# A MICROCOMPUTER BASED GEOGRAPHIC INFORMATION SYSTEM TO PROVIDE INPUT TO SITE SPECIFIC DECISION PROCESSES

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ABSTRACT

Numerous Geographic Information Systems (GIS) have been developed around minicomputers to provide a basis for computer assisted land planning processes on a state or substate regional unit. Generally, the use of these systems involved time consuming data input and analysis processes requiring the skills of professionals specifically trained in computers, spatial data management, and display techniques. The application of such techniques often has inherent timeliness limitations, as a controlling committee or project group must make the decisions related to the data to be input, such as cell size, formation of test scenarios, and so on. The application of the GIS concept to the analysis of dynamic, local land management processes is severely handicapped by these "institutional constraints".

One can assemble low-cost microcomputer systems which possess computing power, color display, memory, and storage capacity approximately equal to minicomputers. They are being used as a basis for the development of GIS that can be used by the individual professional who wants to employ a GIS as an adjunct to environmental or other resource management decision processes. Our prototype, called MIPS for Map and Image Processing System, uses the IBM PC, XT or AT computer.

All raster data input to the MIPS system is geographically referenced to the 7.5' or other U.S. Geological Survey topographic map series in any cell size selected by the user. Satellite images are extracted directly from magnetic tape and geocalibrated into 7.5' image maps for visual or automatic interpretation into land cover maps. Polygonal map data recorded on 7.5' maps (e.g., a soils map redrawn on a 7.5' map base) can be directly and easily rasterized to the selected cell size using an interactive paint-by-numbers scheme which requires a few hours per map for both inputing and editing. Elevation data and its derivatives, such as aspect and slope, can be extracted and interpolated into the appropriate cell size from Digital Terrain Map (DTM) tapes or 7.5' Digital Elevation Model (DEM) tapes distributed by the USGS. Cultural, cadastral, hydrological, and other linear data are extracted from the 7.5' or 1:100,000 Digital Line

Graphs (DLG) being prepared by the USGS. Using only the resources of a microcomputer, the professional can assemble these and other inputs with MIPS and perform all usual GIS functions in a user friendly and timely fashion.

## INTRODUCTION

A Geographic Information System (GIS) could be beneficially used by individual professionals to provide a data base, reference frame, and analysis tools for local, site-specific planning and other spatially oriented decision processes[1,2,3]. A suitable GIS for such applications should:

* provide easy, simple, and economical methods for reducing the available map and image data to a geographical registered digital format,
* yield affordable end products so that its user can apply the techniques to discrete sites,
* have input and output procedures which are flexible to meet a wide variety of local user's diverse and changing needs,
* yield output products in formats which are readily recognized and understood by these local professionals, their support staffs, and clients or constituents,
* employ as much as possible of the microcomputer equipment which may already be available and familiar, and
* be economical, locally maintained, and capable of being used for other unrelated objectives such as word processing and data base management, if the basic equipment must be purchased.

Simultaneous achievement of all these objectives has yet to be accomplished by any available microcomputer-based GIS. The purpose of this report is: 1) to discuss the development of a system focused upon these objectives using IBM PC/XT/AT microcomputers, and 2) to demonstrate the system's application through sample products.

The Map and Image Processing System (MIPS) being researched at the University of Nebraska attempts to meet the above critera as follows[4,5,6,7]:

<u>Simplicity of Data Plane Input/Output Procedures</u>

* Polygonal map data are digitized by a simple, raster oriented technique which "paints" the polygons onto the display screen in the

selected cell size and geoencodes these cells if the source map was so referenced. Editing this raster display uses simple "paint-over" procedures.

* Original Landsat MultiSpectral Scanner (MSS) or Thematic Mappet (TM) multispectral digital images are altered in cell size and geometry, geoencoded, and registered as image maps to the other rasterized maps in the GIS.

* Direct visual interpretation of color displays of these image maps on the display screen provides their final input to the GIS.

* Semiautomated (supervised) and automated (unsupervised) interpretation of these image maps can also be applied to yield land cover and related GIS data planes.

* Direct photointerpretation, geometric correction, and "painting" of annotated photographs directly on the display screen into the raster desired is also being explored.

Familiarity with the Data Plane Input/Output Formats

The user of MIPS is encouraged and assisted to construct a GIS around one or more 7.5' or 15' U.S. Geological Survey (USGS) map quadrangles to facilitate data plane preparation and to provide on-line display and off-line hardcopy products which are easily understood by a client or constituent. MIPS is structured around, but not limited to, this unit of data. Increased microcomputer capabilities, such as those of the IBM AT, have made it possible to begin the design for the expansion of MIPS to treat a county as the basic data plane and GIS unit while retaining its current minimum cell size.

Flexible and Economical Hardware Requirements

The IBM PC/XT/AT series of microcomputers was selected for MIPS as it is already widely available to individual professionals. Thus, many potential land management professionals already have direct, personal access to a microcomputer upon which a MIPS-based GIS can be constructed. Many are currently familiar with, and have justified the use of, this system for other unrelated objectives or could justify the purchase of the system for a variety of other tasks in addition to GIS analysis. This flexibility is particularly important to the individual professional who does not have the time to become familiar with more than one computer and its operational and maintenance procedures and who wants a fixed, rather than reoccurring, cost for all computer needs. MIPS can be retrofit to existing IBM PC/XT/AT systems by the addition of the following components with their estimated acquisition costs (as of March 1986):

* a color image display interface ($2000),

* an analog Red/Green/Blue (RGB) monitor ($400),

* an upgrade to 640,000 bytes of memory ($200),

* an Intel 8087 arithmetic processor chip ($75), and

* a Microsoft mouse point device ($100).

The current implementation (Appendix A) of the MIPS developed to meet the needs of individuals for site specific geographic information systems analysis should not be confused with a "toy level" undertaking with only demonstrational capabilities. The configuration using the IBM AT and the most advanced color display interface cards is fully capable of a throughput and computation at a rate equal to that of a VAX 750. For example, a full color display of 512 by 512 cells can be prepared in 5 seconds from data representing 8 bits each of red, green and blue. This display can be recolored, zoomed, and then panned in a fraction of a second. Any of the currently popular image processing algorithms can be implemented on this system and applied to any size of image if the user adds appropriate peripherals.

None of the MIPS processes makes any use of mini or mainframe computers. All tasks are completed directly on the microcomputer except the preparation of high quality digital film and ink jet plotting in large formats which are done at service bureaus. All open reel, standard tape reading or writing is done directly on a MIPS unit. Most sizes of floppy disks and disk formats are supported including 8", 5.25" regular and high density, and 3.5". Floppy disk access includes importing and exporting images and map files to and from a variety of other commercially available microcomputer based image and GIS analysis systems. A very large capacity, write-once optical drive will soon be added to MIPS to store large versions of our standard multivariable rasters equal to entire Landsat frames. Currently, development of MIPS is guided by the viewpoint that if it can't be done economically with a microcomputer, it will not be done.

