1.84	1.73	1.64
22	0	1.93	1.82	1.73

The false-color print of this composite (Figure 46) shows

Figure 46 near here.

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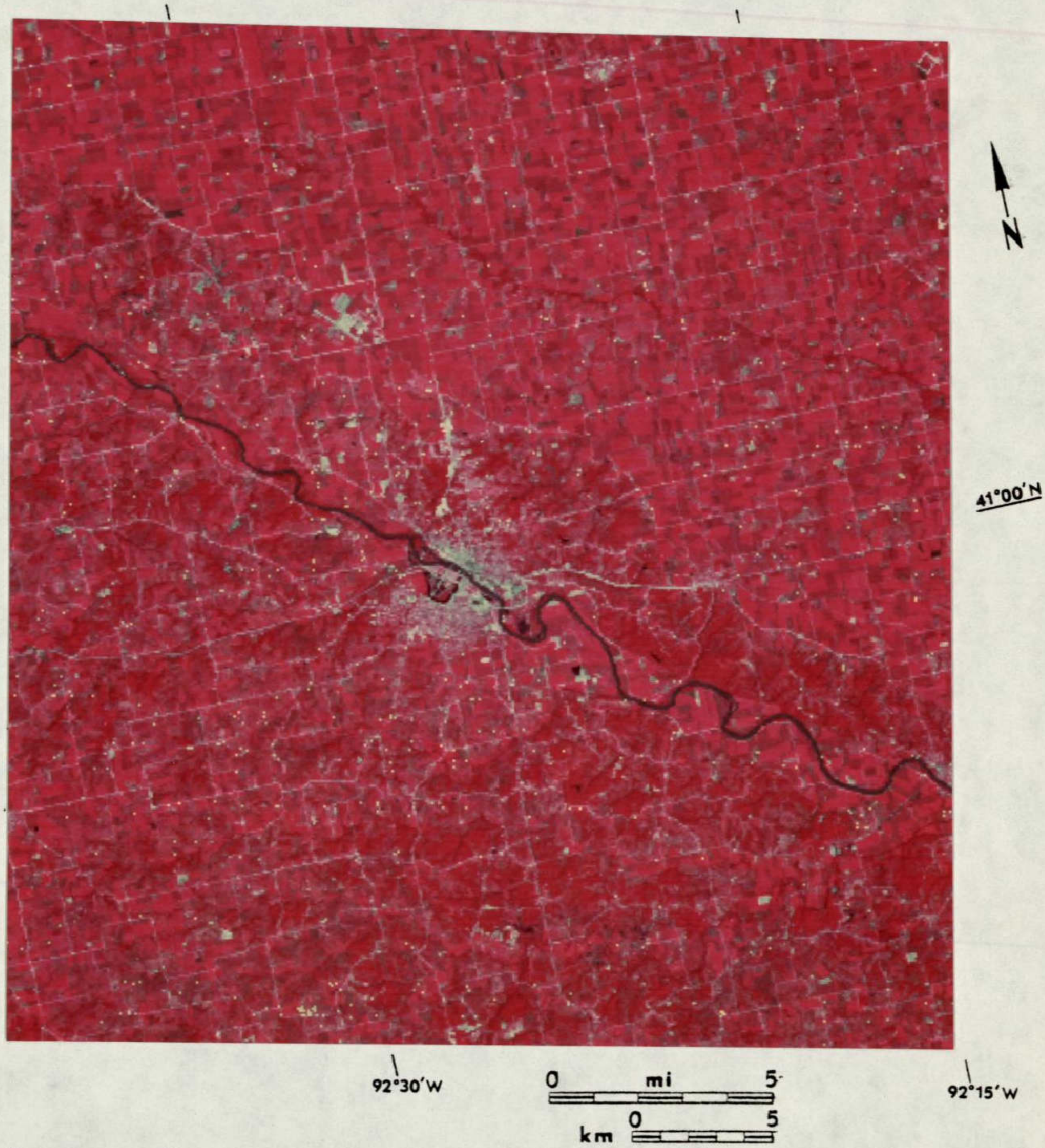
abundant detail in the urban area of Ottumwa. The commercial/industrial section of the city is distinctive in color (bluish-white) from the residential area (reddish-blue). The Wapello County road network is also well defined. Strip mines located northwest of Ottumwa were found to have a distinguishing blue-gray hue. Forested areas appear a characteristically dark red color which permits a fair amount of distinction from agricultural lands. Agricultural fields appear as a variety of colors which facilitates delineation of general crop patterns.

Figure 46. False-color print of the contrast stretched Wapello County subscene for which the stretch bounds were interactively determined. Subscene processed by the IMAGE 100 and recorded on the Optronics system.



Subscene from Landsat image taken on August 29, 1972 (1037-16213). Scale: approximately 1:250,000

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with a transmission densitometer. Maximum scene density with detail (forest land) was 1.20. The objective of this photo-optical enhancement technique is to reassign the scene $D_{min.}$ (0.76) and $D_{max.}$ (1.20) to the selected aim points of 0.40 $D_{min.}$ and 1.60 $D_{max.}$. This process will increase the original scene contrast from the initial density range of 0.44 (1.20 - 0.76 = 0.44) to a density range of 1.20 (1.60 - 0.40 = 1.20). In essence, the image data is being contrast stretched by photographic techniques.

The black and white bands produced from raw image data were low in contrast. MSS band 4 possessed a density range ($D_{min.}$ to $D_{max.}$) of 0.31. Bands 5 and 7 had slightly higher density ranges of 0.40 and 0.44 respectively. When these Optronics positives were duplicated on Kodak SS-7, the density ranges that displayed the original image tones were stretched to the aim point densities. The 22 step density wedge printed on the original film positives was also printed onto the photo-optically enhanced film positives. Densitometer readings from the POE wedge indicate the densities that have been stretched and the range over which they were expanded. By noting the positions of significant densities on the POE step wedge, photographic contrast stretching can be related to digital number equivalents by analogy with digital contrast stretching. The densitometer readings for each black and white POE band are listed on Table 21 with the plotted relationship of density versus digital number being shown on Figure 47. For both bands 4 and 5, the image densities

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Table 21 and Figure 47 near here.

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that have been photographically stretched are equivalent to stretch bounds of DN 0 to about DN 144 in a digital contrast stretch. Scene densities corresponding to digital

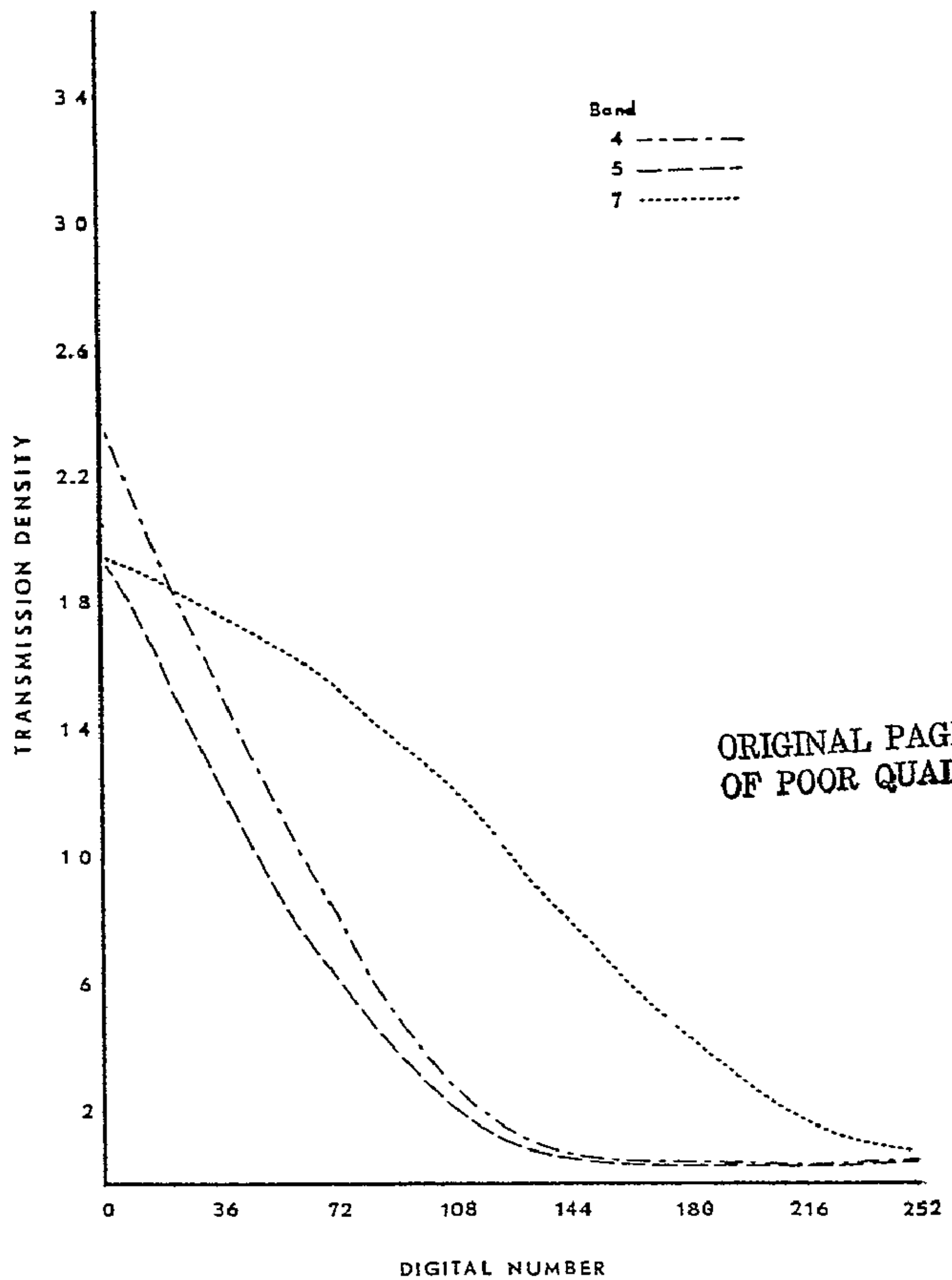
Table 21. Step wedge densities of photo-optically enhanced film positives produced from Optronics film positives for raw data of the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Band 4	Band 5	Band 7
1	252	.04	.04	.07
2	240	.04	.04	.09
3	228	.04	.04	.12
4	216	.04	.04	.19
5	204	.04	.04	.25
6	192	.04	.04	.35
7	180	.04	.04	.44
8	168	.05	.04	.55
9	156	.05	.05	.67
10	144	.08	.07	.81
11	132	.11	.09	.92
12	120	.17	.14	1.09
13	108	.27	.21	1.24

Table 21. Step wedge densities of photo-optically enhanced film positives produced from Optronics film positives for raw data of the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Band 4	Band 5	Band 7
14	96	.44	.34	1.35
15	84	.58	.47	1.43
16	72	.82	.63	1.56
17	60	1.03	.78	1.62
18	48	1.28	1.01	1.71
19	36	1.54	1.25	1.78
20	24	1.78	1.48	1.84
21	12	2.07	1.78	1.91
22	0	2.37	1.96	1.95

Figure 47. Transmission density versus digital number equivalent for the photo-optically enhanced bands of raw data. The original 22 step density wedge, produced by the Optronics recorder, was printed on Kodak SS-7 in the POE process. Data for the Wapello County subscene.



numbers from approximately 145 to 256 have been photographically truncated and saturated to white. The density range of band 7 was increased slightly without photographic truncation. Photographic saturation of scene densities in bands 4 and 5 has produced a severe contrast stretch. The minimum and maximum density ranges in these bands were: band 4, $D_{min.} = 1.22$ and $D_{max.} = 1.53$; and band 5, $D_{min.} = 1.22$ and $D_{max.} = 1.62$. These density ranges roughly related to a digital number range of DN 24 to 90 (see Figure 36). Because densities beyond these minimum and maximum values created no discernable image detail, the truncation of densities corresponding to DN 145 to 256 on bands 4 and 5 did not significantly affect scene detail.

Transmission densities were read for each dye layer of the step wedge on the POE color composite and plotted in relationship to the digital number equivalent produced on the original Optronics film (Figure 48 with data on Table 22). This graph indicated that the color film has

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Figure 48 and Table 22 near here.

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reproduced the densities on the POE black and white bands. The false-color print from the photo-optically enhanced composite displayed on Figure 49 shows a striking change

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Figure 49 near here.

