W. P.

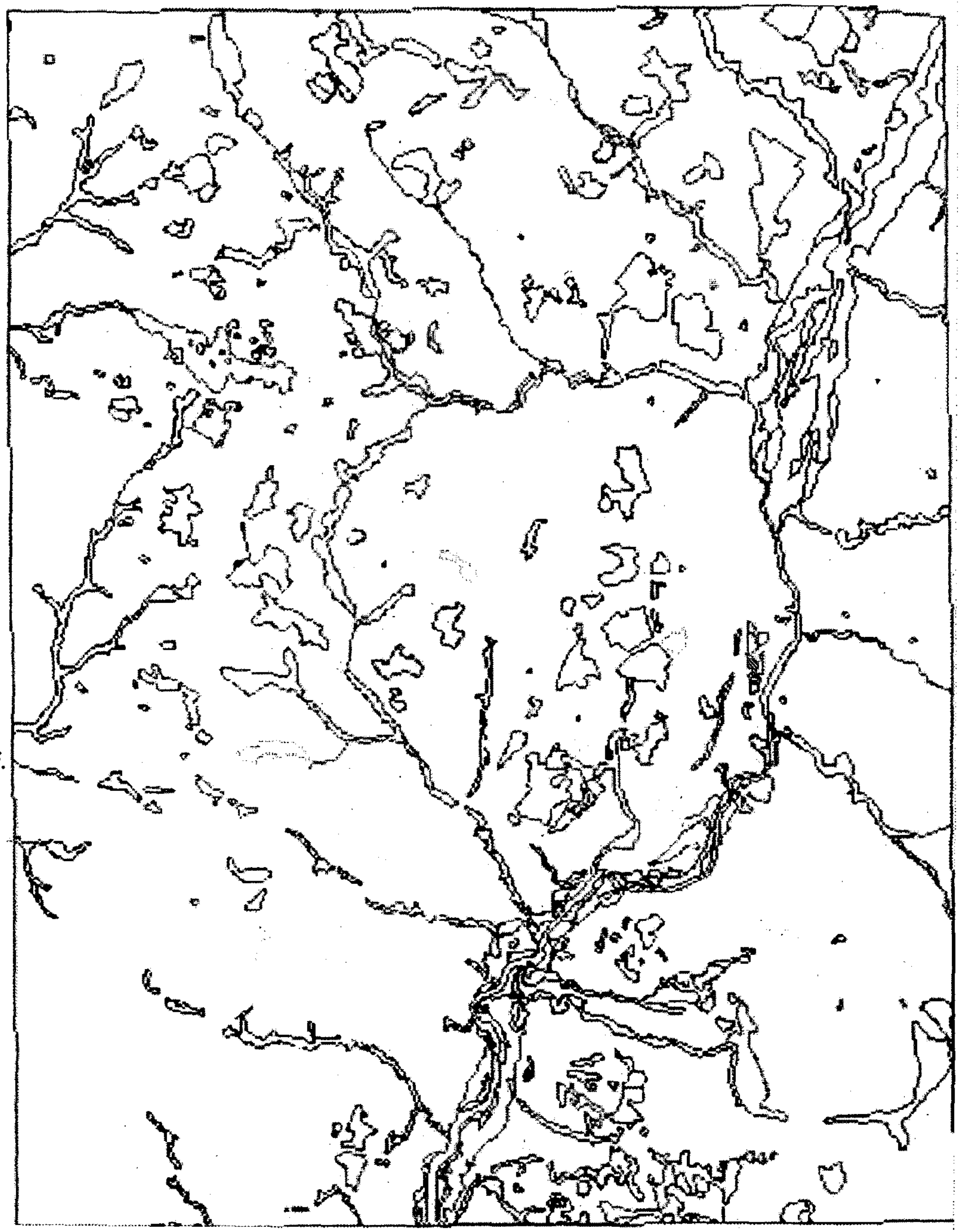
Computerized Monitoring & Management of Nontidal Wetlands

COASTAL ZONE INFORMATION CENTER

Maryland Department of Natural Resources

Print of digital vector file for one complete quadrangle

vector coordinates are in Lambert Conformal proj.



March 1988

Wetland Polygon Outlines Federalsburg Quadrangle	NWI digitized vectors	Interpreted: 01/15/88

Maryland Department of Natural Resources Nontidal Wetlands Division / Salisbury State College

A Computer-Based Assessment and Monitoring System for Non-tidal Wetlands

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Prepared for:

Coastal Resources Division
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March, 1988

Final Report

Preparation of this document was funded in part by NOAA, Office of Ocean and Coastal Management, and by the Maryland Department of Natural Resources.

I. INTRODUCTION

Background

The Non-tidal Wetlands Division of the Water Resources Administration, Maryland Department of Natural Resources, is in the process of developing management strategies for the State's non-tidal wetlands. The project described in this report was completed to demonstrate the capabilities of a computer-based system in fulfilling some of the monitoring and assessment functions required as part of the non-tidal wetlands program.

The decision to develop a computerized system is based on several considerations demanding a computerized approach; principally the expectation that increasing amounts of diverse data will need to be incorporated into management decisions and the necessity to investigate both written documents and graphic mapping data. Further, ecological and legal aspects associated with non-tidal wetland management govern the structure of the numeric and graphic data bases. Although it is not possible here to explore these underlying factors in depth, a brief highlighting of some of the more important considerations governing non-tidal wetland management might help to place this project into its appropriate context.

First among the considerations taken into account while developing the computerized monitoring and management system was the nature of the resource itself.

> "Non-tidal wetlands are valuable areas for plant, fish, and wildlife habitat, are vital to maintenance of the qualify and productivity of adjacent or downstream waters, and provide flood control benefits." (Guidelines for Protecting Non-tidal Wetlands in the Critical Area, 1987:1)

Although public attention has been focused on the dramatic decimation of wetlands in general, it is generally conceded that nontidal wetlands are at least in equal danger of declining unless guidelines for management are developed and followed. Of this total resource, many of the State's non-tidal wetlands are widely scattered and often small in areal extent. An automated system for tracking the health and disposition of these wetlands would prove to be particular useful in developing appropriate strategies for their management.