## IMAGE MAP CONCEPT

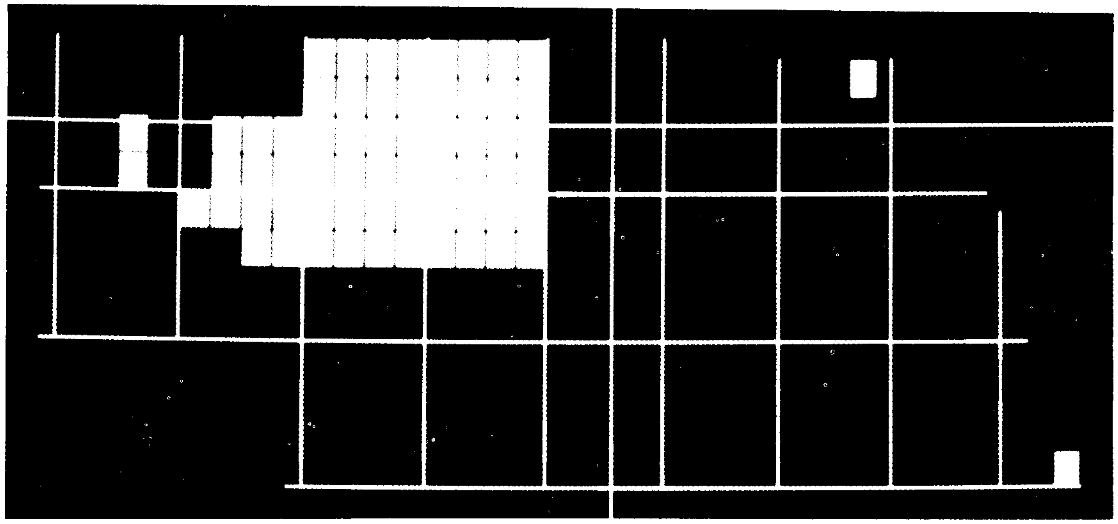
The MIPS concept whose form and use are illustrated here is raster based. All data types in the system for a map area or GIS are stored in a single multivariable raster file and format which will be consistently read from, and rewritten to, for each subsequent operation. Currently, point and line features are not well handled by this approach.

The first analysis decision which the MIPS user must make is which cell size is consistent with the sources of data to be used. This is a relatively simple decision for a site specific GIS undertaking as the data base will generally be built, used, and then discarded. This is completely opposite to state level or institutionalized GIS undertakings where a committee representing all interested parties must determine what types of material will occur in the data base, what its cell size will be, and many other related issues. Many such institutional barriers must be overcome to implement large GIS designed to be preserved and maintained and to "be all things to all people"(8). However, these design decisions are much more easily made in connection with site specific, product oriented GIS analysis.

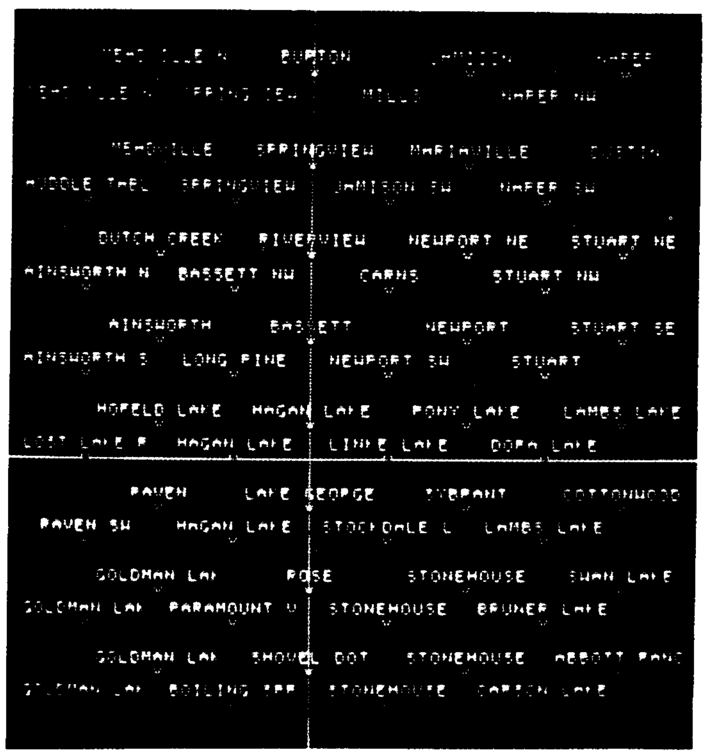
Typical useful cell sizes for a MIPS site specific undertaking would be 0.25 acre, 1 arcsecond of latitude and longitude, or 28.5 by 28.5 meters. The cell size is variable, and several tools are available to assist the user in creating the selected cell size during data plane input and to alter the cell size of existing material already in the raster format, such as USGS Digital Terrain Model (DTM) or Landsat images.

The fixed ground cell size of 28.5 by 28.5 meters will be used for the following illustrations. It is equal to one half the east/west cell size of a Landsat MSS image and just slightly smaller than the 30-meter cell size of the Landsat TM image. Thus 28.5 meters is a compromise cell size for combined use on map data planes of both types of commonly available Landsat satellite images. It also provides a reasonable total raster size for a 7.5' interval of latitude and longitude yielding 488 by 488 cells at the equator. This raster conveniently fits on commonly available 512 by 512 color image display systems A typical 7.5' raster of this cell size is about 380 columns by 488 lines at the latitude of central Nebraska. Selecting the 30-meter cell size of the Landsat TM images would yield 514 lines, which would not fit on the display at one time. Throughout MIPS the raster size, the number of variables, and the cell size are treated as variables and can be selected and changed as the user desires.

The second logical step in a site specific GIS is the extraction and geocalibration of 7.5' Landsat MSS and/or TM image maps for the 7.5' USGS map units covering the site(9,10). A unique USGS map selection and image map retrieval subsystem has been implemented in MIPS for this purpose. A series of disk files has been prepared from a USGS data base containing the names and geographic locations of all of the 55,000 USGS 7.5' and 15' map units for the entire United States, including provisional names for unpublished 7.5' map units. MIPS first displays a color graphic of the United States and its territories from this data base. The mouse pointing tool is used to point and select the state or territory. Within seconds a graphic is displayed (Figure 1a) of the 7.5' and 15' maps covering that state organized into 1-degree cells. Pointing to and selecting a 1-degree cell, or a 7.5' map unit within that cell, displays a third graphic (Figure 1b) which represents an enlargement of the 1-degree cell showing the corresponding 64 7.5'-map units and their official USGS map names. The user may then point to and select the map of interest by name or location to retrieve its name and geographic boundaries, which are passed on to the



a) state level graphic for 7.5' quadrangle selection




b) 1-by-1-degree graphic for 7.5' quadrangle selection

Figure 1. Displays used for the selection by use of a mouse of a 7.5' or 15' USGS map quadrangle for any state or territory for the extraction and calibration of Landsat Multispectral Scanner (MSS) or Thematic Mapper (TM) image maps from tape or optical disk.

next function. This total selection process involves three mouse pointings and about 15 seconds to retrieve the geographic location of the 7.5' unit desired from among the 55,000 available.

The 1-degree cell displayed in the map selection process corresponds with the contents of each single page in the new pending USGS topographic map index booklet. This index in booklet form would be used as a companion tool as it presents 1:500,000 color map detail for each 1-degree area for the easy location of specific maps using a road, road intersection, drainage, cultural or other map feature. Alternatively the MIPS user may choose to directly enter a known 7.5' map name to retrieve its location. The direct entry of the latitude and longitude of any ground point will also retrieve the name and location of the corresponding 7.5' USGS map unit or a 7.5' area of latitude and longitude centered at the point of interest.

MIPS uses the map unit boundary retrieved by one of the available procedures to search data bases which inventory available digital Landsat images. The search will identify those scenes which contain the map unit of interest and report them to the user for his selection. Three inventories of Landsat tape holdings can be searched according to the user's needs. They consist of 1) a regional subsection of the scenes available at the EROS Data Center for procurement, 2) those scenes held by other institutions belonging to the Landsat Digital Tape Clearinghouse, and 3) the user's current on-hand digital Landsat tapes.

Assuming the user already has the appropriate digital Landsat scene, it is mounted on the on-line tape drive and a nominal image map is extracted from the tape and transferred into the standard multivariable raster on disk. A MIPS support service is available for this and other related data plane preparation processes for users whose GIS needs do not justify the addition of a tape drive or other special peripherals. A nominal 7.5' image map is a window of the image which has been geometrically rectified and resampled such that systematic errors are removed, the cell rows and columns are oriented east/west and north/south, and the desired cell size has been achieved.