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when compared to the non-enhanced raw data composite seen on Figure 38. Substantial detail can be seen in the urban area on the POE false-color print of raw data. Most road networks can be delineated and areas of forest can be readily mapped. Agricultural crop patterns are distinctive. Locating strip mines and quarries on the image, however, was found to be difficult.

Figure 48. Transmission density versus digital number equivalent for the dye layers on the 22 step density wedge on the color film positive produced from the POE film positives of raw data. Data for the Wapello County subscene.

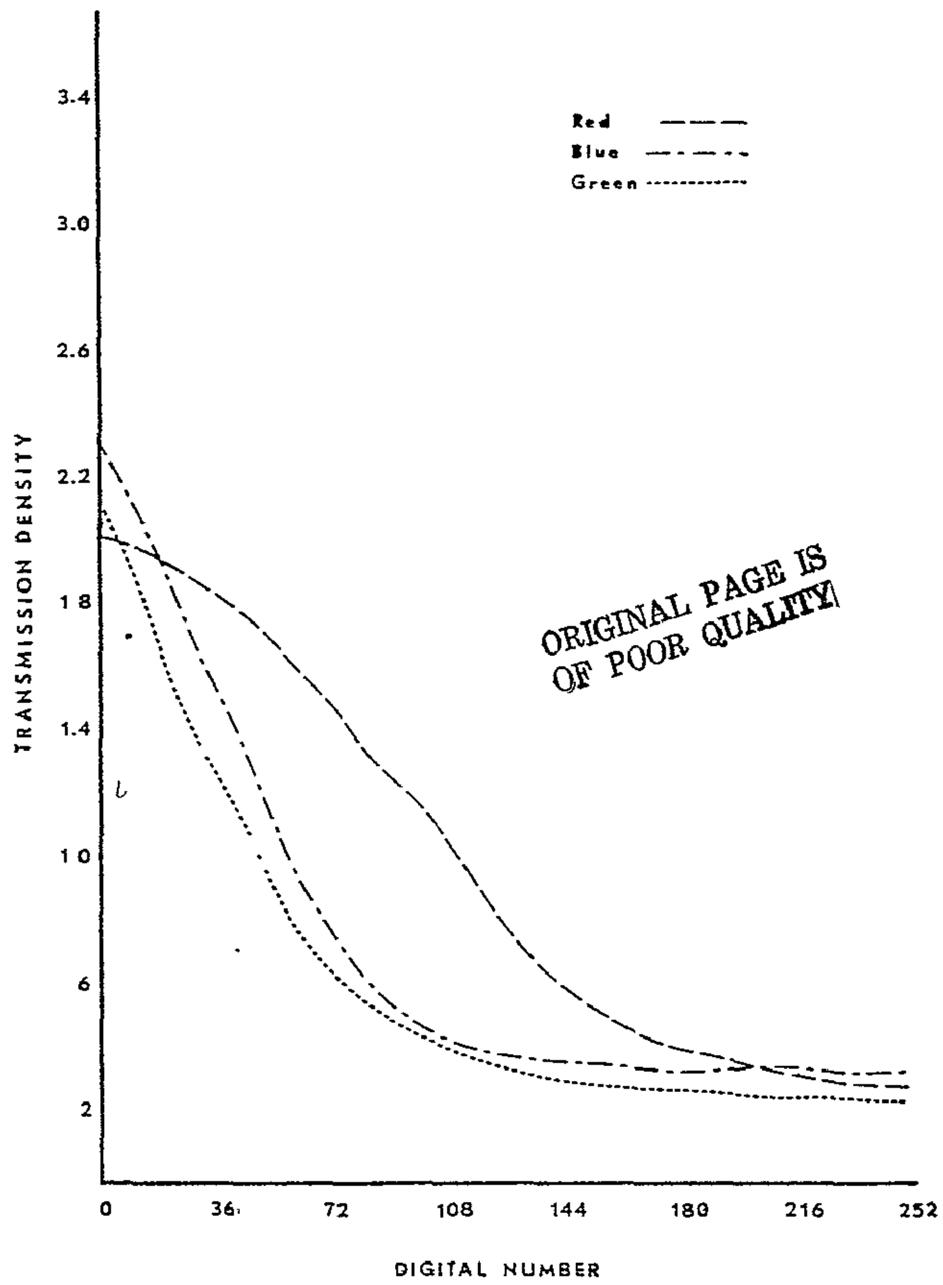


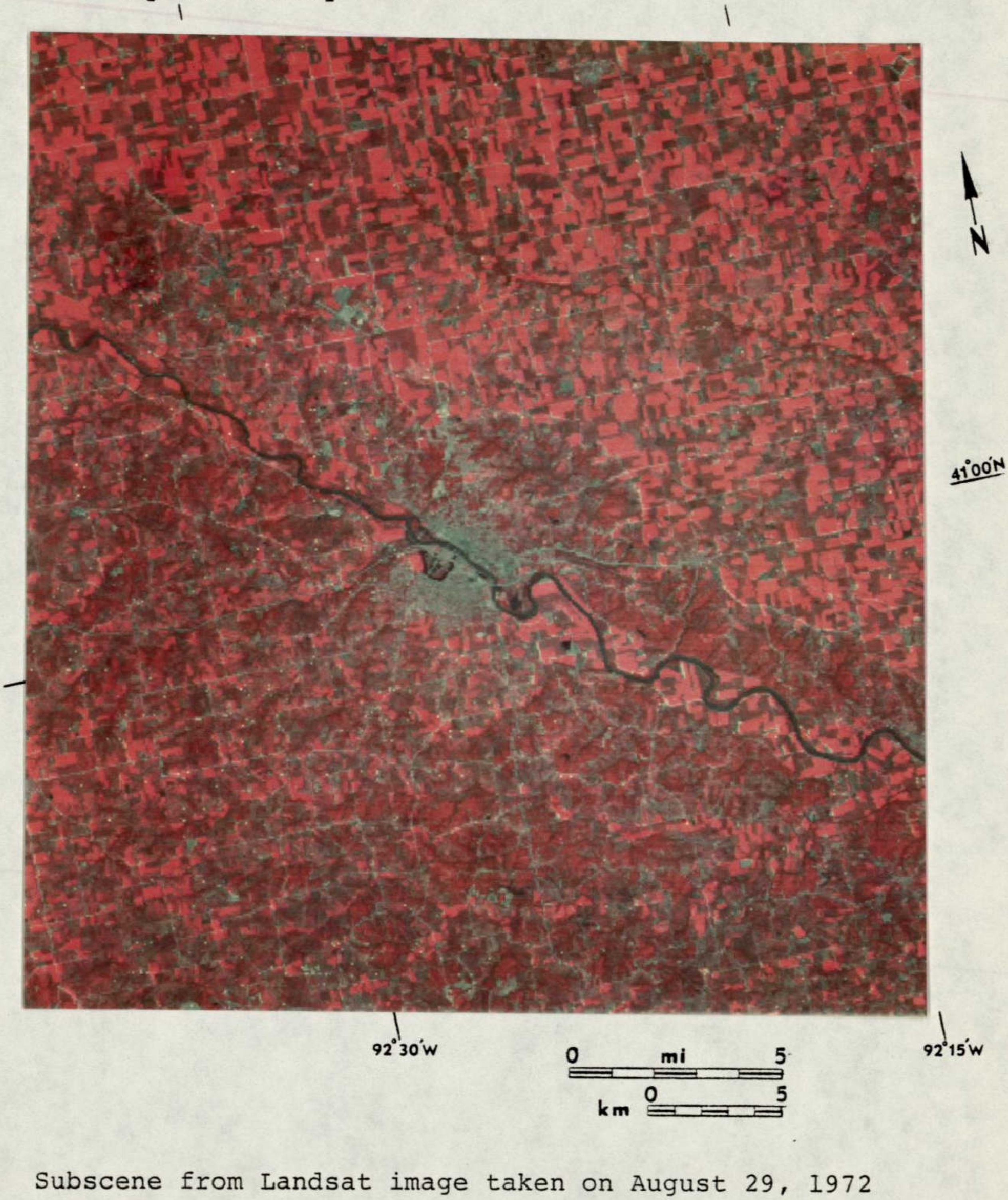
Table 22. Step wedge densities of the color film positive printed from photo-optically enhanced film positives produced from the Optronics system film positives for raw data of the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Red	Green	Blue
1	252	.26	.22	.30
2	240	.27	.22	.30
3	228	.28	.23	.30
4	216	.30	.23	.31
5	204	.32	.23	.31
6	192	.36	.25	.32
7	180	.38	.25	.31
8	168	.43	.25	.32
9	156	.49	.26	.32
10	144	.58	.28	.33
11	132	.69	.30	.34
12	120	.85	.33	.36

Table 22. Step wedge densities of the color film positive printed from photo-optically enhanced film positives produced from the Optronics system film positives for raw data of the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Red	Green	Blue
13	108	1.02	.37	.39
14	96	1.18	.43	.46
15	84	1.30	.50	.55
16	72	1.47	.62	.74
17	60	1.56	.74	.92
18	48	1.69	.96	1.19
19	36	1.79	1.22	1.49
20	24	1.87	1.48	1.76
21	12	1.95	1.80	2.04
22	0	1.98	2.03	2.25

Figure 49. False-color print of photo-optically enhanced Optronics positives produced from raw data for the Wapello County subscene



Subscene from Landsat image taken on August 29, 1972 (1037-16213). Scale: approximately 1:250,000

Figure 50. Transmission density versus digital number equivalent for the photo-optically enhanced bands of linearly contrast stretched data. The original 22 step density wedge, produced by the Optronics recorder, was printed on Kodak SS-7 in the POE process. Data for the Wapello County subscene.

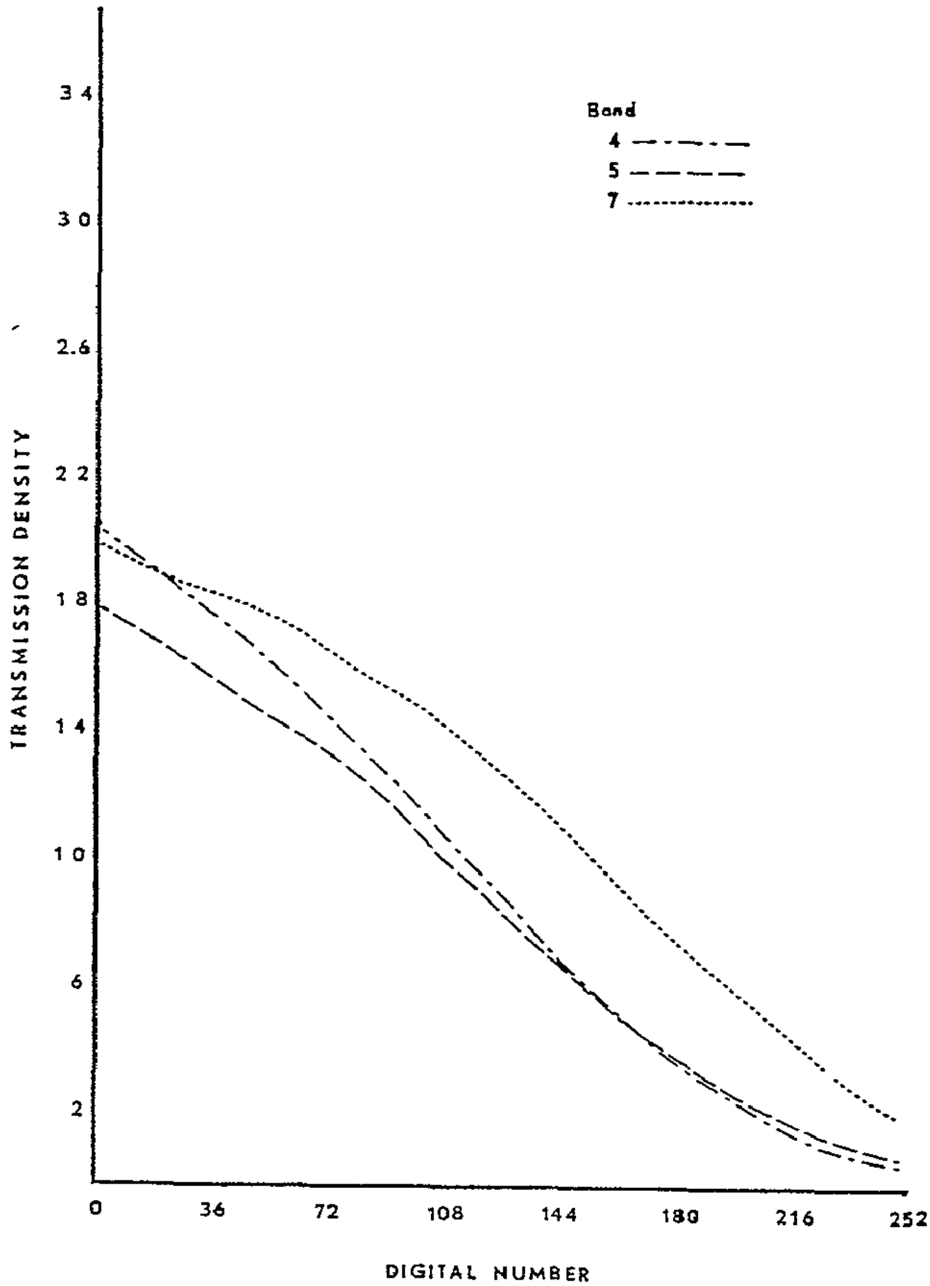


Table 23. Step wedge densities of photo-optically enhanced film positives produced from Optronics film positives for linearly stretched data of the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Band 4	Band 5	Band 7
1	252	.05	.06	.18
2	240	.08	.09	.25
3	228	.11	.13	.35
4	216	.17	.19	.46
5	204	.23	.24	.54
6	192	.31	.32	.67
7	180	.39	.39	.76
8	168	.49	.49	.87
9	156	.60	.58	1.00
10	144	.72	.70	1.13
11	132	.84	.80	1.24
12	120	.97	.92	1.33

Figure 51. Transmission density versus digital number equivalent for the dye layers on the 22 step density wedge on the color film positive produced from the POE film positives of the linearly stretched data. Data for the Wapello County subscene.