A second consideration was based on the need to comply with new regulations. Thus,

> "The Chesapeake Bay Critical Area criteria require that non-tidal wetlands be identified and afforded protection by local jurisdictions. Two types of protection measures are specified. First, a minimum 25-foot setback or buffer around the identified wetlands is to be established within which new development activities, or other activities that may disturb the wetland, are prohibited. Second, local jurisdictions are to protect the hydrologic regime (e.g., the flow of water into and from the wetland) by minimizing land disturbances in the wetland

drainage area. Only under certain circumstances, are alterations to non-tidal wetlands to be permitted by local jurisdictions, but mitigation of the alteration must be undertaken." (Guidelines for Protecting Non-tidal Wetlands in the Critical Area, 1987:1)

This mandate would require that an active record be maintained of all non-tidal wetlands and tracking potential disturbances. A detailed delineation of both non-tidal and tidal wetlands was conducted by the U.S. Department of the Interior, Fish and Wildlife Service as part of its mapping of national wetlands and published as the National Wetlands Inventory (1983). These 1:24000 scale maps were "prepared primarily by stereoscopic analysis of high altitude aerial photographs. Wetlands were identified on the photographs based on vegetation, visible hydrology, and geography in accordance with Classification of Wetlands and Deep-Water Habitats of the United States ... (Cowardin, et al. 1977)" (from annotation on NWI maps). In 1987 DNR contracted with Fish and Wildlife to digitize these maps for the State to permit their eventual use in a computer-based geographic information system. This digitized data set forms the basic inventory to which all additional computerized efforts were linked.

Goals

From November 20, 1987 to November 30, 1987, Salisbury State College, under contract to the Coastal Zone Management Program of DNR, developed a computer-based software and hardware system for use in the management of non-tidal wetlands. This project was funded, in part, by the Office of Coastal Zone Management of the National Oceanic and Atmospheric Administration, United States Department of Commerce.

The purpose of the project was to develop a means by which detailed information on the vegetation of coastal non-tidal wetlands, and the location, extent, and values of different types of vegetation could be interactively manipulated by computer. The management system to emerge with the help of the computerized capability was intended to permit the utilization of a large variety of data types, including aerial photography, satellite imagery (in digital form), soils information, NWI mapping data, and USGS digital line graph data.

The turnkey system provided as the principal product of this project is described below, followed by a review of the tasks undertaken to test the system. With the installation of the computerized mapping system the Non-tidal Wetlands Division will gain a significant capability for managing its growing data base and maintain the ability to constantly update that data base through the inclusion of both visual and tabular data.

II. System Components - Hardware

Overall Concept and System Design

The system designed for use by the non-tidal wetlands program is microcomputer based using standard off-the-shelf components. Compatibility with the IBM-PC standard was a primary requirement. The additional graphics capabilities needed to drive a large-screen monitor act independently of the function of the microcomputer to the extent that other activities may occur on the microcomputer, including data base management, word-processing, and page composition.

Computing Platform

The software to be described below has been tested and found to run successfully on the following microcomputers:

1. IBM PC/XT class computers
   IBM PC
   IBM PC/XT
   IBM Portable
   Leading Edge

2. IBM AT class computers
   IBM AT
   Fivestar 286
   Standard AT
   Compaq 286

3. INTEL 80387 class computers
   Fivestar 386
   PC Limited 386

Based on the compatibility tests completed as part of this project it is felt that most IBM compatible microcomputers running INTEL's 8088, 8086, 80286, or 80386 cpu's will adequately host the software.

All microcomputers used in this project require the addition of an arithmetic coprocessor (INTEL's 8087, 80287, 80387); a minimum of 640 kilobytes of ram (random access memory), console display device, one or more floppy disk drives, a mouse, and either the PC-DOS or MS-DOS Operating Systems (version 2.0 or higher). Practical considerations also dictate the availability of one or more mass storage devices (fixed disk, removable cartridge, optical disk). Because of the very heavy storage requirements for image data, large-capacity off-line mass storage is desirable. The system supports large-capacity hard disks (70 megabytes and higher), nine-inch open reel tape drives, and optical disk (200 megabytes and higher).

Although 80386 machines were used in software development, and one such machine is being used by the non-tidal wetlands program to run the software, it should be noted that such machines are more susceptible to bus timing conflicts. If the bus speed exceeds 8 megahertz some hardware may not run properly, and if the CPU speed exceeds 12 megahertz, careful attention must be given to determining that all components, including base memory, are capable of supporting the higher speeds.

Graphics Platform

Graphics functions are provided through peripheral equipment capable of producing analog rgb output. The following hardware combinations have been tested and found satisfactory:

1. High Resolution Devices (1024 x 1024

or larger)

Vectrix Pepe & Monitronix monitor
Vectrix Presto & Monitronix monitor
Number Nine Pro-1280 & Sony 1030 monitor

2. Medium Resolution Devices
   Vectrix 384PC & Electrohome monitor
   AT&T Targa-16 & Electrohome monitor (or Sony Multiscan)

The software does not require data to be organized to match the resolution of the display device. The graphics displays act as "windows" on any data set, permitting the same data set to be as easily manipulated on a medium resolution system as on a high resolution system.

Data Input Devices

Since data input is a major requirement of any computerized system, considerable attention will be paid to this task in the discussion of the software below. The following devices are supported for data input:

1. Standard DOS-supported devices
   floppy disk drive
   removable hard disk (e.g. Bernoulli Box)
   cartridge tape

2. Non-standard devices
   optical disk drive (may emulate a DOS device)
   9 inch open reel drive
   CD ROM
   mini/mainframe communications link with file transfer

Data Storage Devices

Data storage utilizes the same hardware types as Data Input Devices. See above.

Output Devices

Once data has been input into the system, stored, and manipulated in some fashion, there is usually a requirement to produce some physical representation thereof. Although one might consider data storage to be a form out data output, we will consider only hardcopy devices here.