The nominal 7.5' image map usually needs only a final east/west and/or north/south translation and trimming of a few rows and columns to match its features and boundaries to those of a corresponding 7.5' USGS topographic map to within one cell (Figure 2). This final accurate calibration of the nominal image map uses a 7.5' map on an optional X-Y digitizer and the mouse pointing device to co-locate points in the nominal image map display and the corresponding topographic map. The total tape extraction and calibration process takes about 1 hour and concludes with the final calibrated, multivariable raster being trimmed from the nominal image map. The image rasters which result are geoencoded with latitude and longitude to a one-cell accuracy by the calibration techniques. This is adequate to register them to available map data compiled on this 7.5' map


a) natural color image map


b) color infrared image map

Figure 2. Orthographic display of an image map of N. Central Nebraska which is accurately registered to the USGS 7.5' Pony Lake map and derived from the Landsat Thematic Mapper (TM) image of 24 September 1982.

or with images of other dates and types independently registered to the same map(11).

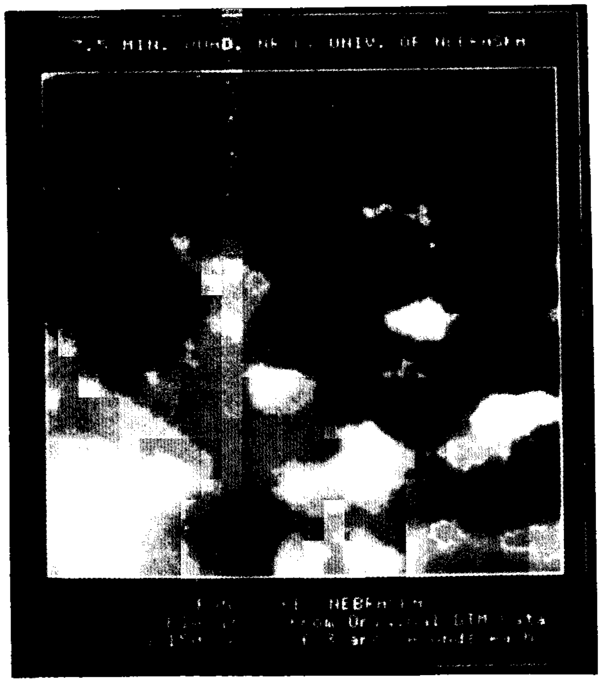
Two new MIPS procedures are being added to the Landsat image map extraction and calibration techniques, which should reduce the total time elapsed to obtain a 7.5' image map to a couple of minutes. This new approach will use an on-line, low-cost, write-once optical disk drive to give rapid, random access to complete Landsat MSS and TM scenes. This will greatly reduce the time needed to extract the nominal images using the inherently serial reading of magnetic tape. The second improvement will use the section corners or other cadastral information available from the 7.5' USGS Digital Line Graph (DLG) maps or other sources to provide a basis for rapid, visually based geocalibration of the nominal image map to within one cell. The use of on-line optical disks and the common use of larger hard disks now enables the adaptation and easy use of these image map extraction techniques for larger image maps matching the commonly available county highway maps or the new USGS 1:100,000 map series.

Landsat images of various dates and types can be selected, altered in cell size and geometry, and registered to the corresponding map unit by the MIPS user. Thus geoencrypted, multitemporal image maps are easily created and input to the GIS. Mixed resolution image overlay is also possible for mixed image types that can be registered to the map unit. For example, Landsat MSS and TM images are readily combined by this procedure(11) and overlay of SPOT image maps of mixed resolution will also be possible.

Multimedia combinations of digital images, airphoto interpretations, and map information readily follow from the map image orientation of MIPS. Elevation and elevation-derivative raster data are readily located and entered into MIPS via the same map selection procedure outlined above. Again, the map unit is selected using the same graphical point/select procedures. However, the geographic location of the desired unit is passed on to routines which locate the appropriate 1-by-1-degree square of Digital Terrain Model (DTM) data on tape, subdivide it into the appropriate 7.5;' raster of 3-arcsecond cells, and transfer it to disk (Figure 3a). This 3 arcsecond cellular structure is then interpolated to the desired cell size using cubic convolution to locally refit the topographic surface to the original cells (Figure 3b). Additional surface properties can be computed from this refit surface to form new derivative rasters, such as the slope and the orientation of the tangent plane at the interpolation point, yielding topographic slope and aspect rasters of the desired cell size.

## IMAGE MAP AND RASTER DISPLAYS

Image map display involves a number of alternative color balancing and output techniques. Color-infrared, pseudo-color, and color coded map displays are readily accomplished if the user is tolerant of their color balance and has no preconceived bias. Displaying full, natural color image



a) 3 by 3 acrsecond elevation raster


b) interpolated elevation raster

Figure 3. Elevation rasters derived from USGS Digital Terrain Model (DTM) 3 by 3 arcsecond rasters and interpolated using cubic convolution to match a 7.5' image map (Fig. 2).

maps and raster versions of color photos is just the opposite. Every MIPS user has his own idea of what constitutes a properly color balanced natural color image map. The conversion of the three variables to be displayed from their Red, Green, and Blue (RGB) assignments into Hue, Intensity, and Saturation (HIS) has been implemented. The color balance of image maps can be finely tuned by the user in the HIS domain and the results converted back to RGB for final display. Unfortunately, this conversion process is computationally intense and currently takes too much time for interactive color balancing. Eventually it should be implemented in hardware on the color display board. However, conversion to the HIS color domain is very useful for other objectives as discussed below. RGB color stretching and balancing schemes do provide reasonable quality displays of the image maps including natural color (Figure 2).

Georeferenced image maps can be combined with the corresponding elevation raster to provide a perspective or three-dimensional representation of the site (Figure 4). These realistic, bird's eye views are quite useful in assisting the customer for a GIS analysis (e.g., a planning board) in visualizing the spatial relationships usually portrayed in orthographic views of complex variable combinations. Further MIPS development is underway to allow an additional fifth variable to "float above" these perspective displays of four variables. Discrete polygons, such as a particular wetland cover type or a GIS derived combination class, can be masked into the image map rasters and then plotted in a perspective form to illustrate the interrelationship between that class or feature and the realistic color representation of the site.