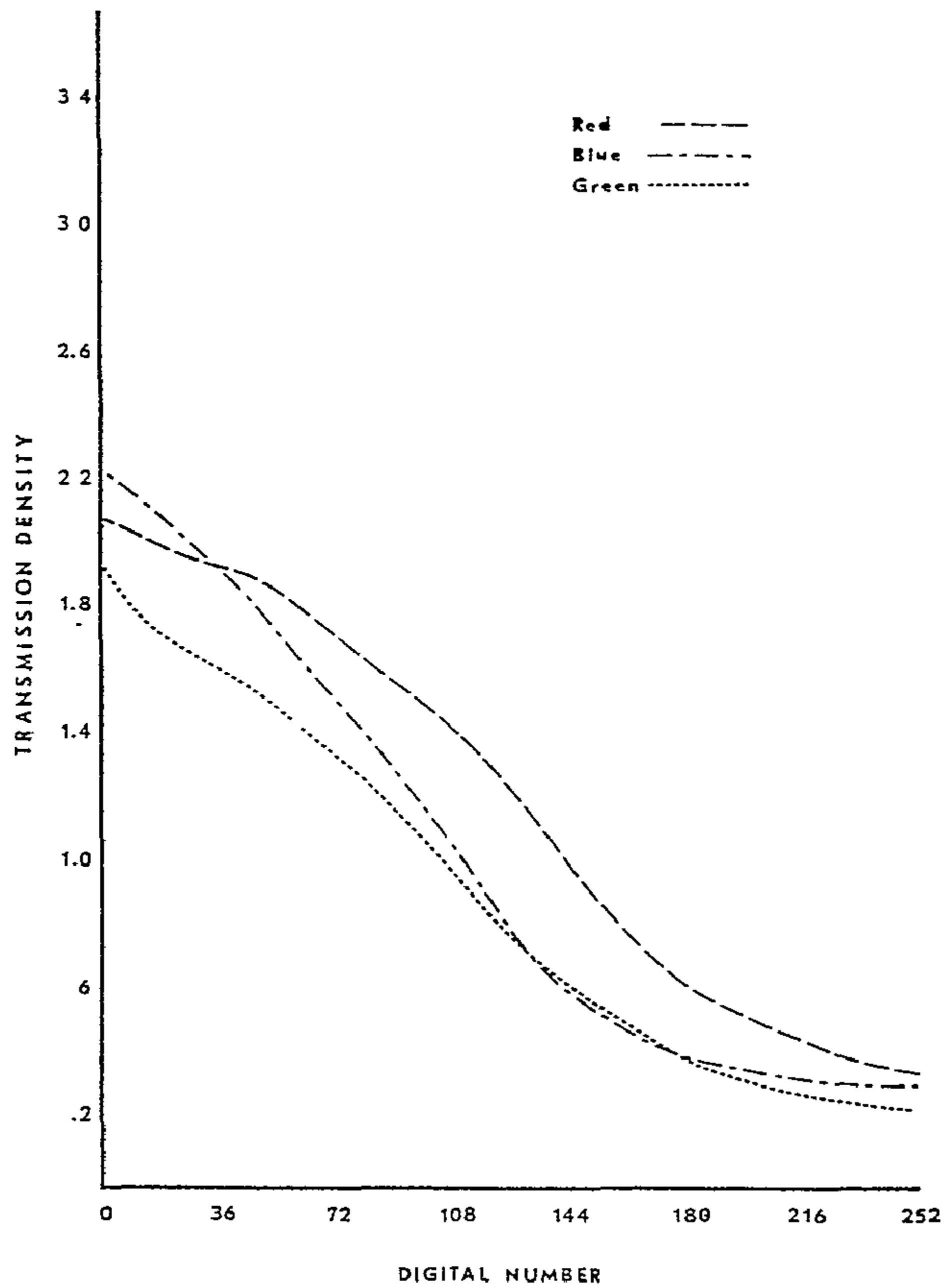


Table 23. Step wedge densities of photo-optically enhanced film positives produced from Optronics film positives for linearly stretched data of the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density		
		Band 4	Band 5	Band 7
13	108	1.10	1.01	1.43
14	96	1.24	1.16	1.53
15	84	1.35	1.26	1.58
16	72	1.49	1.35	1.67
17	60	1.58	1.42	1.75
18	48	1.69	1.51	1.82
19	36	1.79	1.58	1.86
20	24	1.88	1.66	1.89
21	12	1.97	1.73	1.95
22	0	2.05	1.79	2.00

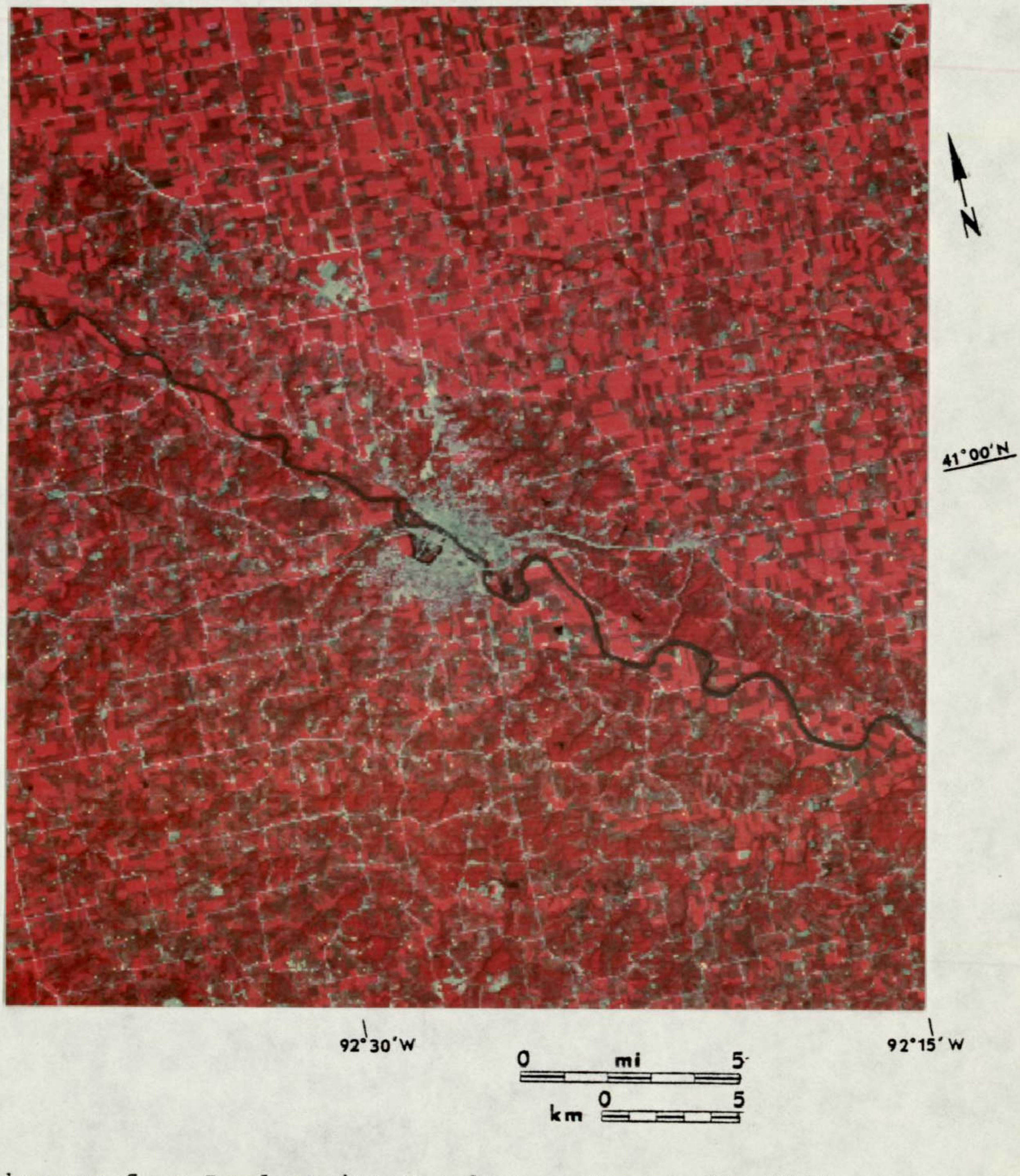
Table 24. Step wedge densities of the color film positive printed from photo-optically enhanced film positives produced from Optronics system film positives for linearly stretched data of the Wapello County subscene

Step Wedge Number	Digital Number Equivalent	Transmission Density Red	Transmission Density Green	Transmission Density Blue
1	252	.33	.22	.29
2	240	.35	.23	.29
3	228	.38	.25	.30
4	216	.44	.27	.32
5	204	.48	.30	.33
6	192	.55	.34	.36
7	180	.61	.38	.39
8	168	.71	.45	.44
9	156	.85	.52	.51
10	144	1.00	.62	.60
11	132	1.14	.70	.69
12	120	1.30	.82	.83

Table 24. Step wedge densities of the color film positive printed from photo-optically enhanced film positives produced from Optronics system film positives for linearly stretched data of the Wapello County subscene--Continued

Step Wedge Number	Digital Number Equivalent	Transmission Density Red	Transmission Density Green	Transmission Density Blue
13	108	1.40	.94	1.01
14	96	1.52	1.10	1.20
15	84	1.61	1.24	1.37
16	72	1.72	1.34	1.51
17	60	1.80	1.43	1.63
18	48	1.89	1.52	1.77
19	36	1.93	1.60	1.91
20	24	1.97	1.68	2.02
21	12	2.04	1.77	2.14
22	0	2.08	1.92	2.21

Figure 52. False-color print of the photo-optically enhanced Optronics positives produced from linearly contrast stretched data for the Wapello County subscene



Subscene from Landsat image taken on August 29, 1972 (1037-16213). Scale: approximately 1:250,000

purposes. This approach to contrast enhancement does not take into account the location of pixels that are being transformed to white or black brightness values. Consequently, significant losses in image detail may be concentrated in critical areas such as urban classes if automatically determined stretch limits are imposed.

3. Raw picture element data that have been recorded on film can be photo-optically contrast stretched in a manner similar to digital contrast stretching. The range of contrast detail produced by the POE process can approximate the range and contrast produced from digital enhancement.
4. When photo-optically enhanced film products are produced from digitally contrast stretched black and white film products, specified land classes can be selectively enhanced without additional computer processing.

EROS DATA CENTER DIGITAL IMAGE ENHANCEMENT SYSTEM (EDIES) PRODUCTS

As discussed earlier in this report, the EROS Data Center produces digitally enhanced imagery on a laser beam recorder from preprocessed Landsat CCT's. Two examples of EDIES false-color prints for the Wapello County subscene are included for demonstration purposes. Image data for the first EDIES example (false-color print on Figure 53)

Figure 53 near here.