The following devices have been tested and found satisfactory for the production of tabular and graphic output:

1. Tabular/Text Only
   all dot-matrix printers
   laser printers (preferred)
   ink jet printers
   thermal transfer printers
2. Graphics/Text Output
   thermal transfer (e.g. Calcomp Plot master)
   color ink jet (e.g. Tektronix 4060)
   solid color ink (e.g. Howtek Pixel master)
   monochrome laser (e.g. HP Laserjet Series II)

There are many considerations regarding the number of colors that can be produced, the resolution capabilities of individual printers, and the ability to emulate pen plotters, that must be taken into account. As a rule of thumb, resolution should be at least 200 dots/inch in either monochrome or color, color dithering must be possible to produce hundreds of colors, and hardware limitations governing output size must be defeatable if a printer is to be considered satisfactory. In all cases special drivers were written to extend and enhance the capabilities of printers tested for this project.

III. System Components - Software

Overall Concept and System Design

A wetlands assessment and monitoring system useful to state and local governments was enhanced to encourage monitoring individual and cumulative impacts to estuarine and freshwater wetlands from activities occurring within the wetlands themselves, and from adjacent land uses. The current system uses data from the National Wetlands Inventory, and from classified LANDSAT satellite imagery (Thematic Mapper digital data). Capabilities include interactive display and mapping of wetlands types and their spatial distribution. Through software developed in previous projects and significantly enhanced as part of the current project, NWI wetlands data can be joined to existing files containing information on wetlands permits, watershed land use maps, and other tabular data. In addition, digitized soils data and aerial photography can be included as data layers into the management system. Geometrically registered base maps can be used to overlay vegetation data, land use, land cover and soils. Video digitized data, although not registered, can be manipulated through vector overlay to enhance the interpretative capabilities of the full system.

The management and monitoring system developed as part of this project derives from a commitment to manipulate maps and images. Hence, the core system is given the acronym MIPS for Map and Image Processing System. The graphics support aims to present maps and images in full color. Thus natural true-color screen images may be stored in those instances where the original data was in the form of a photograph. The preservation of subtle shades of hundreds of colors from palettes of millions of colors is a characteristic of high-end analog rgb display systems and an important requirement where photogrammetric considerations are involved.

Among the various features of the extended MIPS are an intuitive interface made possible by the almost exclusive use of C-language program modules which directly address the appropriate microcomputer dependent hardware. Software functions are menu-driven (see Supplement: User's Guide), but support of a graphics pointing device (most often the mouse) permits point-and-shoot routines to be supported as well. Additionally the mouse is used for manipulating geometric shapes (e.g. various elastic box routines used to define active areas within the full screen). When used in conjunction with pop-up functions the mouse permits control of such functions as color balancing, interactive three-dimensional modeling (wire-frame and solid renderings), drawing (including on-screen digitizing), and windowing.

Data Import Procedures

Getting data into a computerized system is potentially among the costliest parts of building and maintaining the system. Most GIS's (Geographic Information Systems) depend on layers of digitized data, where each layer is carefully matched to a known base map. Consistency of the geographic projection, accuracy of the digitized layers, and reliability of the attribute listings associated with digitized layers require careful planning and data preparation.

Regardless of the sophistication of a computerized Image Processing or Geographic Information System, there is no substitute for careful data preparation.

Given the fact that a great deal of data has already been collected, often either at considerable cost, or under circumstances that are never likely to be replicated, it was our aim to create the most flexible procedures possible for data import. Thus we recognize that it would be important to provide means for introducing both new and historical data. Further it was anticipated that data collected for other purposes might be usefully integrated into the system. A variety of procedures were developed to exploit known data structures associated with extant software. For example, using MIPS menu selection techniques, it is possible to easily import data that were originally prepared in a variety of different formats; e.g.:

1. SSURGO (Soil Conservation Service)
2. MOSS (U.S. Fish & Wildlife)
3. EDIPS/TIPS (Landsat MSS & TM)
4. DFX (Autocad)
5. DLG (USGS)
6. DEM (USGS)
7. SPOT (Spot Image)
8. NASS (National Agricultural Statistical Survey)

Generic import procedures to permit inclusion of byte, ascii, and binary data are also included, as is support for some of the newer file formats, including tiff rio, and targa.

The system user is insulated, for the most part, from the details of data import. The data import menu allows selection by name of a foreign data set (see Supplement: User's Guide). Once selected, the software opens an appropriate new or existing data file, skeletonizes the file if necessary, and writes the converted data to the file. For raster data, histograms are automatically produced the first time images are displayed. For vector data, automatic fit-to-screen and coordinate orientation routines are accessed by the software to help the user not be distracted during data analysis.

The preceding discussion and examples assume that existing data is being imported and that this data resides on a device supported by MIPS. Since all common forms of media can be directly accessed through software, there is considerable power to this system. It doesn't matter whether the data is on diskette, optical disk, magnetic tape or CD Rom. If the devices are available as part of the microcomputer system, they serve as an active shared resource.Thus both DLG and Landsat satellite data, supplied by USGS on 9 inch open reel tape, requires no special procedures to import, a stumbling block for many other microcomputer based systems. If an open reel tape drive is not always available or convenient, the software provides a method for reading nine inch tapes onto optical disks and then using the optical disk as an alternate input medium.

New data can be created by using either live video or a digital scanner for the creation of rasters. A digitizing table is used for creating vector files. Since there is increasing support for the digitizing capabilities of AutoCad, MIPS currently imports and exports DFX files with AutoCad. This assures compatibility not only with DFX files in general, but also with COGO software that utilizes the DFX file structure.

Among the most powerful of data input capabilities is the ability to interactively scan, in full color and at up to 300 dpi resolution, maps, photographs, transparencies, and virtually any reflective or transparent media. Although current technology limits the total size of reflective material to 11" by 17", and the total size of transparent material to 8.5" by 11" when scanned on equipment costing under $10,000, there is rapid development occurring in this area. The software support in MIPS of the Howtek Scanmaster demonstrates some of the best qualities of the software when used in a management context.