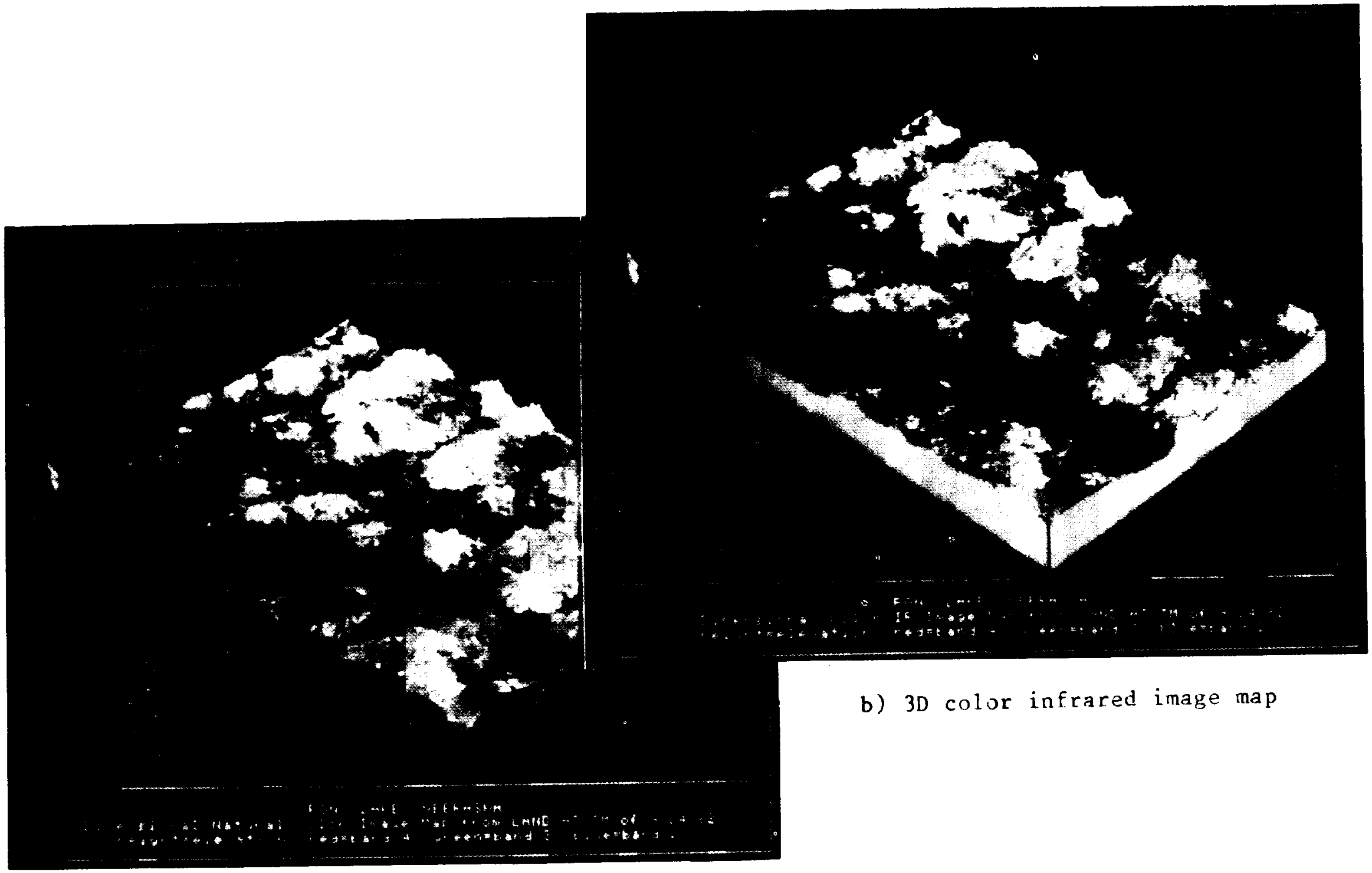
The MIPS system rigorously supports the concept of maintaining all map and image data planes in a single multivariable raster file matching a selected map unit. Any subsequent processes applied to this file preserve the geoencrypted map unit format. For example:

* The direct or automated image interpretation of image variables is added back as another raster(s) into the input multivariable raster.

* The process for manually digitizing polygons annotated on the base map corresponding to this file directly creates another variable in the file.

* Convoluting a GIS variable in a raster, such as computing minimum distances for every cell to linear road features in another raster, produces a new raster variable.

Hard copy maps can be produced at any scale for any input or product raster. These image maps are produced off-line by sending plot files on magnetic tape generated by MIPS to service bureaus. Capabilities have been implemented to produce plot tapes for large (9" by 9") and small (35 mm) digital color film recorders and large format color ink-jet plotters. A typical final product produced from any MIPS raster or combination of



a) 3D natural color image map

b) 3D color infrared image map

Figure 4. Perspective display of the combination of Landsat 7.5' image maps (Fig. 2) and the corresponding digital elevation raster (Fig. 3).

rasters would be a 7.5' map printed in full color at a scale of 1:24,000 (Figure 5). This map matches the corresponding 7.5' USGS topographic map to within one raster cell, which would be about 1 mm on the map for a 28.5-meter raster cell. Usually, the corresponding 7.5' USGS topographic map is photographically converted to a 1:24,000 clear film for direct overlay upon hardcopy products of MIPS. The large format digitally generated photographic products can also be accurately enlarged to this or any other map scale. This yields even higher quality color images but does not hold the geometric scale as well due to the dimensional instability of the photographic print paper. Any image processing or spatial GIS product is thus available, through this hardcopy output process, for further direct field interpretation, such as a base map for planning or for public review in meetings.

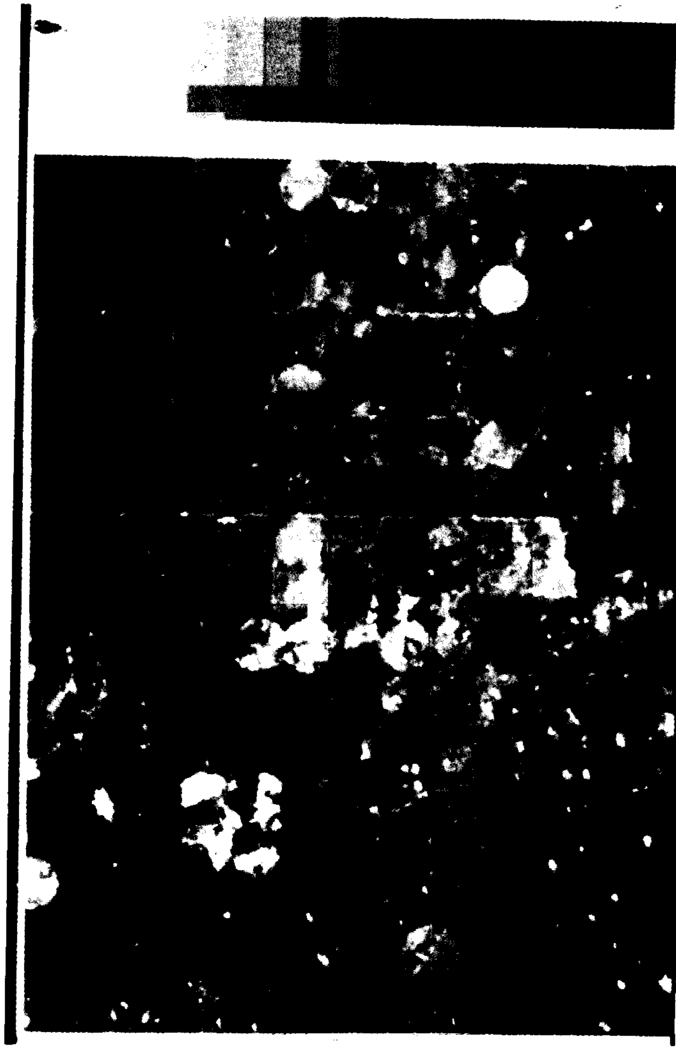
## IMAGE ANALYSIS AND ENHANCEMENTS

A variety of image processing tools is available to assist the user in converting MIPS's multitemporal, multivariable, multimedia image maps into GIS variables such as land cover. These include direct visual interpretation of color or computationally enhanced image maps on the display screen, semiautomated multivariable interpretation (supervised classification), and automated interpretation (unsupervised). Direct visual interpretation of image maps is the most intuitive method for creating land cover data planes for those professionals not yet interested in the more automated, but more synoptic, interpretations provided by MIPS computer image interpretation procedures.

Automated computer interpretation of images to extract land cover has not yet produced results acceptable to the end user on a site specific basis. This is partly because they are confused by the processes: specifically, the probabilistic interpretation which must be placed on the results. This happens even when the results from the automated method may be as accurate overall as those produced by a direct interpretation method. Direct visual interpretation will be illustrated here, as it appears to be the easiest technique for a novice to use to build a GIS to solve a site specific problem. While the approach is simple, it can employ computer assisted techniques to significantly enhance the results achieved and the efficiency with which they are achieved. In an example that illustrates the process Landsat TM imagery was used to map out wetlands in the Sand Hills area of north central Nebraska.

Direct visual interpretation of natural color or color infrared photographic reproductions of TM images or MIPS direct screen portrayals of 7.5' image maps yield only four or five distinct wetland categories (Figure 2). Wetland interpretation of three band color combinations of the seven-band TM image maps can be significantly improved by reprocessing the image map before visually interpreting it. The principal variations between wetland categories are manifested in TM images in terms of greenness of

a) natural color image map



b) color infrared image map

Figure 5. Reproductions of paper image maps of N. Central Nebraska extracted from the Thematic Mapper (TM) image of 24 September 1982. The original image maps were produced by a color ink-jet plotter and accurately scaled to match the USGS 7.5' Hagan Lake N.E. map.

green biomass per unit area, wetness of the vegetation and its soil background, and brightness as it is intercoupled with wetness. These three properties can be extracted from six of the TM bands (exclusive of the thermal band) using a constrained form of principal components. This technique directly results from an understanding of the biophysical processes involved in the interaction of solar radiant energy with the vegetation and soil surfaces. The six TM bands for a 7.5'-image map are convolved by this process into three new bands which contain almost all the information in the original six spectral bands but have convoluted them into a form which maximizes the separation of the desired greenness (G), brightness(B), and wetness (W) for the land covers present. (Figure 6).