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have been contrast stretched with no data truncation to fill the entire digital range. Spectral histograms (Figure 54), which were sampled from only 3% of the CCT

Figure 54 near here.

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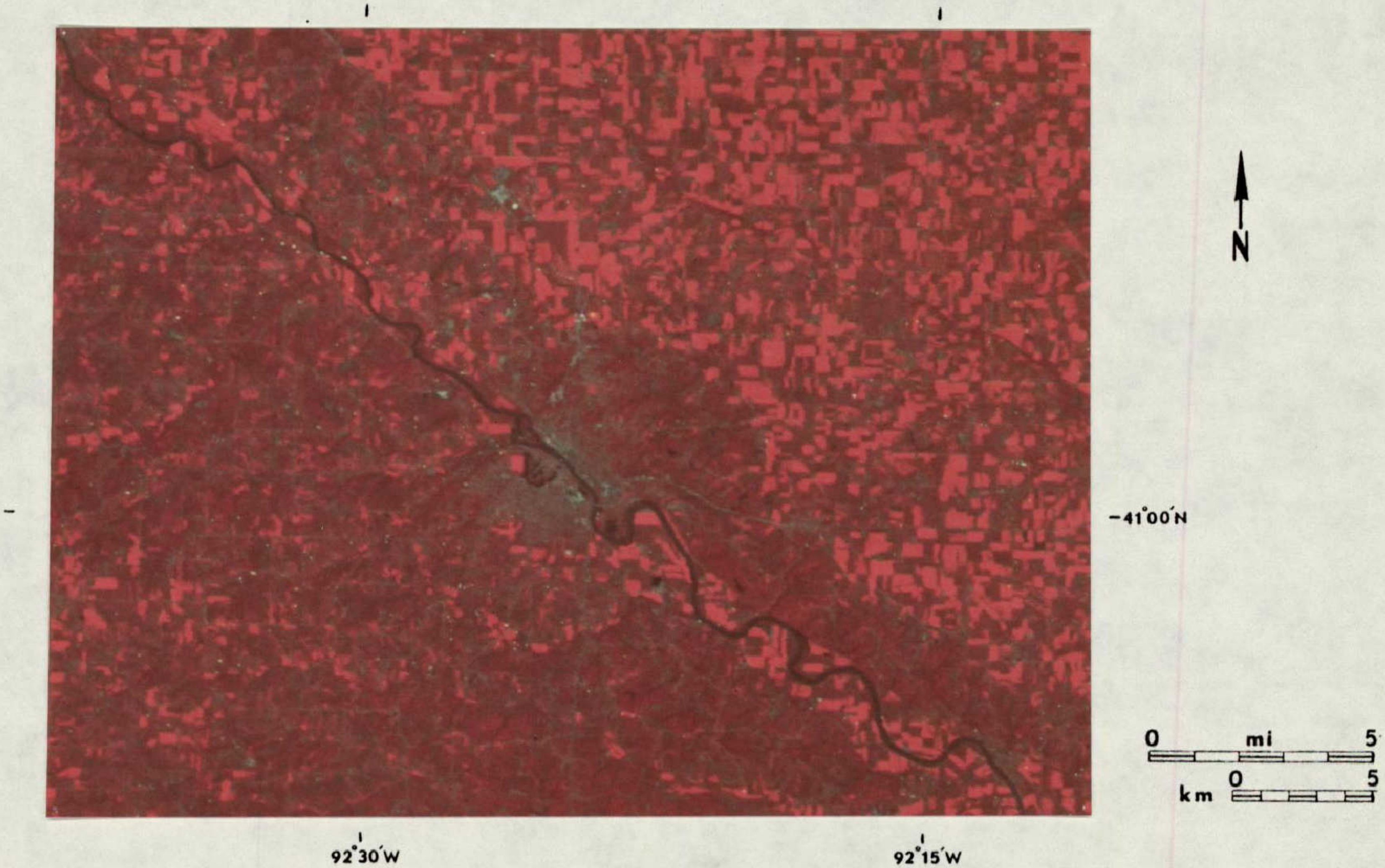
data, show the original data bounds for an overview of the August 29, 1972 scene (1037-16213). When the IMAGE 100 is used to determine spectral histograms, only this small percentage of a scene's picture elements are sampled because the television monitor is capable of only displaying a matrix of 512 by 512 pixels. EDIES black and white film is recorded with transmission densities being linear

Figure 53. EDIES false-color print produced with no data truncation for the August 29, 1972 Landsat scene (1037-16213)



Wapello County subscene shown

Scale: 1:250,000

to digital numbers (Figure 55 with data on Table 25).

Figure 55 and Table 25 near here.

Because no truncation of data was performed in image processing, thereby severely limiting the range over which the image data could be stretched, the generated false-color composite was low in contrast. Consequently, little detail is apparent in the area of urban land use. Roads are faint in some places and cannot be delineated. Agricultural field patterns are distinct, but cannot be differentiated in places from forest land.

Figure 55. Transmission density versus digital number for the 15 step density wedge recorded on the EDIES positives without truncation for the August 29, 1972 scene (1037-16213)

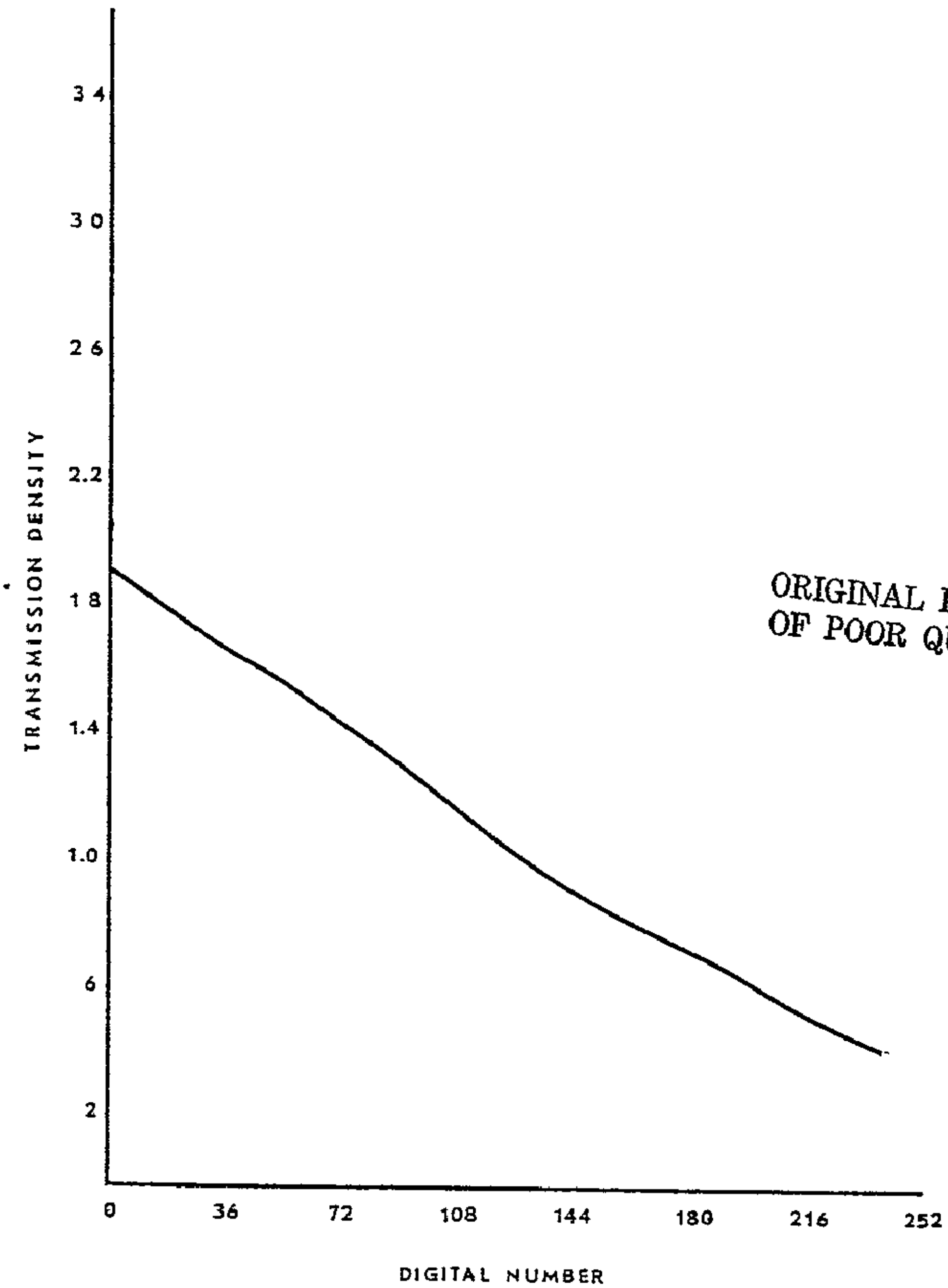


Table 25. Step wedge densities for the EDIES image without truncation for the August 29, 1972 scene (1037-16213)

Step Wedge Number	Digital Number Equivalent	MSS Band 4 Data Bounds (34-216)	MSS Band 5 Data Bounds (18-198)	MSS Band 7 Data Bounds (0-248)
1	255		Density not recorded	
2	238	.43	.43	.41
3	221	.51	.51	.50
4	204	.61	.60	.60
5	187	.69	.69	.68
6	170	.78	.78	.78
7	153	.88	.88	.89
8	136	.97	.98	.98
9	119	1.10	1.11	1.11
10	102	1.24	1.24	1.25
11	85	1.36	1.36	1.37

Table 25. Step wedge densities for the EDIES image without truncation for the August 29, 1972 scene (1037-16213)--Continued

Step Wedge Number	Digital Number Equivalent	MSS Band 4 Data Bounds (34-216)	MSS Band 5 Data Bounds (18-198)	MSS Band 7 Data Bounds (0-248)
12	68	1.47	1.48	1.49
13	51	1.59	1.60	1.61
14	34	1.69	1.70	1.71
15	17	1.79	1.79	1.83
16	0	1.92	1.93	1.94

The second EDIES product of the scene was both contrast stretched and edge enhanced (false-color print on Figure 56). The contrast stretch bounds were initially

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Figure 56 near here.