All functions of the scanner are

clearly shown on a graphic representation, previewing of the entire scanning surface or any subsection is possible, and a scanned image can be brought directly to the graphics monitor and/or stored on disk for additional analysis.

Data Manipulation Procedures

Since there are a large number of ways in which data can be manipulated, Appendix A: System User's Guide, should be consulted for details. To illustrate the graphics capabilities of the system, one pop-up utility will be considered here: MEASURE.

There is a frequent need to determine the location, extent, size, and other physical characteristics of wetlands and associated natural and cultural features. In a typical case, the investigator may need to quickly determine the proximity of a wetland to a proposed construction site and to respond to a permit request that might affect the status of the wetland. Using MIPS it is possible to either bring to the screen a stored photographic image, map, or other image appropriate to examining the potential impact on a given wetland posed by a construction permit request. If no such photograph or map has been stored, or if a new photograph or map is available a rapid scan can create the needed screen image.

Once on the screen, the pop-up utility MEASURE allows the analyst to quickly perform several useful operations. If the scale of the image is known (as in the case of satellite data) the image may be directly calibrated. If the scale is not known (as in the case of most photography), on-screen measurement of known features (e.g. distance between two road intersections) may be used for calibration purposes. Calibration can be in either metric or english systems. Linear measurements may be in one system and areal measurements can be reported in either the same or the alternate system of measurement.

Using the mouse, MEASURE allows the manipulation, on-screen, of calipers, a protractor, an elastic box, an elastic circle, and a user-definable polygon. Thus in the hypothetical example, the calipers can be used to measure the linear distance between the proposed construction site and the edge of the wetland. The protractor can be used to project an angle, where a change in orientation of a linear feature may serve to mitigate a negative impact on the wetland. The elastic box and circle may be used to define an area of known size and then to interactively move the box about on the screen to explore alternate placements for a proposed construction that has a known areal extent. Finally the user-definable polygon can be used to measure the amount of wetland loss, if any, that would occur as a result of various mitigation strategies.

Quick, easy, almost effortless use of powerful computer techniques can help to augment photogrammetric and engineering skills that most managers and their staff bring to the job of monitoring such natural resources as non-tidal wetlands.

A second data manipulation process requires the use of text data. For example, the National Wetlands Inventory digital data allow each wetland to be located spatially (initially by Lambert Conformal, but through conversion by Latitude/Longitude, State-Plane, UTM, and other coordinate systems). The data also allow each wetland point, linear or polygon to be given a type attribute and measure of length or area. These statistical and descriptive attributes of wetlands are best handled by a relational data base. For the computer-based non-tidal wetlands management system dBase III+ was chosen as the appropriate relational data base. The decision to use dBase III+ was made partly on the capabilities of the software and partly on the basis of its wide distribution in many local, state, and federal agencies.

Using dBase III+ it is possible to query the data base by quad and county, determine the types of wetlands that exist within the entity considered, sort the data by wetland type, and report statistics about the wetlands. It is further possible to link other types of data to the NWI data, including permits and regulations files, field data from water quality testing stations, geological and environmental measurements, and many other kinds of data that become available. The flexibility of a relational data base is that it permits the regular addition of not only new types of data but specialized data bases that can then be linked to existing data bases. Appendix A: System User's Guide, provides examples and directions for utilizing dBase III+ to access and manipulate the NWI data sets.

Finally, a goal of this project was to explore the capability of the system to merge raster and vector data in the form of overlaying the NWI vector data over base maps, such as quads, aerial photography and satellite data. This overlay capability differs somewhat from the current GIS technique of overlaying multiple vector files. The simultaneous investigation of raster and vector data by on-screen overlay and manipulation is possibly one of the most important new computer capabilities that will substantially contribute to the effectiveness of management and monitoring tasks for natural resource managers, geographers, and others currently involved in GIS development.

Fulfilling this task posed the greatest challenge to this project and also consumed considerable more time and resources than had originally been anticipated.

A technical discussion of the methods used to manipulate a vector graphics plane alongside a raster graphics plane can be found in Appendix C: Technical Details-Software. Briefly, an image is displayed to the screen as a raster. Then a vector file is accessed and the vectors plotted on top of the screen image. If all data conformed rigidly to a specified base map, the process of at least presenting a merge of vector and raster data would be complete. However, the inclusion of photography, the probability that at least some data sets are at different scales, different projections, and different angular rotations requires that the vectors and rasters be made to "fit" each other.

Enhancements to MIPS now allow floating vectors over images and then rubbersheeting the vectors to the image. This is done interactively with the mouse by matching identifiable points on the vector overlay to identical points on the raster. The computer then uses a least-squares fit algorithm to recompute the vectors and replot them over the image. The process is iterative. When a satisfactory fit has been achieved, the results are displayed and the calculations stored.

Individual elements in the overlay file may then be selected for display, permitting the investigator to view the distribution of a single class of wetland types, for example. In a further refinement of the software it will be possible to directly access the dBase III+ information by pointing at vectors or vector classes on-screen. It will also be possible to overlay multiple vector files over multiple raster images, thereby setting up the necessary basis for a modeling system that incorporates the best of vector-based GIS systems currently available with the best of raster-based systems. By providing this active merge of the two most important graphic-oriented data types currently in use by planners, managers, and academicians, it will become possible to more fully exploit the wealth of field data that has accumulated and to suggest more productive ways in which additional data may be acquired to address specific management and monitoring needs.

As a final note in concluding this brief overview of data manipulation procedures, it should be noted that the computerized system described here overcomes many of the restrictions that are still currently hampering the efforts of other systems.

First, there is no requirement that all data conform to one common scale and projection. Data may be imported in many ways and then handled interactively. This process emulates the manner in which data has been traditionally handled by photogrammetrists, but replaces some of the tedium of either mentally adjusting for variations in scale and projection or using mechanical devices, such as the zoom transfer scope.

Second, consistent vector overlays can be projected over user-selectable base maps and images. This extends to the use of inherently distorted images, such as aerial photographs, giving the analyst an extremely powerful means by which he can bring highly detailed interpretive vector-based data (e.g. DLG) information to his evaluation of imagery.