Three monochrome images are difficult to interpret simultaneously by visual means unless they are combined in color (Figure 7). Maximum wetland cover-type variability can be portrayed in a new color composite by selecting the greenness component (Figure 6a) for greatest emphasis and by assigning it to control the hue or color of the display. Had wetness been the most important variable to separate the final interpreted wetland cover categories, then it would have been assigned to hue to control the color component of the final display. Scene brightness (Figure 6b) was assigned to control the display's intensity. Scene wetness (Figure 6c) was assigned to saturation in the display. These three rasters representing hue (H), intensity (I), and saturation (S) were then convolved by MIPS to red (R), green (G), and blue (B) for direct display (Figure 7).

The resulting TM 7.5'-image map presents in color the maximum amount of information for direct visual interpretation of wetlands land cover categories. Eleven distinct wetland vegetation categories can be readily distinguished and may be identified or labeled by direct field inspection. This improvement in interpretability has also been achieved by a process which was not an arbitrary color enhancement but was logical and based upon the biophysical processes of radiant energy exchange of the vegetation/soil surface (Figure 8). The process and the computational treatment of the image are also understandable to the MIPS user in contrast to the black-box oriented nature of fully automated image interpretation.

## DIRECT VISUAL IMAGE MAP INTERPRETATION

The GBW/HIS wetlands cover type image map is in a form which lends itself to easy interpretation and entry into a site specific GIS. It may be printed as a color ink-jet image at a 1:24,000 scale and directly interpreted in connection with other available materials such as a topographic map overlay, inexpensive 35mm airphotos (e.g., section-centered ASCS photographs or equivalent), 9" airphotos, and/or field inspection. The final polygons annotated on this paper version of the image map can then be rerasterized into MIPS at the same or at an altered cell size using the map entry procedures to be outlined in a subsequent section. The alternative is to directly interpret this image map on the display screen.

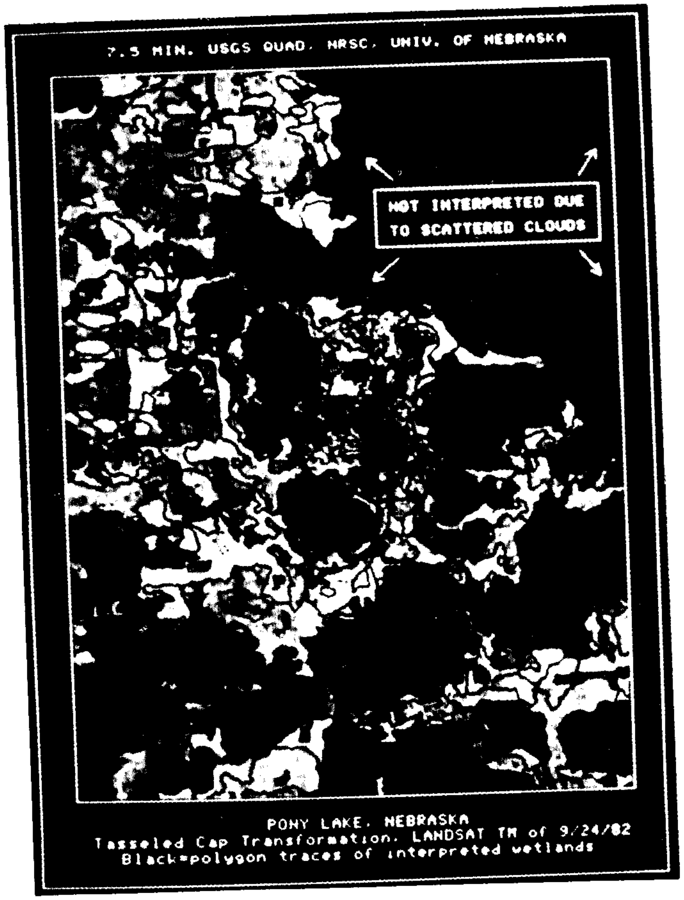

a) greenness image map

b) brightness image map

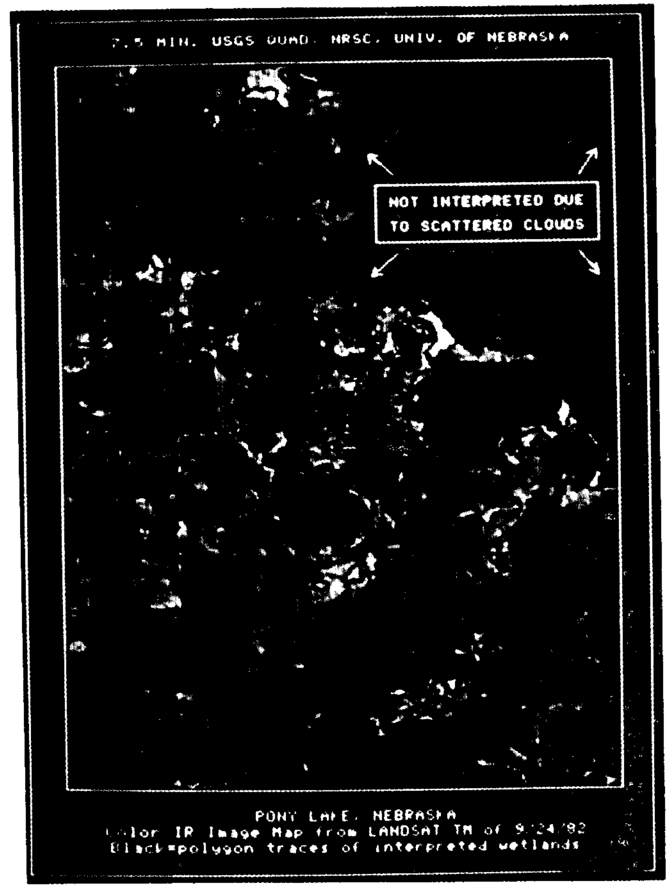
c) wetness image map

Figure 6. Landsat 7.5' image maps created by computing the Greennes Brightness, and Wetness (GBW) components of the 6 Lands Thematic Mapper (TM) spectral bands (excludes the thern band).


Figure 7. Wetlands enhanced pseudocolor Landsat Thematic Mapper 7.5' image map created by assigning its Greenness, Brightness, and Wetness (GBW) components to Hue, Intensity, and Saturation (HIS) respectively.




a) greenness, brightness, wetness with wetlands polygons




b) color-infrared with wetlands polygons

Figure 8. Illustration of the improved interpretability of wetlands types from the GBW/HIS enhanced Landsat Thematic Mapper (TM) 7.5' image map (a) versus its standard color infrared rendition (b).

This maintains the original raster format but eliminates the advantages of taking this GBW/HIS image map to the field site for interpretation in the full-scale paper format. However, digitized elevation and its derivative rasters, 3-D displays, and other related materials may be readily incorporated into the direct display interpretation.