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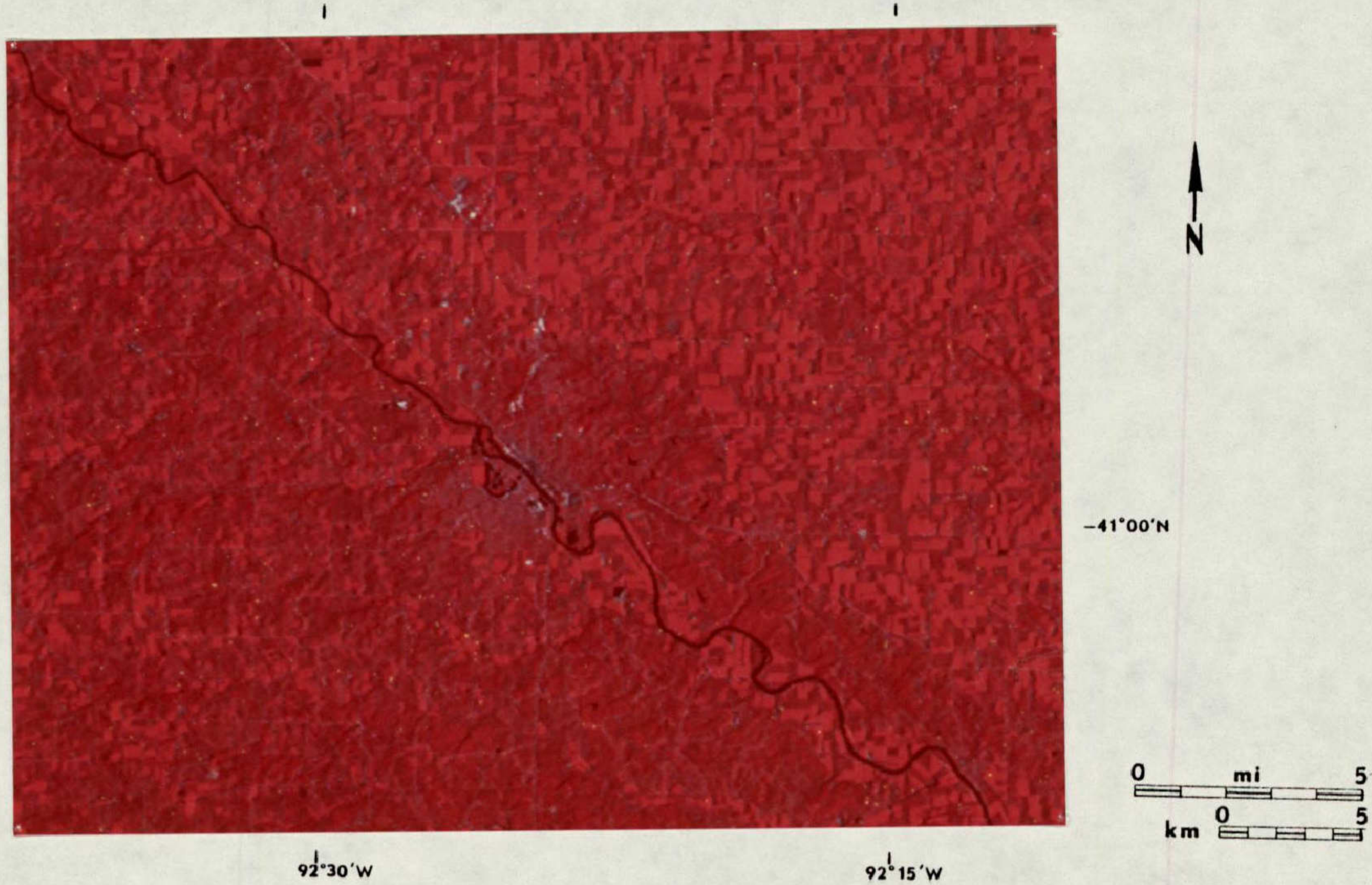
chosen from a histogram table which displays, band by band, the number of pixels assigned to individual DN values across the entire digital range. A stretch bound (either upper or lower) was first chosen on the basis of the distribution of the majority of picture elements within this range. When a bound was specified, the location of saturated pixels was checked on the IMAGE 100 monitor to ascertain if any significant scene detail was being lost. This process of interactively choosing stretch bounds allows a minimal truncation of image data while substantially increasing scene contrast. The stretch bounds shown on Figure 54 for this EDIES product are much more conservative than the bounds for the false-color print on Figure 46 which was linearly stretched with greater data truncation (histograms on Figure 44). The black and white EDIES positives produced from the selected stretch bounds are low in contrast. This lack of tonal contrast in the spectral bands in turn causes a lack of color contrast in the false-color composite. Road networks, for example, are not

Figure 56. EDIES false-color print produced with interactively determined contrast stretch bounds for the August 29, 1972 Landsat scene (1037-16213)



Wapello County subscene shown

Scale: 1:250,000

always clearly defined in this subscene. Detail in the urban land cover class is also subdued. Field patterns are distinct but often cannot be separated from forest land. The similarity of this EDIES product to the example without data truncation is based solely on the conservative manner in which the image data were stretched for this scene.

COMPARISON OF LANDSAT IMAGE PRODUCTS

The primary limitation in utilizing Landsat standard products and photo-optically enhanced standard products for land classification is the inability to print these images at large enough scales (such as 1:63,360) to display large variations in color on the composite or tones on the black and white bands. When large scale enlargements are made from these products, MSS striping becomes very prominent. Some Landsat standard product scenes taken over Iowa in the summer do not inherently display large variations in color and tones because of the complete vegetative canopy. Enlargements of these types of scenes are consequently of limited value for land classification. Photo-optical enhancement techniques can increase color variations and contrast. The POE process, however, does not alleviate the problems of enlarging the standard product Landsat scenes to large scales.

Jet Propulsion Laboratory computer enhanced false color composites have been routinely printed to 1:63,360 scale at the Iowa Geological Survey. Individual picture elements are clearly visible but are not so large that image patterns are obscured. The ability to see individual picture elements is an advantage for land classification because the extreme details of the landscapes have been aggregated by the multispectral scanner into approximately 1.1 acre blocks. Being that planners in south central Iowa organize land classification data on a cell basis, this lack of detail on Landsat scenes makes the decision process easier for the assignment of data cells to a specific land class.

The photo-optical enhancement of a computer enhanced scene was experimentally implemented at the EROS Data Center. Results from this work suggest that landscape patterns can be additionally enhanced using photographic processes rather than to reprocess the image data in the computer. By avoiding additional computer processing, variations in image enhancement can be produced at a much lower cost.

The EROS Data Center digital enhancement system (EDIES) products became available in February 1977. The EDIES examples included in this report were not evaluated by the planners in the project area. The purpose of displaying EDIES examples and explaining the system in this report was to illustrate a computer enhanced Landsat product that is available to the public for a specified price--$1,000 per scene. Included in this price are four black and white transparencies, a false-color transparency, and a 20 inch false-color print. The Jet Propulsion Laboratory Image Processing Laboratory is, on the other hand, chartered as a research and development center. Their image processing services are consequently not available commercially. Most of the enhancement techniques applied to produce the JPL products can be duplicated on EDIES products. The major exception is that EDIES scenes cannot be digitally rotated to true north.

CONCLUSIONS AND RECOMMENDATIONS CONCERNING IMAGE PROCESSING TECHNIQUES

1. The most critical aspect in the image enhancement process is contrast stretching. To produce an image with the maximum scene contrast while preserving maximum tonal variation, both the amount of truncated data and the location of saturated pixels must be determined during the contrast stretching process. By using an interactive system such as the IMAGE 100, the picture elements that are to be saturated to white or black can be assessed to determine the losses in tones (or detail) within the scene. Stretch bounds can be selected to assure maximum scene contrast without sacrificing useful tonal variations within a scene.

2. The practice of contrast stretching image data with automatically applied truncation limits is not recommended for land classification purposes. Because only the number of pixels to be saturated are determined in automatic truncation methods, significant losses in image tones can occur.

3. Research in this project has suggested another alternative for Landsat image enhancement that involves a combination of digital and photo optical enhancement. With this approach, digital techniques would be used to cosmetically enhance and geometrically correct image data. Contrast stretching would be limited to expansion of data to fill the full brightness value range. No truncation of data would

occur. When all densities for the MSS bands are recorded on black and white film, photo-optical enhancement techniques could be implemented to photographically contrast stretch the bands to selectively enhance land classification categories. By following this approach, image enhancement may be done iteratively in a photo lab, not requiring the use of computer facilities to produce a different scene enhancement.

Contrast enhancing EDIES black and white bands photo-optically and then producing a color composite can be accomplished at EDC for $150 after the original computer enhanced bands are produced. Prints of the POE color transparency, however, are not included in this price. If a different image enhancement is produced through computer processing, a new EDIES scene would cost $1000. On this basis, photo-optical enhancement would be a more cost-effective method of selectively enhancing land classification categories rather than the application of iterative computer processing.

OVERVIEW OF LAND CLASSIFICATION AND THE REGIONAL PLANNING PROCESS

The objective of the regional planning process is to optimize the utilization of physical and cultural resources. This necessitates the development of a data base upon which planning objectives may be formulated and implemented. Relevant variables must be extracted from a variety of sources and integrated in a manner consistent with the regional plan. A regional resource inventory can be derived from the traditional sources of physical and cultural data, conventional low altitude air photos, or Landsat imagery. Because state level planning agencies must work within specific budget constraints, careful consideration must be given to the selection of the type of aerial coverage to be acquired for image analysis. Satellite imagery provides synoptic coverage of a region and hence can be a more cost effective means of land cover interpretation at the regional scale. Enhanced Landsat imagery has proven to be generally superior to Landsat standard products for land classification purposes, as certain cover types are more distinct on enhanced products and thereby easier to interpret.

Traditional approach to image analysis for land classification

The Area XV Regional Planning Commission has traditionally used low altitude black and white images for land classification purposes. Through conventional air photo interpretation techniques, land class data has been aggregated into varying size data units ranging from cells of 2½ acres to 40 acres. The Commission has recently completed an inventory of ten counties in the project area covering approximately 5000 square miles. A 40 acre grid was overlaid on the air photos and the dominant land class within each cell was determined. The land classification categories used in this study were:

1. Urban (more than 40 dwellings per 40 acres). This class was subdivided into:
   a. Residential, and
   b. commercial/industrial.
2. Countryside development (12 to 40 dwellings per 40 acres).
3. Agricultural lands (less than 12 dwellings per 40 acres).
4. Forestland.
5. Woodland/Pasture. This class was subdivided into:
   a. pasture, and
   b. pasture with trees.
6. Disturbed land. (mostly strip mining activities).

7. Water.

The analysis time to classify the land into 40 acre cells for a ten county area took three months for three analysts to complete. The air photos used in the project were at a scale of 1:12,000 (1" = 1000'). The classified cell data was transferred to a map base. Statistics for the land classes were calculated by counting cells within the counties and deriving percentages. A $\pm$ 15% error was estimated from available U.S. Department of Agriculture statistics for the area. The cost to complete this land classification analysis was approximately $7,200 or $720 per county. These figures are based on the analysts earning five dollars per hour and taking a combined 480 hours of analysis time.

Because the air photos used in this study were more than five years old, the Commission obtained price estimates from a local aerial contractor to supply black and white photos for the area. The prices, included 24 inch by 36 inch black and white prints and half tone mylar copies:

1. Images at 1:4,800 scale (1"=400') $3,500 per county
2. Images at 1:12,000 scale (1"=1000') 1,500 per county

The average county size in the study area is about 500 square miles. To cover the entire eleven county study area would cost $38,500 for 1:4,800 scale or $16,500 for 1:12,000 scale imagery.

Landsat imagery and land classification

A Landsat based analysis from computer enhanced images was performed on Jefferson County. Landsat false-color prints at 1:63,360 scale were used as the image base to classify land categories on a 40 acre basis. The analysis time was estimated to be 33 percent less than using the 1:12,000 scale air photos. Land classes could be more quickly evaluated because the multispectral scanner integrates the reflectance from ground cover over 1.1 acres. The lack of fine detail on Landsat images makes the decision process for land classification easier. The analysis cost for Jefferson County from satellite imagery was about $480.

If all the land in the 11 county area was classified from Landsat images, four scenes would be needed for complete coverage. Four EDIES products would cost $4,000. To have color prints made for each county area at a scale of 1:63,360, the cost would be $150 per print from the EROS Data Center. The price for 11 false-color prints would be $1,650. The total Landsat imagery order would cost $5,650. Assuming a one third less image analysis time, the evaluation costs are estimated to be $5,280 for the entire 11 county area ($480 per county analysis). The total price for a land classification analysis based on a 40 acre data cell would cost $10,930.

Image cost comparisons on a five year basis

Areas in Iowa not showing rapid growth need land resource inventories to be completed every five years. This means that in ten years, three acquisitions of imagery covering the 11 county area must be obtained. The costs for three image acquisitions, based on the previous discussions, are summarized below:

1. 1:4,800 scale
   (black and white 24" by 36" prints with
   mylar half tone prints of the same size) $115,500.
2. 1:12,000 scale
   (black and white 24" by 36" prints with
   mylar half tone prints of the same size) 49,500.
3. Computer enhanced Landsat (EDIES)
   1:63,360 false color prints of each county 16,950.

If the analysis costs were included for a 40 acre cell land classification, the low altitude imagery evaluation would be $720 per county. In ten years, three analyses would have been performed at an estimated cost of $21,600. A Landsat based analysis would cost about one third less or $14,400. The total costs for the imagery and analyses for three acquisitions would be:

1. 1:4,800 scale imagery + analysis $137,100.
2. 1:12,000 scale imagery + analysis 71,100.
3. Landsat, 1:63,360 scale imagery + analysis 31,350.

From the view point of the Area XV Commission, the low altitude costs and analysis are prohibitive. Landsat imagery costs and analyses, however, would be feasible on a ten year basis.

The advantages of using Landsat data in regional planning are:

1. The initial image acquirement is cheaper than low altitude black and white imagery.

2. The analysis time is approximately one third less using a 40 acre data cell.

3. Landsat coverage is available for virtually each month of the year.

4. Landsat data costs less to update on a five year basis.

The use of Landsat data does, however, have some disadvantages:

1. There is less utility in Landsat imagery for other aspects of regional planning that could be supplied from higher resolution imagery.