Thirdly, multiple vector overlays and interactive attribute manipulation constitute the core of a new generation GIS approach. The result is a system committed to intuitive data exploration and would suggest interactive modeling as a system function to parallel the more traditional raster classification schemes used in image-only data analysis. In all likelihood, proper development of such software would also require a stronger computing platform. Currently the 80386 machines offer considerable promise, but parallel processors, specialized hardware, and UNIX-based operating systems might ultimately prove a desirable alternative to the current PC/DOS environment. To be successful, a session should perform calculations rapidly enough so that the analyst can constantly interact with the data rather than waiting for protracted computations to complete. The microcomputer is a worthy alternative to the mini or mainframe system only if it is fast and interactive.

Data Export Procedures

The same devices and procedures used to import data may also be used to export data. Since data export may be for the purpose of either transferring existing data to another system or for transferring or storing manipulated data, there are two somewhat different procedures to follow.

Data on the system may be exported in either a generic form or in a systems-specific form to a similar or a different image processing or GIS system. This is done by selecting appropriate export forms from the menu and then writing the data out to disk or tape. MIPS allows extraction of rasters from within rasters if a subset of a larger data set is desired. Vector interchange is often best done through an industry-standard or well understood file format such as DFX, TIFF, or TARGA file formats. Although it is relatively straightforward from a software implementation point of view to transfer generic or specific versions of byte raster data or vector co-ordinate data, the increasing commitment to arc-node data with associated attribute files does pose new challenges. This task will require a significant effort if a smooth integration with the existing system is to be achieved.

Transfer and storage of data following manipulation may require no more than a disk-save of a screen-image that has been operated upon. Although many image processing systems allow effortless saving of screen raster images, few provide a sufficiently generic form of such a screen save to permit display of a saved image on different hardware. MIPS is addressing that problem currently by supporting, through software, screen-restoration techniques that identify the original save format and then convert, if necessary, the save files to allow them to be displayed on incompatible hardware.

Data that might have been altered by filtering or classification can be saved as a new element within the original file, thereby becoming appended to the original data set. Storage is therefore automatic. Export would be similar to import except that some consideration must be given to the way in which computed histograms, color lookup tables, and other computed information is passed to external systems. Currently data export is being tested first for software compatibility within the same computing platform. Export to other software packages running on micro or mini or mainframe systems is also scheduled for testing.

Often, it is desirable to save the results of an analysis session so that a hardcopy can be made at a future time. Since a separate section on hardcopy techniques follows, discussion of this task will be deferred and the reader is invited to investigate the relevant section.

A final note of caution should be inserted at this time. Vector and arc-node data require relatively little storage space. For example, an entire quad of NWI data may take up less than two megabytes of space on a disk. Text data also requires comparatively little space. Large data bases may exceed ten or twenty megabytes, in some cases perhaps more. But typically even fairly complex dBase files are under five megabytes in size. Image data, on the other hand, particularly of high resolution, can occupy such vast amounts of space that until recently very little serious consideration had been given to microcomputers because of their limited storage capabilities.

A single nine inch color photo, scanned at 300 dpi, for example, can occupy over 21 megabytes of data storage. In compressed form it will still occupy over 7 megabytes of storage. Aerial coverage for the state of Maryland to determine wetland types and distribution can easily account for several thousand photos in one acquisition. It is clear that storage capacities far exceeding those of the floppy and fixed disk are mandatory.

The solution has been the optical disk. A new technology, there are still no standards and only recently have some manufacturers been able to make their drives and media be DOS transparent. This means that the user notices no difference between using an optical disk with over a hundred megabytes of storage per side and a Bernoulli cartridge, for example, which is limited to a total of 20 megabytes per cartridge. Although the 250 megabyte optical disk is currently available in sufficient quantity to constitute a viable storage medium, the gigabyte drive and disk are the likely stars of the immediate future.

In this and other projects for the Maryland Department of Natural Resources, Salisbury State College has demonstrated the utility of optical disk cartridge storage as a means of ensuring that vast amounts of data can be accessible to the microcomputer user. The non-tidal wetlands project has benefitted from this work by being able to access these large databases directly without the need to support either tape drives, or requiring a link with a mini based system for data storage.

Analysis Procedures

Appendix A details the methods to be used for analyzing data using the Computerized Non-tidal Wetlands Management System. This section presents a concept-oriented overview of all analysis procedures currently implemented.

As indicated previously, MIPS at is core is an image processing software package which has been significantly enhanced to include vector handling capabilities. Since the core systems is devoted to image processing it is explicable that many of the analysis procedures begin with a means of displaying an image on-screen.

There are two basic ways of displaying an image. The first is to access the original data and using density slicing or other algorithms present a monochrome or color rendition of that data. Figures 3-7 (in Supplement: Figures, Charts, Tables) illustrate this process by showing single-channel grey-tone images of satellite data (SPOT and LANDSAT), an aerial photograph, a soils map, and a tax map. All are common forms of data types likely to be of interest to a wetlands manager. A second way of displaying an image is to load a previous screen save. This presumes that once data has been translated into a screen image, the result is then saved in compressed form. The advantage to working with screen saves is that they load very rapidly since no new calculations have to be performed. The disadvantage is that some of the information inherent in the data is lost due to compression. A hardcopy output from a screen save is identical to that of an original data extraction if the screen is acted upon. However, higher resolution output can be achieved by using the original data rather than a screen save.

Regardless of whether the on-screen image has been generated by reading the data or loading a screen save, the next step is to perform some investigatory or analytical task. The MEASURE pop-up utility has already been described and exemplifies productive interaction with stored data. If color lookup tables are supported by the hardware it is also possible to enhance an image so as to highlight certain natural features. In Figure 8 (Supplement: Figures, Charts & Tables), sediment loads are clearly visible as exaggerated color differences.