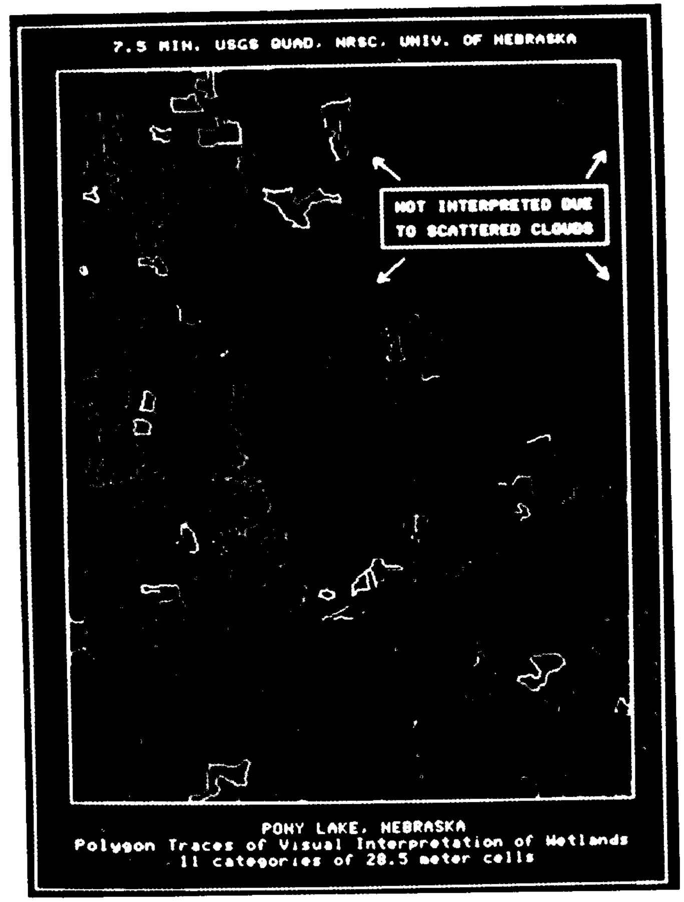
Direct interpretation of the GBW/HIS processed wetlands image map (Figure 9) is accomplished by using MIPS's mouse pointing device to outline or draw each polygon directly upon the display. Direct outlining of each polygon representing a wetlands cover type is accomplished just as one would draw with a pencil. After the polygon boundary is drawn and closed, the user points to the interior area and it is "painted" or filled with the color selected to represent that cover type. The user then proceeds to outline and fill each successive occurrence of that cover type. Sequentially mapping all occurrences of a given type saves time as the same polygon color is used over and over and the user need not remove his hand from the mouse for each subsequent polygon (i.e., a new polygon color or type need not be keyed in). Any polygon can always be modified by painting over it with a new polygon of the same or another color.

Filling the polygons as the interpretation proceeds obliterates the underlying image features and may make more difficult the intercomparison, adjustment, and revision processes typically employed in direct visual image interpretation. The MIPS user may elect to draw and color code only the <u>boundary</u> of the polygon as he proceeds so that the original image features show through. When the interpretation and all revisions are complete, all polygons can then be sequentially pointed to with the mouse and filled with a color corresponding to their type as indicated by their boundaries.

MIPS makes a fast save display screen function available globally via a function key throughout all other processes. This key rapidly saves or snapshots the display contents to a compressed file form on disk. This display image backup file can be just as rapidly restored using another global function key. The display screen backup and restore function works just as in a word processor to protect the user's investment of time in a particular process. It would be used periodically to protect the work invested in progressively interpreting such an image against permanent display errors incorporated by the user via eye strain and interruption or by software idosyncrasies. Within this process a backup image map can be restored at any time and its interpretation resumed. This approach significantly reduces the product editing procedures, as reinterpreting from the last backup is often easier than correcting recent errors.

The GBW/HIS wetland image was first interpreted down to the wetlands areas of interest by drawing a polygon around a small cluster of clouds and painting in that area with a specific value (Figure 9). Next, using reference to the elevation raster, the upland areas were outlined with polygons and "painted out" by filling them with the background color of


a) cellular form of wetlands type map




b) vector form of wetlands type map

Figure 9. GIS overlay which results from using direct visual interpretation and a mouse to draw polygons on the display of the GBW/HIS enhanced Landsat Thematic Mapper (TM) 7.5' image map of Figure 7.

black or zero (Figure 9). This suppression of uplands or drylands for a particular area might also have been accomplished by direct masking with the corresponding elevation raster. The remaining wetlands areas were interpreted and color coded and the cover-type map copied back into the multivariable raster containing all the other data planes. The raster may be retrieved to the screen from the GIS data base and the boundaries adjusted at any time.

This procedure illustrates the friendly, easily understood features being incorporated throughout MIPS for creating, selècting, and using map data planes in a site specific GIS. The creation of a wetlands land cover raster started with the creation of geoencrypted image rasters that possessed the geometric and cell size properties desired for the GIS analysis and subsequent hardcopy products. These image maps were processed into a form that maximized their display of the specific information desired. The end user then directly interpreted this product into the desired GIS overlay by using simple procedures which directly yielded the desired raster.

The GIS user can spend as much or as little time and care in this interpretive and drawing process as the subsequent use of the specific data plane requires. No photographic products, zoom transfer scopes, or other intermediate materials or equipment are involved. Any MIPS raster containing such categorical data can be converted back from raster form to vector or polygonal format (Figure 9). Thus, the wetland land cover type rasters can be converted back to polygons for use in plotting a polygon map on an optional line plotter. This yields a 1:24,000 scale transparent overlay for any map of that scale such as the 7.5' USGS topographic map.

Larger areas may be interpreted using multiple 7.5' or 15' image maps, arbitrary images, or the pending addition to MIPS of support for the 1:100,000 map series; all of which can be subsequently concatenated or mosaiced in their raster form by other MIPS functions. MIPS storage and retrieval functions also support using any size of raster that can be manually accessed and displayed as windows of a larger area being processed, interpreted, and organized into a GIS. MIPS has also been tested to support a virtual display window concept where the display and its interpretations are a window of a larger file whose subsections are automatically rolled on and off the hard disk as the mouse is used to draw polygons in the virtual display window. The availability of economical, larger hard drives for the faster IBM AT may make this automatic or virtual window approach practical throughout MIPS.

## HARDCOPY MAP INPUT

Polygon oriented maps that already exist or that must be compiled in a hard copy format are rasterized into MIPS by a procedure very similar to that for direct visual interpretation. Often the GIS user has access to, and a need to use, existing paper maps such as the Soil Conservation Service (SCS) soil maps. The required data plane, such as a 7.5' topographic map, may also need to be recorded directly on a paper map base for use in the field or for detailed airphoto interpretation. Regardless of how the map is obtained, it can be input to MIPS using a polygon drawing approach that substitutes a suitably sized X-Y digitizer for the mouse.

A typical example of the paper polygon map entry process might be the rasterizing of an SCS soils map which has been compiled from its original form of annotated black and white orthophotos onto a 7.5' topographic map (Figure 10a). This intermediate map is placed upon the X-Y digitizer. Then the desired final raster cell size is projected onto the map by a simple calibration process in which the display cursor is used to register the three corners of the map with the same three corners on the display, using the mouse pointing device. Using the same set of procedures outlined above for direct interpretation, the user "paints" the soil polygons onto the display screen.

A multivariable image raster usually already exists for a map being "painted" into the GIS. It is common to display an existing raster such as elevation or a single TM image map in black and white to facilitate calibration and to make the "painting" process more interesting (Figure 10b). For example, it is more interesting and intuitive to "paint" colored soil polygons onto an existing black and white display and see the correspondence, than to paint them on a blank screen. This visually confirms that this new raster is being correctly correlated to the existing raster(s) and thereby increases the user's confidence and understanding of the process. Should no other rasters exist for the site, the user must then resort to "painting" on a blank screen.

The map rasterizing process is designed to provide the user with direct visual feedback if the digitizer is placed directly in front of the color display screen. As the outline of a polygon is traced from the map, it is correspondingly drawn on the screen. The user may back up or erase any or all of the points constituting the current polygon, even if it is closed, up to the point he fills it or begins to draw another. The user may overpaint or add to a polygon at any point.