2. Landsat image analysis requires slightly more training or experience.

A STRATEGY FOR USE OF ENHANCED LANDSAT IMAGERY FOR REGIONAL PLANNING PURPOSES

Geometrically corrected and cosmetically enhanced Landsat images provide the resolution necessary to produce large scale photographic bases and are therefore superior to Landsat standard products for classification purposes. Synoptic repetitive Landsat coverage can be used in a planning methodology designed to optimize the utilization of an area's resources. The following proposed resources analysis procedure demonstrates that enhanced Landsat imagery can be used as a regional planning tool when effectively integrated with other appropriate spatially referenced data sources. The area XV Regional Planning Commission has developed and is applying this strategy to southwestern Jefferson County to illustrate the compatibility of image and non-image data sources. Jefferson County, located directly east of Wapello County in south central Iowa (Figure 57) has been chosen

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Figure 57

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because it has a physical setting (Figure 58) similar to

Figure 58

Wapello County and already possesses a comprehensive data

Figure 57. Location of the southwestern Jefferson County test site (cross-hatched) in south-central Iowa

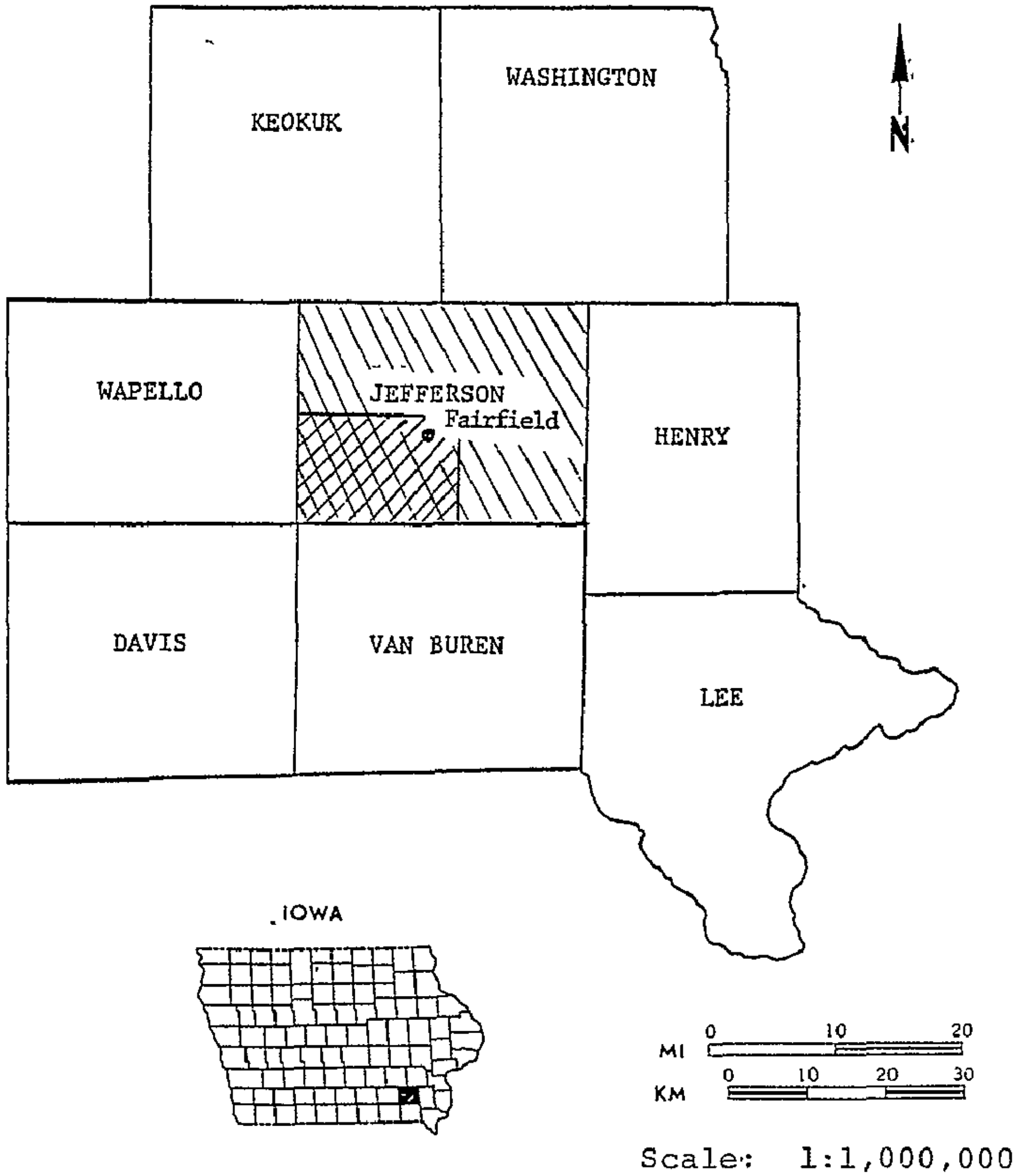
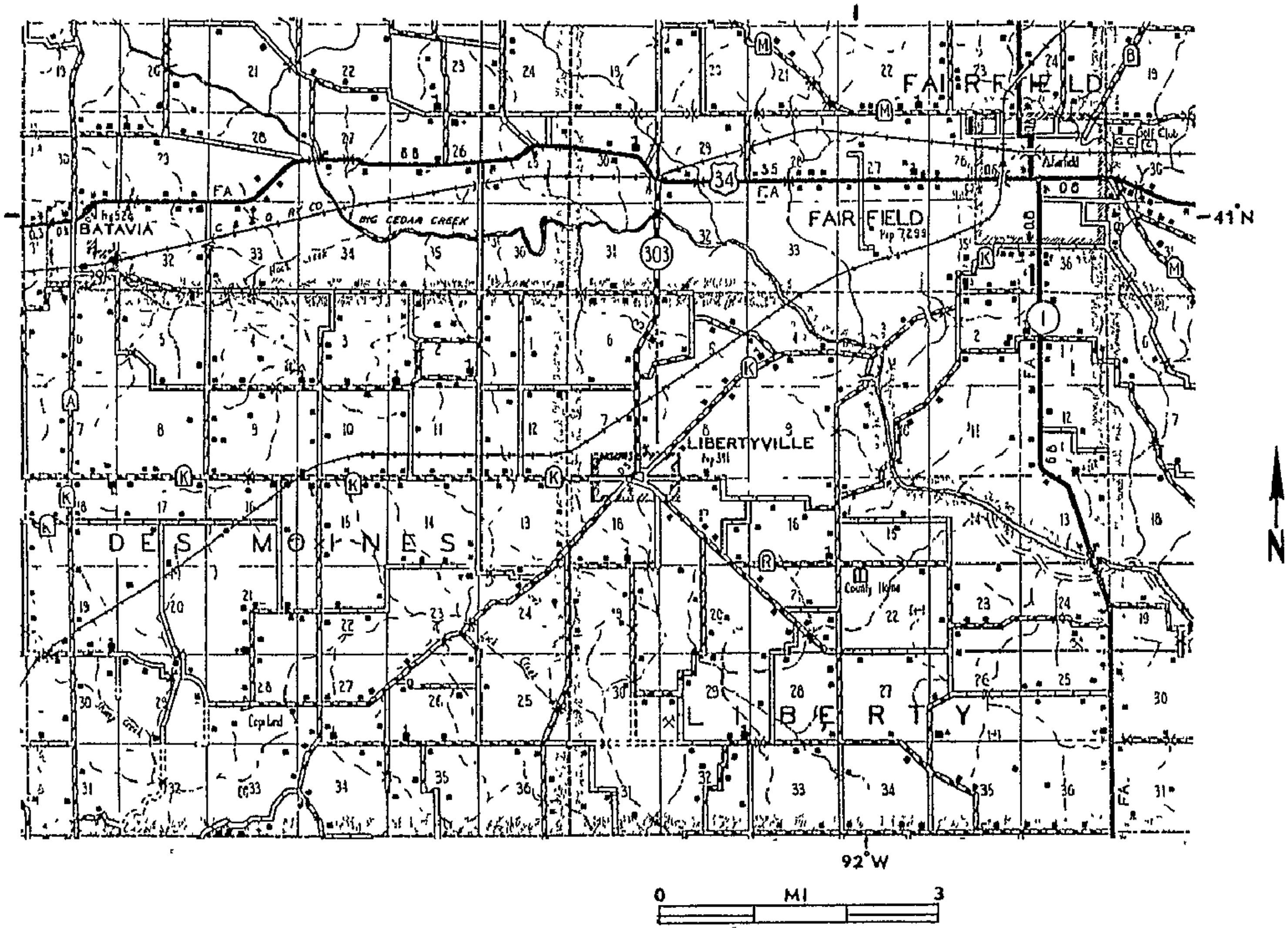


Figure 58. Southwestern Jefferson County general highway map



Source: Iowa State Highway Commission

Scale: 1:125,000

compiled by the Area XV Regional Planning Commission under the direction of Bruce W. Bullamore. Conventional resource data has been synthesized by the Commission into spatially referenced ten acre cells within selected areas. A ten acre grid was also used with Landsat imagery to facilitate resource evaluation and land classification at the county level.

The data used in the formation of the Jefferson County planning strategy were based on both JPL computer enhanced scenes and from a variety of non-image sources. False-color Landsat images that were linearly contrast stretched (non-interactive method) and rotated to true north were printed at a scale of 1:63,360 in the Iowa Geological Survey Photo Lab using April, August, and September color composite negatives of the southwestern portion of the county. Four land use categories, including urban areas, pasture lands, crop cover, and forest lands, have been delineated from these temporal Landsat scenes. Traditional sources of county data such as soils reports, urban zoning maps, and mineral resource documents have been integrated with the Landsat resource inventory in order to demonstrate the compatibility of image and non-image information sources as a planning tool.

Satellite data provides a pictorial means of portraying temporal information. Seasonal variations within the selected land use categories were assessed on early spring, late summer, and early fall Landsat scenes of the project area to decide which time of year best displays the spatial characteristics unique to each of the land use divisions. Urban areas and the county transportation network were found to be most clearly defined on the August 29, 1972 scene (1037-16213). The September 24, 1974 image (1793-16105 [Figure 59]) proved to be superior for the delineation

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Figure 59 near here.

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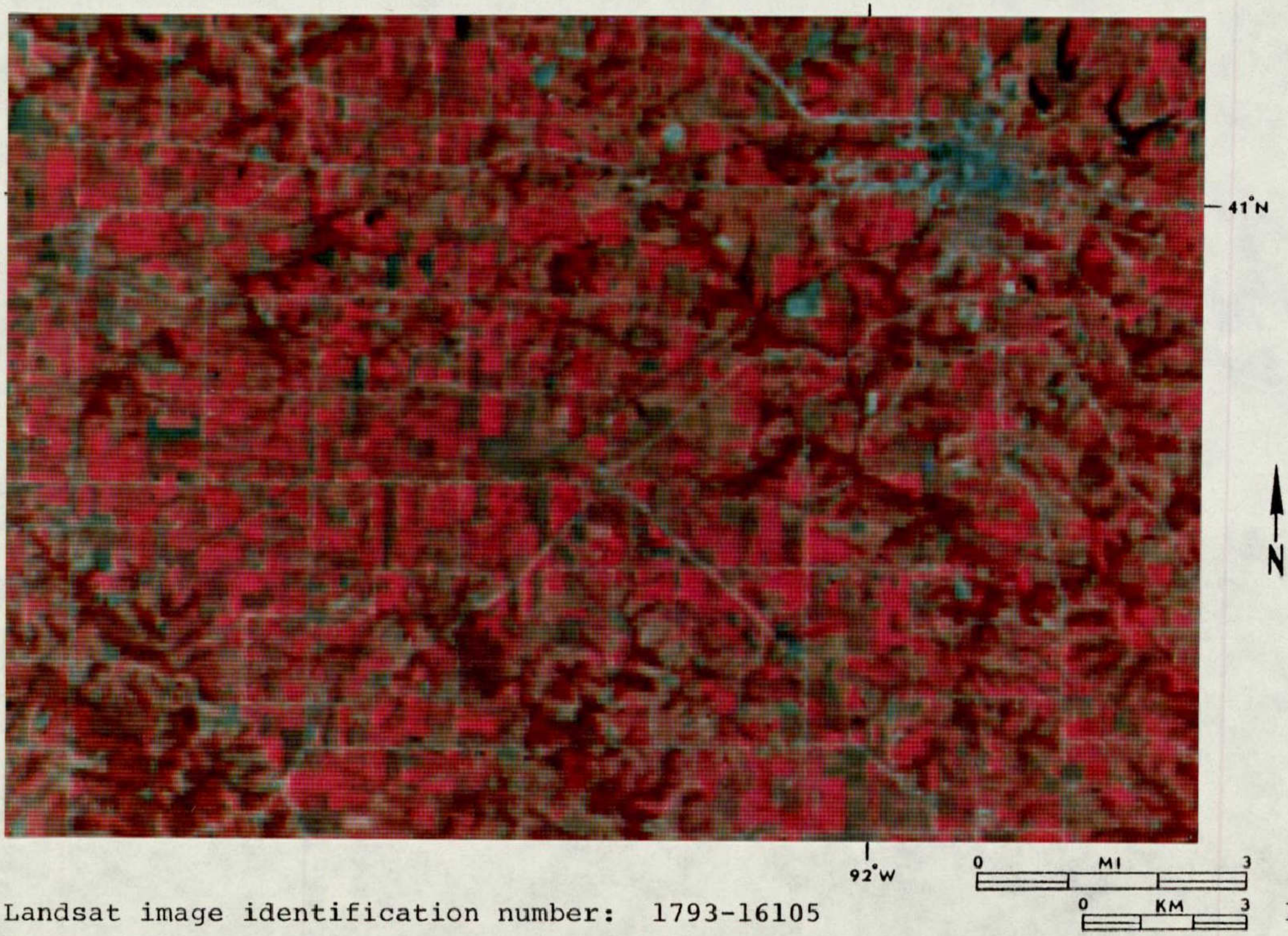
of forest lands. Areas of loess mantled uplands that had been recently winter plowed, as well as the contrasting unplowed slopes, were most apparent on the April 15, 1974 scene (1631-16161). A combination of both the September and April images was used to best determine the extent of crop and pasture lands. In all cases of land use determination, however, the acquisition of ground truth information must be included to assure proper identification of surficial features on Landsat images. Ground truth may be acquired by the analysis of any available black and white, color, or color infrared high altitude photography, low altitude black and white coverage, or data from ground-based