Vector data may also be manipulated on-screen. The NWI data sets have been produced in both paper form and digital form. Figures 9 and 10 (in Supplement: Figures, Charts and Tables) compare the paper and digital products. It is clear that if the data is presented in too small a space, important details are lost to the observer. Even when the scale is changed so that a one-to-one match is achieved with a 7.5 minute topographic quad, the paper NWI map continues to contain so much information that it challenges the user to use it effectively. The computer-drawn vector renditions, however, provide better detail by separating the base map layer from the interpretation layer and by allowing interactive zooming to focus on any detail, no matter how small.

Combining base map and vector data together allows the interpreter to evaluate the vector data against various base maps, chosen to suit the particular purpose of the analysis. The power of the computer is realized when base map and vector data at different scales are combined and matched to a common scale, and when inherently distorted base map data is combined with undistorted vector data.

The ability to easily manipulate rasters and vectors is an important capability. But of even greater importance is the ability to perform measurements on these data, to enhance them using CAD primitives, to generate hardcopy products rapidly, and to include tabular data as part of a photogrammetric analysis at a cost and speed that cannot be achieved in any way other than through the use of a computer and the type of software made available through the implementation of the non-tidal wetlands management system.

Analysis goes beyond visual inspection, however, and MIPS provides more powerful tools than have been described thus far. A particularly useful feature that has great future potential is the generation of three-dimensional displays. MIPS can manipulate three raster planes to provide the equivalent of a two-dimensional color image and a single elevation plane to fit the image data into a three-dimensional matrix. Three dimensional modeling can take advantage of digital elevation data and thermal emission data as well as other kinds of data that would aid in the analyst in understanding his imagery better. Wetland analysis might use edaphic variation as measured by in-field moisture sensors or topographic elevation as provided by DEM data sets to better reflect the condition of wetland placement.

Three dimensional modeling proceeds in two steps. The first is the creation of a wire-frame that reacts instantly to changes introduced by the analyst. Once again the mouse is used to move on-screen sliders, eliminating the need to introduce numbers for elevation, rotation, scaling, and other required inputs. The numerical values are, however, always reported on the menuing monitor in response to mouse movements.

The second step is the creation of the solid model with, or without, hidden line removal. The data may be sampled to permit a more rapid display of the solid model. A complex, large, three-dimensional solid may take up to fifteen minutes to draw. Although this would seem to be excessively long, mini and mainframe computers require an even longer time to perform this task than an 80386 PC with an arithmetic coprocessor. Since the data can always be sampled and the wire frame is available for rapid manipulation, the longer time required to produce a finished product is still consistent with the philosophy of demanding a rapid response from the microcomputer.

For individuals familiar with traditional image processing techniques, the software offers a suite of tools that may be used to operate on raster data. Included are the ability to compute the correlation between rasters, to compute a convolution on a single raster using filters, a semiautomated interpretation of rasters using preidentified features, and several predefined index calculators. The last of these includes the ability to calculate a normal difference vegetation index, a transformed vegetation index, and a leaf area index. Arithmetic and algebraic manipulations can also be performed on rasters.

Vector data can be analyzed by category where vectors are classed as they are in the case of the NWI digital data set. Thus subsets of larger data sets can be extracted and further overlays made to allow determination of the value of combining several criteria in analyzing the relation of different attributes to each other.

In the future the expanded ability to deal with multiple vector files, to edit these files through graphics techniques, and perform computations on combination vector planes will provide the essential GIS tools to permit dynamic modeling.

Output Capabilities

Practical applications of image processing and GIS capabilities require that the results of an analysis can be graphically shared or included in a report. Plotters and laser printers have provided reliable and effective means by which presentation graphics can be created. More complex is the process of creating high quality hardcopy output of analog rgb screen images which are of photographic quality. Two processes currently are used to produce good quality prints of analog color images: color ink jet and color thermal transfer.

Considerable effort has been expended to provide the non-tidal wetlands management system to produce good-quality hardcopy output. Software control of color separation output characteristics is fairly sophisticated, giving the user control over almost all variables that would affect the quality of the hardcopy product. Additionally, the user is given the opportunity to accurately scale his hardcopy output so as to provide standard map product capabilities. Where the maximum size of the paper that a hardcopy device can handle is less than the required map or image, the software presents a multi-page graphic on-screen. Using techniques associated with page composition, the software automatically generates multiple page output which can then be panelled, if desired, to produce a map of appropriate size and scale.

More details concerning the specific procedures involved in producing hardcopy output is provided in Appendix A. More than a dozen printers are currently supported and there is a strong interest in supporting new printing technology as it becomes available.

Compatibility with GIS and Other Management Structures

During the course of this project, a significant revision of the file structure used by MIPS was undertaken to allow easier manipulation of raster data and also the inclusion of vector data in a common file format.

Currently the file structure is a superset of the enhanced DLG structure published by USGS. Thus a single file, identified by the system as a raster/vector file (.rvf) may contain groupings and subgroupings of data types that are inherently different in their individual structures. By maintaining a single file for both raster and vector data it is possible to investigate the relationship among different data layers more effectively with the additional benefit that the user is not required to maintain a list of compatible files.

To aid the analyst in deciding on which file groupings to investigate, the system now supports an extended labeling feature that permits descriptive labels to be attached to individual file elements as well as the file itself. This may also serve to identify the file element as an import or export data set. The software maintains its own labels to indicate whether the file element is byte raster, compressed raster, binary, ascii, vector, or arc-node.

Import from other image processing and GIS systems requires only knowledge of the file structure used by that system or of the structure of the file exchange format. MIPS will directly import known structures and provides a generic import utility for previously undefined structures that do not appear on the menu. Export to these external software packages is the inverse of import and requires no special knowledge other than the desired export label or format.

Export routines for attribute files linked to arc-node files have not yet been developed. This is a high priority item since true compatibility with other GIS systems necessitates carrying along the attribute files with the vector or arc-node files.

IV. Data Types

Thus far a number of data types have been identified in conjunction with the description of features of the software. Below each of these data types is considered individually and a brief discussion is included to indicate the utility of each type in addressing the needs of wetlands monitoring and management.

Aerial Photography

Large frame (9" by 9") aerial photography is among the most useful of all imagery in the delineation of wetlands and wetland boundaries.