A series of brush tips or cursor shapes are currently being added (a la MacPaint™) so that the user may "brush-in" a polygon instead of drawing it. These alternate tools are equivalent to making the choice in real painting to outlining the area with masking tape and then rapidly filling the internal area; or, choosing an appropriate brush(s) and delicately working around the perimeter or the area and then choosing a bigger brush with which to fill in the area. The choice of the tool in MIPS is just as in painting and depends upon the nature of the item being painted into raster form.

Any rasterized polygon map can be converted back to vector form (Figure 11) and plotted on transparent paper to any map scale. After the complete soils map has been "painted" the raster-to-vector conversion process is run, and the resulting vector map is plotted to the scale of the input map. This 1:24,000 soils polygon map is then overlaid upon the source map (Figure 10a) and checked for accuracy of detail. The initial painting is then restored to the display and the errors edited using the paint brush or polygon drawing routines and appropriate colors. This process is interactively repeated as many times as necessary to achieve an accurate raster and vector representation of the source map. The test map (Figures 10 and 11) contained 24 soil types representing 288 polygons and, depending upon user experience, required between 4 and 8 hours to completely convert to the raster form by MIPS.

Map entry to a GIS in a vector form is also easy. However, editing polygon maps in this form can be complex and confusing. The "paint-by-numbers" approach implemented in MIPS is designed to be easily used and understood. Unfortunately, the technique does not as readily lend itself to the entry of point and line map features. A new multivariable MIPS format is being designed which will support the combined storage of both raster and vector data in a single file.

A wide variety of other functions exist or are being implemented within MIPS to assist in the preparation of GIS data planes. Linear features stored in raster form can be used as the basis of convoluting a new raster containing a distance or area measure for each cell such as:

* the minimum distance to a secondary road by a north/south and/or east/west excursion,

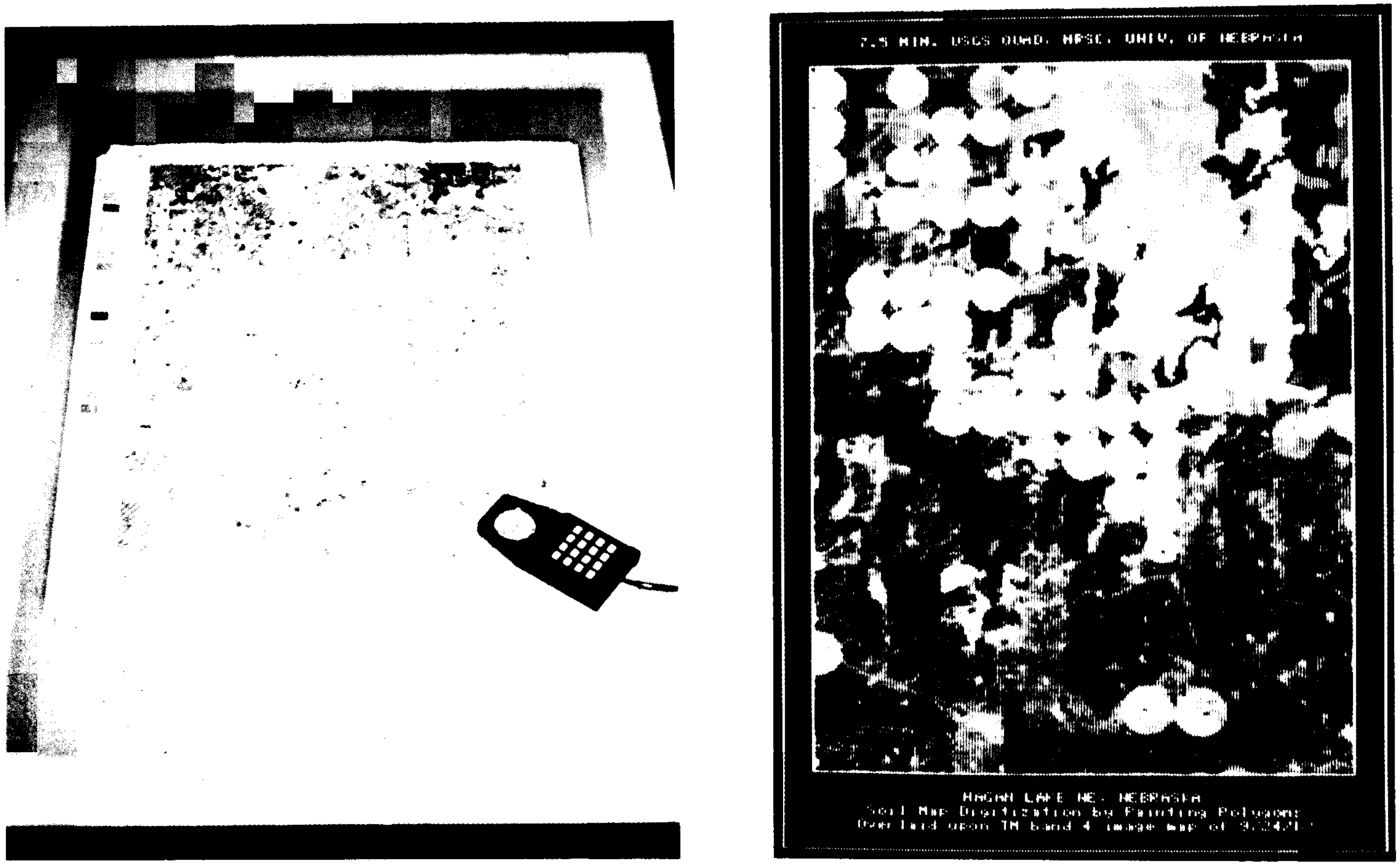
* line of sight distance to a feature or features,

* total area viewed from each cell, or

* the distance by maximum slope path (from elevation plane) to the nearest stream of a given class (from a DLG hydrological plane).

CONCLUSIONS

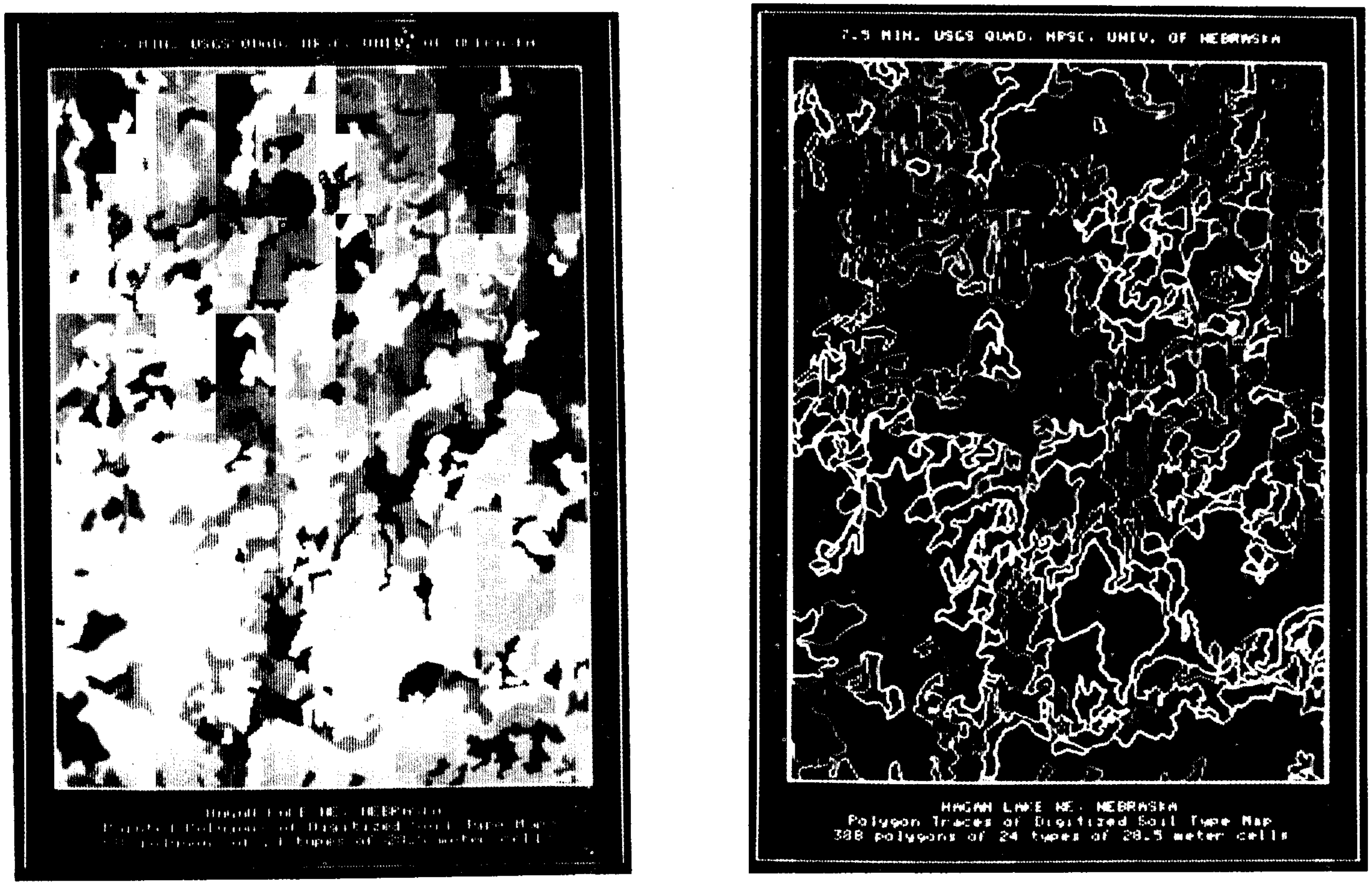
A MIPS multivariable raster and appropriate analysis tools constitute a site specific GIS. The system is further described in a fact sheet (Appendix A). Data planes can be put into this GIS with a relatively simple set of tools from a variety of available sources to represent a known ground area such as a 7.5' topographic unit. The user can also re-create data planes in a paper format for the selected area at any scale. The data sources that can currently be collated into a single raster file and cell size include:




a) source map of soil types

b) "painting" of soil types over an image map

Figure 10. Rasterizing a 7.5' polygon map of soil type using an interactive, "paint-by-numbers" approach.




a) cellular form of soil type map

b) vector form of soil type map

Figure 11. Completed reduction of 7.5' polygon map of soil type into raster and ve... formats.

* image maps extracted from any EROS Data Center Landsat MSS or TM image format,

* surface features interpreted by direct visual and automated computer techniques from these image maps,

* direct visual interpretations of airphotos compiled into a map format,

* elevation and its derivative data planes, such as slope and aspect, from USGS DTM tapes, and

* existing polygon map data of appropriate scale, such as soils maps.

Any plane or combination of planes in a MIPS raster can be treated with any MIPS analysis tool. A large variety of analysis tools occur in MIPS, and the user must be carefully trained to apply the appropriate tool to the proper raster, as all MIPS raster oriented tools will work with any data plane. For example, several image spectral bands could be weighted and logically combined to produce meaningless output. Similarly, interpolation based on cubic convolution can be meaningless if applied to a plane containing categorical soil type data. MIPS currently contains the common techniques required for local, site specific GIS analyses. These tools are simple to use from within a single MIPS menu-driven shell. MIPS is currently being adapted to use a mouse for all pointing and area selection functions (polygon drawing, rotatable elastic box, etc).

MIPS users should not need a very detailed user's guide. However, MIPS is a generic system, not a cookbook procedure, and thus the user must learn how to employ GIS procedures for his objectives. Learning is best accomplished through study of generic text books on GIS applications as well as case studies showing both simple and complex uses of MIPS to organize a GIS data base and extract information from it for specific uses. Currently the development of MIPS is focused upon implementing simple tools for the input and output of GIS data and for its interpretation.

The fashion in which the professional user interfaces to the MIPS system has been carefully considered. The majority of land management decisions are made by professionals from other disciplines. A very powerful GIS for site specific analysis will find little use if it cannot be understood and used by a professional not particularly interested in computers, remote sensing, image processing, geographic data analysis, or related technical topics. For as far as it has been implemented, MIPS has addressed this objective with some success.

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APPENDIX A

MIPS FACT SHEET

## General Design

The Map and Image Processing System (MIPS) has been developed at the University of Nebraska under a joint study contract with the IBM Scientific Center in Palo Alto. With additional hardware added to an IBM PC, XT, or AT, MIPS is capable of accessing and processing a wide variety of images available on magnetic tape, floppy disk, and film. The MIPS system is written in Microsoft C and is an integrated menu-oriented system with all programs under 64 kilobytes. Appropriate DOS functions can be performed from within MIPS such as directory search, file erase, disk capacity, path directing, and so on.

Currently MIPS supports the Vectrix Corporation's VX-384 color display interface via a parallel 1/0 interface and a Vectrix VX/PC dual board set via DMA. Both of these display interfaces are capable of displaying 512 colors from a palette of 17 million for 672 by 480 picture elements. The Number Nine Computer Company's model 512-32 single display board is also supported and is capable of the direct display of 256 thousand colors from a palette of 17 million for 512 by 512 picture elements. MIPS also requires 640 kilobytes of memory, the Intel 8087 or 80287 arithmetic processing chip, and the Microsoft 2-button mouse.

Additional optional hardware supported by MIPS includes a 1600 bpi standard 2400' tape drive, 8" floppy disk drives of 1.2 megabytes each, a 30" by 40" X-Y digitizer, a 20" by 30" line plotter, and an 8 bit, 512 by 512 picture element video digitizer board. A write once (DRAM) optical disk drive will soon be added.

## Summary of Capabilities

* Direct on-line extraction of images in a wide variety of formats from 3.5", 5.25", 5.25" high density, and 8" disks; standard 1600 bpi tape; black and white and color photographic film; and digital optical disks.

* Flexible color balancing and display of multivariable images using Red, Green, and Blue (RGB) and Hue, Intensity, and Saturation (HIS) color models.

* Contrast stretching of images for display using linear, logarithmic, exponential, gaussian and other transformations.

* General image cosmetic functions, including character and graphical annotation, zoom, and rotation.

* Two dimensional histogram displays and associated statistical computations to examine the relationship between any two images or other rasters.

* Altering the cell size and geometric properties of images and other rasters using interpolation by nearest neighbor, bilinear, and cubic convolution techniques.

* Filtering images by a variety of techniques.

* Display of three-dimensional solid models of four-dimension rasters (e.g., from elevation plus a coregistered color image).

* Simple, but instantaneous, classification or interpretation of images using point or rectangular feature selection.

* Combination of coregistered or multivariable images using a variety of transformations ranging from simple algebraic to specific satellite image biomass indicies to user defined mathematical transforms.

* Dimensional reduction of multivariable images using principal components analysis.

* Preparation of complex polygon maps or drawings as raster overlays for images using an on-line X-Y digitizer and an interactive "paint by numbers" approach.

* Direct visual interpretation of displayed images and the isolation of polygonal bounded subimage areas using a mouse and an interactive "paint by numbers" approach.

* Conversion of polygons from a raster to vector form and their replotting to any scale using a line plotter.

* Color hardcopy of images to any scale and size using large ink-jet plotters available at service bureaus.

* Conversion of the MIPS internal image format to and from a wide variety of other microcomputer image processing system's disk formats including PCIPS, APPLEPIPS, MICROPIPS, ERDAS, Decision Images, Terra-Mar, IMAVISION, RIPS, and VIPS.

* MIPS also contains a large number of menu utility functions to support image processing users ranging from beginners to experienced programmers. These include a fast save and restore of the currently

displayed image, numeric display of image file data to console, dumping of any disk file to console, internal common file display and editing, menu editing, error code editing, device selection, color map construction using the HIS and RGB color models, color display memory histograms, magnetic tape diagnostics, and others.