Figure 59. Landsat JPL contrast stretched and rotated to true north false-color composite print of the September 24, 1974 southwestern Jefferson County subscene



Landsat image identification number: 1793-16105

Scale: 1:125,000

investigations. Simultaneous acquisition of satellite imagery and ground truth is not essential in areas where rapid land use change is uncommon. Supportive information sources are useful in assigning the appropriate land use classification to apparently indistinct features on Landsat images.

This photo interpretation process forms the basis of a three-phase resource analysis procedure that is designed for the combined use of image and non-image data sources. This strategy requires the selection of seasonally appropriate Landsat scenes, the production of photo interpretation overlays at the selected image scale, and the production of graphical representations of traditional data at this scale. Superimposition of these spatially referenced data sources provides the foundation for the integration of image-based and conventional resource information. The analysis procedure, illustrated on Figure 60, effectively

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Figure 60 near here.

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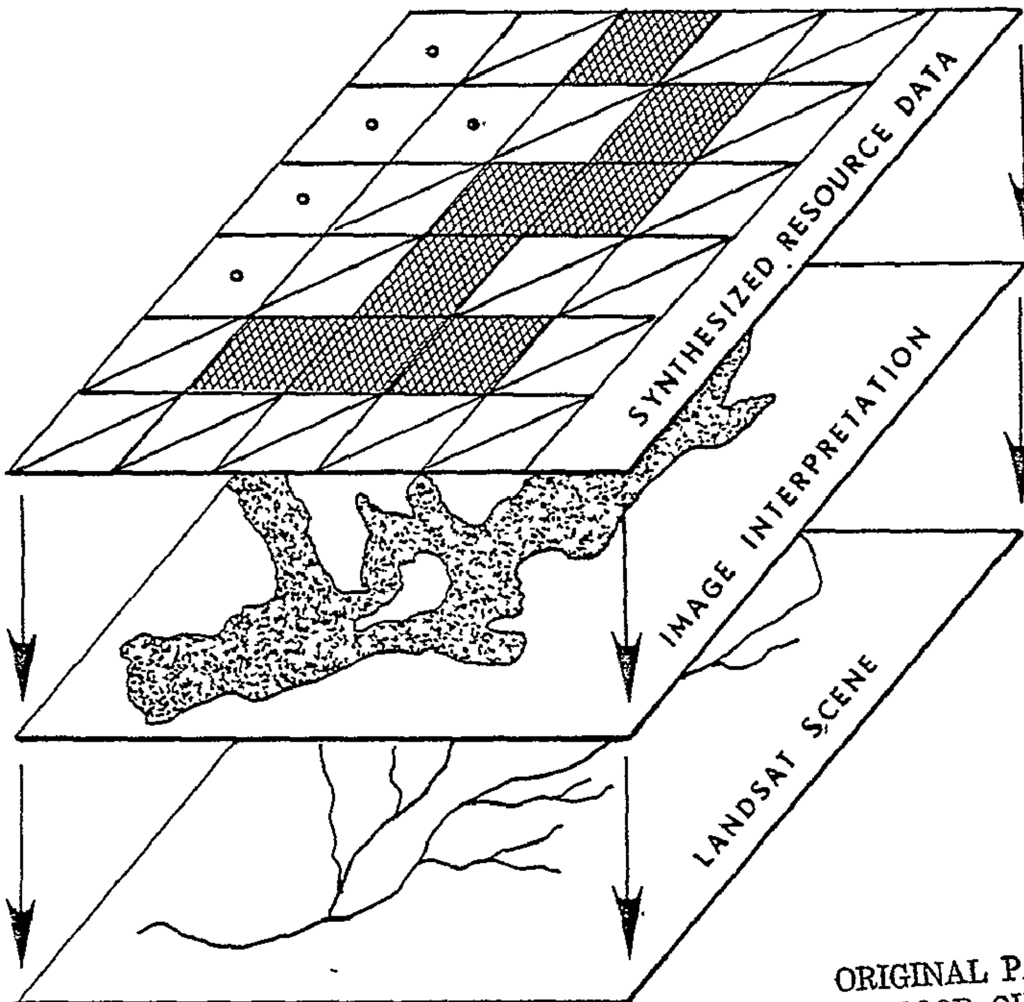
produces a graphical display of management alternatives which can be used by regional planners to optimize the utilization of physical and cultural resources. This model is clearly adaptable to changing land use patterns and can be continuously updated as current information becomes available. The use of overlays to simultaneously portray both photo-interpreted and non-temporal data on a Landsat image base can be easily understood by the layman and hence can be vitally important in stimulating citizen involvement and understanding of the regional planning process.

Figure 60. Integration of spatially referenced data sources



Specialized data is required to formulate decisions to efficiently use an area's resources. Resource management programs depend upon the acquisition of spatially referenced information sources that are both current and tailored to the specific resources common to the project area. Because of the existence of the comprehensive conventional resource data base compiled by the Area XV Regional Planning Commission, Jefferson County has been chosen to demonstrate direct applications of the proposed resource analysis strategy. This readily available traditional data have been integrated with the image-derived resource inventory to provide a basis from which management alternatives can be evaluated that concern such regional matters as recreational site suitability, management of agricultural lands, monitoring of urban growth trends, and resolution of potential resource management conflicts.

Recreational site potential

The growth of urban centers has created an increased demand for recreational facilities. To deal with this need, soils information for a portion of southwestern Jefferson County has been superimposed on an image-based pasture land inventory (Figure 61) in order to evaluate the potential of

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Figure 61 near here.

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this land cover class for the siting of such facilities as golf courses, picnic shelters, and campgrounds. Pasture land is considered marginally productive agricultural land and hence is not nearly as valuable as prime crop acreage. It is therefore economically feasible to develop suitable pasture land into recreational sites. Soils reports have been used primarily to gain data on the engineering characteristics of the area soils, including such elements as foundation suitability, and soil erosion and compaction potential. A number of physical resource variables have been synthesized by the Area XV Regional Planning Commission and assigned correlative ten acre values which reflect the averaged recreational site suitablity of these units (Figure 62). Categories were designated on the basis of

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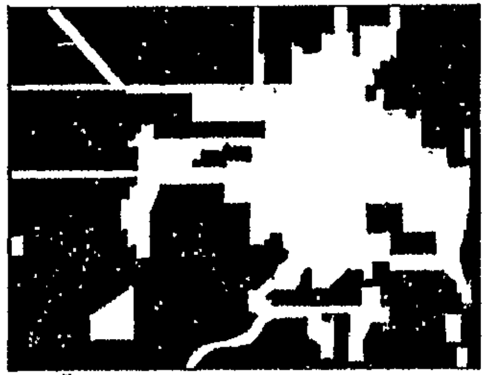
Figure 62 near here.

Figure 61. Landsat image interpretation of land cover classes (delineated in white) for southwestern Jefferson County

CROP COVER

PASTURE LAND



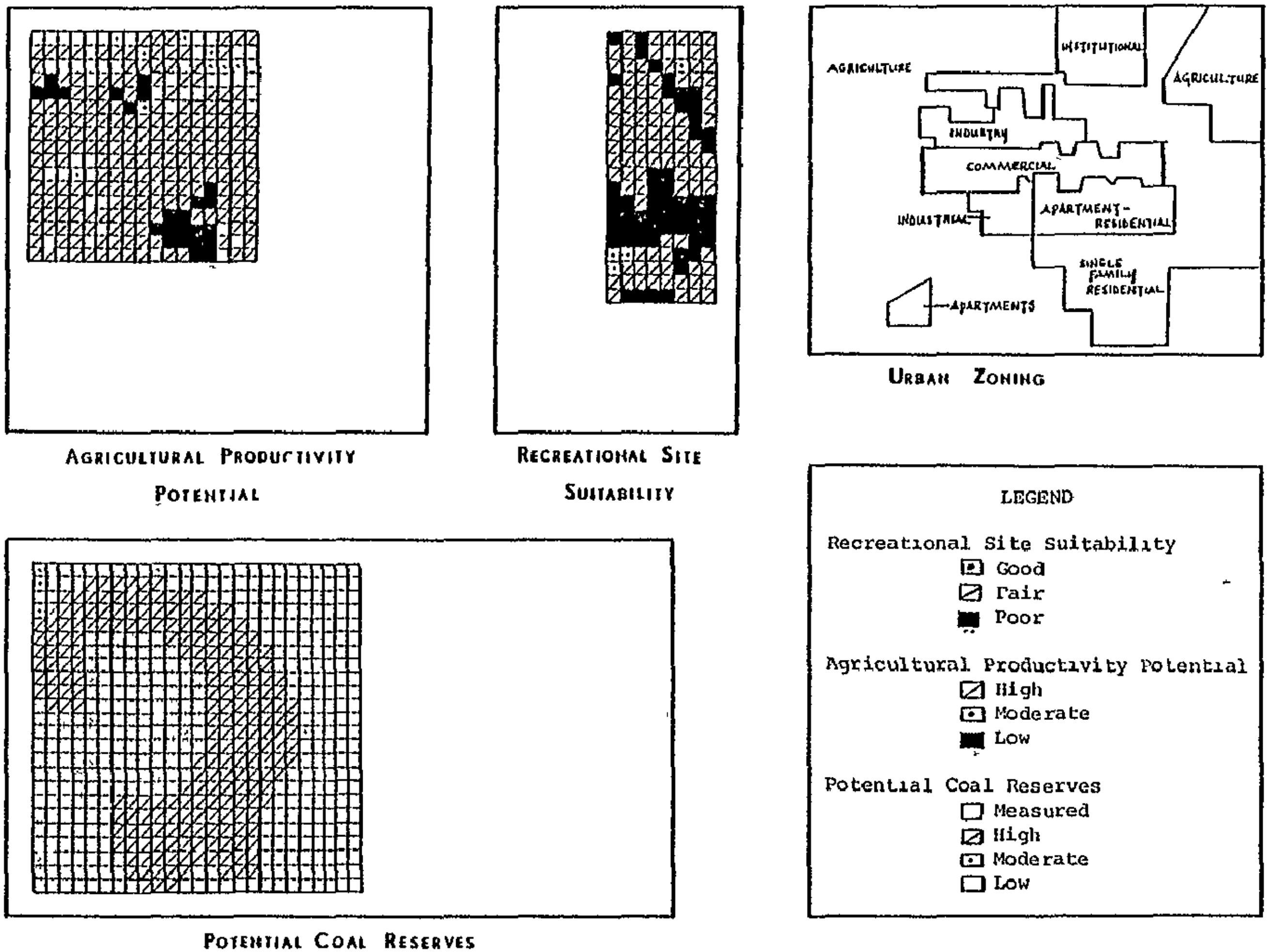
FAIRFIELD, IOWA

FOREST LAND

For display purposes, these figures were originally produced on clear acetate overlays to illustrate seleced land cover classes when placed over Landsat scenes Consequently, areas of land cover unrelated to the delineated classes have been blackened out. This type of overlay derived from Landsat imagery is easily understood by non-technical personnel due to its geographic perspective. Conventional aerial photo interpretation techniques have been used in this analysis produced at the Area XV Regional Planning Commission by J.R. Lucas and B.W. Bullamore.