The photography may use a variety of films and filters. Natural color film with a yellow filter has been shown to be very desirable both as a resource for making wetland spatial extent and species type determinations, as well as for day-to-day reference when a permit request requires viewing the area.

Very popular also is color infrared (CIR) photography. The value of CIR photography lies in its ability to clearly delineate shore from water, to be sensitive to subtle variations in moisture content, and to permit biomass extraction through computerized means.

Wetland photos flown for the State of Maryland are usually either at a scale of 1:24000 or 1:12000. Both paper and transparent products are customarily generated. Transparencies require special viewing equipment, but provide a richer variation in tonal gradations than paper prints and are particularly desirable as input into a computerized data base through scanning.

Other photographic products are available. The Soil Conservation Districts often fly low-level aircraft and acquire oblique 35 mm color photography. The USGS and NOAA sponsor acquisition of high level aerial photography (e.g. NHAP). Individuals may also acquire photography that would be useful to the non-tidal wetlands program. Regardless of the nature or origin of photography, it can be brought into the system through scanning and storage on optical disk.

Landsat Satellite Digital Data

The U.S. has provided satellite coverage since 1972 of most parts of the world. The instruments have included return beam vidicon's, multi-spectral scanners, and thematic mappers. The highest resolution available is the 28 meter cell size achieved by the thematic mapper. Further, with seven spectral bands, the thematic mapper is able to provide valuable data to the natural resource manager because the bands go well into the visible infrared and thermal portions of the electromagnetic spectrum.

Since Landsat data is digital, import into the system only requires knowledge of the structure of the specific data one has acquired. There are many data formats and most are supported by MIPS to allow automatic extraction through menu selection.

SPOT Satellite Digital Data

In a move to commercially exploit the market for earth-resources satellite data, the French government has launched the SPOT satellite which is capable of imaging at 20 meters resolution multispectrally (three bands) and at 10 meter resolution panchromatically (single wide band).

The sensors aboard the satellite can be "pointed" so that acquisition of data for a particular ground area is not strictly limited by the path of the satellite. Both multispectral and panchromatic data have been acquired in digital form by Salisbury State College as part of other contracts. It is clear that the addition of this important data type is valuable from the standpoint of wetland monitoring. Satellite data, especially high resolution satellite data, can be used not only to identify wetlands but also to assess the surrounding land use and land cover.

Soils

The intimate association of soils with specific wetland types is significant. Hence:

> The presence of undrained hydric soil is one of the three major criteria used to define wetlands. Hydric soils are either: (1) saturated at or near the soil surface with water that is virtually lacking free oxygen for significant periods during the growing season or (2) flooded frequently for long periods during the growing season." (Atlas of National Wetlands Inventory Maps of Chesapeake Bay, vol. 4, p. 4)

Figure 11 (in Supplement: Figures, Charts and Tables) lists a preliminary list of hydric soils for Maryland. Remapping of Maryland's soils would be required in many areas to account for natural changes since the last county soil maps were prepared.

Soils data remains one of the most detailed data types available for natural resource assessment. Since most soils data has not been digitized, the value of the data cannot be fully realized. In an attempt to remedy the situation through software development, this project has sponsored the conversion of raster to vector data through automated techniques. Algorithms for converting 8-bit data to binary data, thresholding, raster and vector editing, and line thinning are well under way.

Prior to the actual conversion of soils map to vector files it is possible to scan the soil maps and use them as a base map for projecting NWI vector data. Since the soils delineations are made over aerial photography, the ability to float vectors over the base map and fit the vectors to the base map is a necessary prerequisite to using the soils data in this form.

Digitized NWI Maps

The U.S. Fish and Wildlife Service conducted an inventory of the wetlands of the United States using aerial photography commencing in 1979. All wetlands were classified according to the Service's official system: "Classification of Wetlands and Deepwater Habitats of the United States" (Cowardin et al. 1979). The National Wetlands Inventory (NWI) committed to establishing a wetland database for the country, in both map and computer forms. The initial emphasis was on map production and the original NWI maps are available at the standard U.S. Geological Survey topographic map scale of 1:24000.

The Chesapeake Bay inventory was completed in 1984 and wetland maps have been produced for the entire Bay area. In 1987 U.S. Fish and Wildlife completed digitizing the Maryland maps. These are available on 9 inch open reel tape in MOSS vector format. All digital data is being compressed, read onto optical disk, and imported into the non-tidal wetlands management system.

Appendix F: NWI Map Preparation describes the method of preparation for the original large-scale 1:24000 maps, the collateral data sources used, and photo interpretation problems encountered.

In addition to the digitization of the Maryland wetland maps, U.S. Fish & Wildlife also provided wetland acreage summaries by quad and boundary files for county boundaries by quad where quads were transected.

Tabular Data

As indicated above, one of the benefits achieved by digitizing the National Wetland Inventory Maps was the creation of wetland acreage statistics. This information has been provided in both paper form and on magnetic tape by Fish & Wildlife. Initially these data will serve as a primary reference set, allowing manipulation using dBase III+ of the statistics by quad and wetland category.

As the conversion from MOSS to MIPS is completed a duplicate set of statistics will be generated, defining both area coverage by acre (or any other system of measurement), as well as linear coverage (in the form of perimeter or line-length statistics).

By using the on-screen graphics utilities it will be possible to not only regenerate the U.S. Fish & Wildlife statistics, but to modify those data as a function of modifying the wetland vector (to become arc-node) data.

Finally, the linking of a database to the vector files will allow a large collateral data base to be established. This will become the basic engine that will ultimately drive the management utilities by accessing case studies, published literature, legislation and published regulations, and ancillary raster/vector data.

Text

Legal reviews demand access to an extensive collection of case histories, court decisions, and findings. In the promulgation of laws governing the protection of such natural resources as non-tidal wetlands, it becomes important to gain control over an extensive literature if enforcement and control are to be seriously contemplated.

There already exist a variety of approaches towards searching text for specific purposes. At this point it is anticipated that dBase may be used to index reports, findings, published legal decisions, and similar text data. At some point it might become desirable to explore a fuller support of text data manipulation.