Scale: approximately 1:125,000

Figure 62. Synthesized resource data for southwestern Jefferson County as compiled by the Area XV Regional Planning Commission



Scale: approximately 1:125,000

Each grid cell = 10 acres

good, fair, or poor siting potential of each locality. The majority of pasture land in the test site is included in the fair potential category, indicating moderate siting limitations. A substantial portion is poorly adapted and hence is indicated as possessing severe limitations. Very few ten acre sites were found to be highly suitable for recreational sites in the test area.

Agricultural productivity potential

Soils documents and Landsat-based inventories of crop cover can be used concurrently to monitor and manage agricultural productivity. The extent of crop acreage (including both row and cover crops) has been delineated from April and September imagery for a portion of southwestern Jefferson County (Figure 61). Considering variations in parent materials, topography, soil associations, soil erodability, and soil compaction, the Area XV Regional Planning Commission has assigned synthesized values to ten acre sites within the test area. Limitations on soil productivity determined the high, moderate, and low agricultural potentials designated on Figure 62. Graphical overlays of synthesized spatial information can be superimposed on a photo-interpreted crop cover inventory to monitor agricultural soil useage on a county-wide basis. This methodology illustrates current utilization of high potential agricultural areas and can be used to effectively manage and protect these invaluable lands.

Urban zoning

Urban areas are characterized by great diversity in land use patterns and are subject to relatively rapid change. Specific metropolitan activities are normally concentrated in various portions of a city. An urban land use inventory is traditionally based on these functional categories in order to define homogeneous classification areas. Landsat images can provide the temporal data necessary to monitor this dynamic setting. Fairfield, Iowa, has been selected to illustrate the spatial distribution of typical urban land uses, including industrial, commercial, and institutional activities, and various types of residential areas. Landsat-based delineation of the urban area (Figure 61) can be utilized in conjunction with the city's zoning plans (Figure 62) to compare general growth trends with the current zoning pattern. In this manner, regional planners can continuously and cost-effectively monitor changes in the overall distribution of facilities in urban areas on a county-wide basis. City managers can regularly monitor changing land use patterns to detect newly forming growth trends and variations from planning policies. Hence, enforcement of zoning restrictions can be undertaken or planning policies can be revised by the area's management personnel.

Potential coal reserves

A possible conflict in resource management has been demonstrated in Jefferson County by the integration of image and conventional data bases. September imagery has been utilized to delineate forest lands within a test site located in the southwestern portion of the county (Figure 61). The Commission has identified the status of coal reserves on a ten acre basis for this test area. Values assigned to these units include low, moderate, and high potentials of coal deposits, and, in addition, areas of confirmed deposits are specified (Figure 62). Although not as economically valuable as this non-metallic deposit, forests are a precious natural resource due to their potential for recreational activities and their service as wildlife habitats. These ecologically fragile areas are difficult, if not impossible, to replace and hence are a limited resource in Iowa. Superimposition of the data delineating forest lands and coal reserves in the test site illustrates the spatial extent of this management conflict. Resolution of this environmental dilemma may lie in the effective use of an analysis procedure which is based on the integration of image and traditional data sources and graphically illustrates management alternatives.

CONCLUSIONS CONCERNING IMAGE PROCESSING AND LAND CLASSIFICATION

Enhanced Landsat imagery was most useful for land classification purposes because these images could be photographically printed at large scales such as 1:63,360. The ability to see individual picture elements was no hinderance as long as general image patterns could be discerned. The lack of land cover detail of Landsat images in contrast to the detail seen on low altitude air photos, help planners to more quickly evaluate and quantify land classes on a data cell basis. This was accomplished by overlaying a grid over enlarged Landsat imagery and determining the dominant land class within the data cell.

2. Digital image processing of Landsat is a very complex operation. Even though the state of Iowa possesses the computers and personnel capable of implementing the software required for image processing, the investment of time and money would be substantial. In addition, if the state of Iowa were to do its own image processing, a film recording device (such as an Optronics P-1700) and photographic processing laboratory would also have to be available. Film recording devices are relatively expensive, but most important, they require extensive maintenance. A photographic laboratory to accomplish the development and printing of black and white film and paper, color transparencies, and

color photographic paper would also require a substantial investment. Additionally, false-color compositing techniques and photo-optical enhancement would require extensive photographic equipment and trained personnel. Considering all these factors, the state of Iowa could more easily justify purchasing computer enhanced Landsat products than producing their own.

3. Low cost photographic processing systems for color prints have proved to be effective in the utilization of computer enhanced Landsat products for land classification purposes. The initial investment for this type of system is very low, ranging from \$100 to \$200 beyond a black and white photo lab. In addition, the technical expertise can be acquired from reading a color printing and processing manual. The professional quality prints produced with optimal color balance, exposure, and scale can be made to best serve the needs of the user for imagery analysis and interpretation. Both the low cost and limited photographic expertise required for color photographic processing makes the implementation on the regional planning commission level a realistic goal.

RECOMMENDATIONS FROM PLANNERS IN THE AREA XV

REGIONAL PLANNING COMMISSION

1. NASA must "market" Landsat products to make practicing planners more aware of the system's capabilities. In additon, federal agencies such as the Department of Housing and Urban Development (HUD) should assist in the establishment of standards that could be met through the use of Landsat data. This could be encouraged by setting a uniform federal land planning policy. Federal agencies could encourage state level participants in the utilization of Landsat data by funding projects with objectives that could be met by using Landsat data.

2. Training and assistance must be available to planners. This could be offered in the following three ways:

a. Private consultants could be trained by NASA who would in turn market their services to planners.

b. Training could be given by NASA to state regional planning agencies through state government offices.

c. Personnel of federal agencies such as HUD could be trained in the application of Landsat data. These agencies could then provide assistance and training to planners. Planning projects could be subsidized with Landsat image products and assistance in applying Landsat technology rather than just dollar finding.

3. If Landsat data is to be operationally used for planning purposes, there must be a consistent national land planning program in which Landsat data could be used to meet the criteria of the program. In addition, because the Landsat system is not an operational system, traditional planners are reluctant to invest time and money in the development of Landsat based studies. In initial stages of development for an organization trying to utilize Landsat data, the cost must be subsidized to encourage innovation. These subsidies could be made through imagery, training, or assistance.

4. The views of Bruce W. Bullamore, Director of the Area XV Regional Planning Commission are expressed in Appendix A.

SUMMARY OF NASA FUNDING

The funding for this project of land classification in south central Iowa from computer enhanced images was supplied by the National Aeronautics and Space Administration under contract NAS5-20832. The Jet Propulsion Laboratory Image Processing Laboratory was funded by NASA for $20,000 to provide computer enhanced imagery for the contract. $28,775 was allotted to the Iowa Geological Survey to support contract-related research. A further breakdown of the contract budget is shown on Table 26.

Table 26 near here.

Table 26. Budget allotted by NASA for contract NAS5-20832

Land Classification of South-central Iowa from Computer Enhanced Images

Element of Cost	Budget Allotted by NASA
Salary for Project Manager based on 16 months	$16,874.00
Employee benefits for Project Manager	2,038.00
Travel related to project - transportation	2,400.00
- per diem	1,600.00
Expendable materials and photographic supplies	863.00
Publication expense	5,000.00
Subtotal	$28,775.00
Funding to the Jet Propulsion Laboratory (JPL) by NASA	
Salary for JPL scientific and technical staff and computer processing time (billed to NASA by JPL directly)	20,000.00
Total funding by NASA for Contract NAS5-20832	$48,775.00

REFERENCES CITED

Hoyer, B. E., et. al., 1973, Resource Development Land- and Water-Use Management Èleven-County Region South-Central Iowa: Iowa Geological Survey, Miscellaneous Map Series 4. Iowa City, Iowa.

APPENDIX A

AREA XV
REGIONAL
PLANNING
COMMISSION

Building #46 Ottumwa Industrial Airport Ottumwa Iowa 52501 515-682-8932

April 15, 1977

Dr. James R. Lucas
NASA Principal Investigator
Technicolor Graphic Services, Inc.
Applications Branch
EROS Data Center
Sioux Falls, SD 57198

RE: NASA Contract - "Land Classification of South Central Iowa from Computer Enhanced Images"

Dear Dr. Lucas:

We believe that the information provided by this investigation may help to give land use classification a new perspective. We found the images provided to be an effective tool in making a quick analysis of land use conditions in our area. We are presently using this information in developing a land use plan for Jefferson County, Iowa.

We would like to thank you, as well as Mr. Richard Blackwell and Mr. Fred Billingsley, for the information furnished and for the opportunity to participate in this project. The Area XV Regional Planning Commission is confident that receiving satellite image data on a continuing basis would be of great value to our planning operation.

It is our hope that in the future we can continue to look to NASA for technical assistance in applying satellite imagery to practical land use planning.

Sincerely,

Bruce W. Bullamore
Executive Director

BWB:bab

AREA XV
REGIONAL
PLANNING
COMMISSION

Mahaska Keokuk
Lucas Monroe Wapello Jefferson
Wayne Appanoose Davis Van Buren

Building #46 Ottumwa Industrial Airport Ottumwa Iowa 52501 515-682-8932

June 18, 1976

Mr. Richard Blackwell
Acting Task Manager
Earth Observations Program
Jet Propulstion Laboratory
4800 Oak Grove Dirve
Pasadena, California 91103

Dear Mr. Blackwell:

The Area XV Regional Planning Commission would like to express its deepest appreciation for the Land Classification Study which used enhanced Landsat image that are being conducted in our area. As a result of this study, not only has our staff expanded its appreciation of the Landsat programs and their applications, but we have been able to come up with techniques for using Landsat information in our long-range and day-to-day planning programs which makes it possible to make rational decisions concerning land use planning and management from a set of relatively complex data bases The major advantage of the Landsat information is that it allows us to inexpensively evaluate changing conditions and to portray those changing conditions through the use of imagery to relatively non-technically oriented policy makers Thus we are able to develop a heuristic model capable of dealing with issues in land management in a relatively inexpensive manner

In my opinion, if regional planners and aerospace scientists could sit down to decide how to fully utilize those Landsat processes which are already proven and how to integrate them with other natural inventory data systems, the resulting system based on Landsat imagery could revolutionize land use planning in this country Perhaps the two reasons planners have not fully utilized Landsat information sytems is the lack of technically understandable systems on the part of planners themselves, and the somewhat indefinite nature of the availability of NASA information to state and local agencies

Certainly a formal committment by the federal government to follow on Landsat programs would do much to alleviate this But beyond that, there is a need for a definable set of policies as to what role NASA, JPL, and the EROS Data Center might play in assisting regional and state agencies in developing their own Landsat systems.

I think future demonstration projects in the nature of this one could be conducted in other regions in the United States with the assistance of people like Jim Lucas, who obviously has an understanding of the technical aspects of the Landsat system. People such as Mr Lucas are extremely helpful in getting broader recognition and eventually broader applications for the Landsat systems.

As a side note, I would like to point out that one factor which is centrally important in expanded applications of Landsat systems is that of appreciation of key state agencies of the Landsat system and what they have to offer Since most of the hardware and software equipment needed to carry on Landsat analysis on an ongoing basis is beyond the capability of the majority of regional planning commissions the key to further use has to lie with state agencies, or perhaps state associations of regional planning commissions. In this respect there is a great need for further intensive application training sessions with state officials This should be conducted by people from the JPL, EROS Data Center, or other NASA agencies.

What I hope is that this study can be reviewed, not as a highly technical document pointing out the ultimate applications of Landsat imagery and land use planning, but as a document that would show the possible types of advantages and applications that the Landsat information system would have in local planning

This agency, for one, is deeply appreciative of the services which NASA and JPL have rendered us in allow these studies to be conducted here.

Sincerely,

Bruce W Bullamore
Executive Director

BB kb