Legal concerns are only one of several that might be taken into account when mitigation is attempted. Assuming that there is need to frequently mitigate the impact of natural and cultural forces on non-tidal wetland stability, it might also be desirable to build a database of scientific information on the study of wetlands. Microcomputers have demonstrated their ability to easily handle the task of searching and organizing such data. With the increasing reliability of optical character recognition (OCR) software and digital scanners, it may become desirable to build up an extensive collection of machine-searchable published scientific data.

V. Conversion of Data to Computerized Form

Until recently the task of achieving compatibility between software and data has fallen to those who prepare data. The result has sometimes been a repetitive collection of the same basic data to test out new software and to demonstrate the "superiority" of each new system over the old.

The danger inherent in customizing data so that it fulfills software needs is that it ceases to be universally usable. Database, spreadsheet and word processing software have led the way in showing that there is a better way. The first attempt was to establish a "standard" exchange format. There are many and few can claim anything beginning to approach universal interchange. The second attempt was to provide conversion utilities. Increasingly this appears to be the correct solution. Just as a typist is reluctant to re-enter the same set of numbers or the same document again and again to suit the needs of different software to be found within the bureaucracy, so, likewise, is the resource manager loath to commit resources to the collection of data in a somewhat different form than it had been collected previously.

MIPS uses the second approach outlined above. By converting bidirectionally to and from a composite file form it is possible to accommodate the complex file structures associated with both vector-oriented GIS systems and the multidimensional rasters common to image processing.

Another consideration in data conversion is the degree to which hardware can be expected to perform translation functions as opposed to manual entry systems. A good case-in-point is the conversion of raster to vector data. Thematic maps, optically merged interpreted imagery and hand drawn mylars are common forms of data of interest not only to wetland managers but resource managers in general. Raster to vector conversion through hand digitization is a proven method of creating vector files. However, the cost of producing these files can be quite considerable. Automated vectorization is particularly desirable where data of historical importance might be of value if vectorized. For example, shoreline erosion maps and older land use/land cover maps may be valuable in providing comparative data. If they can be introduced in a cost-effective manner into a computerized GIS through automated data conversion, such maps may readily form the basis for longitudinal modeling studies.

Complex maps containing numerous hand-drawn annotations, overlain over photography, such as the NWI maps, may prove too difficult to vectorize by automated means. Often the task of removing extraneous annotation through vector editing and supplying information about vectors is as time-consuming and labor-intensive as redigitizing by hand. Thus the choice of whether to attempt automated digitization rests with the individual and must be determined on a case-by-case basis.

Maps and photographs have traditionally been the mainstay of resource managers in their attempt to visualize the potential impact of both natural and cultural forces on the resources they are charged to monitor and manage. With the advent of scanning instruments, whether mounted on aircraft or satellites, the traditional photo product and interpreted resource map declined in importance.

There is little question that scanner data, whether collected by passive sensors (e.g. multispectral scanners) or by active sensors (e.g. SLAR and LIDAR), is of enormous value in resource monitoring. However there are two problems that cannot be easily overcome. First, much of the scanner data, especially that from satellites, provides insufficient resolution for specific monitoring of localized resources. The scanners are especially useful in collecting data synoptically, but less useful in such tasks as species typing and monitoring of heterogenous resources. Further, airborne sensors tend to produce vast quantities of data that require considerable effort to process. The cost and effort associated with cleaning and correcting Daedalus data, for example, may be more than a particular project can warrant.

Until recently, photographic and map products could not be easily converted into computer-readable form. Drum scanners were both expensive and slow. Optical scanners lacked sufficient resolution to produce good results. The emergence of new flatbed scanners capable of rapidly converting photographs, transparencies, and published maps into digital form has raised the interest in these forms of data. The major limitations are storage requirements and overall size restrictions for the media to be placed on the scanners.

The continuing interest in vector-based GIS's has created a new wealth of data. The NWI mapping project has already been briefly discussed. The commitment by the USGS to prepare digital line graphs and digital elevation models has contributed substantially to the extant database of vectorized data. Increasingly it is possible to manipulate this data without regard to original scale other than to recognize the inherent limitations of the data. The work currently being carried out in merging these vector data sets with rasters will produce powerful new tools for both management and monitoring of a large variety of natural resources.

Finally there is the potential to include text data into an automated system. Published data can, in many cases, be directly imported as a computer-readable text file through the use of optical character recognition software. The cost of performing this translation has dropped dramatically over the last several years and should continue to do so while the sophistication with which the translation is carried out will continue to increase as well.

Ultimately it should be possible to blend many different kinds of data into a seamless automated system. Querying relational data bases has already proved valuable and will increase in value as the link between microcomputer and minicomputer databases is made easier. Most promising here is the common use of SQL (Structured Querying Language), which will allow microcomputers to directly access mainframe databases without the need to translate from one structure to another.

VI. Manipulation and Analysis of Individual Data Types

Rasters

Using the image processing core (MIPS), the non-tidal wetlands management system is capable of acting on individual rasters for the purpose of either data extraction or analysis.

The best example is the use of digital data, either satellite data or scanned photography. Without the aid of the computer, the analyst must depend on his experience and ability to interpret subtle spectral variations. The computer can be used to dramatically highlight those subtle differences and ease the work of the analyst. In the case of the system described here that highlighting is done through manipulation of the color lookup tables. The computer can also be used to quantify cell data. The measurement routines described earlier are a good example of an application of the computer's ability to quantify raster data.

Traditional image processing techniques such as filtering, density slicing, contrast stretching, and edge enhancement may also be applied to single rasters. These techniques are especially useful in making determinations about land use and land cover in areas where wetlands abound.

Vectors

One of the appeals of vector data is that objects of any size can be accurately represented at virtually any scale based on a single digitization effort. Unlike rasters, which, when enlarged, tend to break up into blocky representations, vectors are redrawn whenever they are moved to a screen or output device.

The digitized NWI data is much more useful, in many ways, than the original map products. Even scanning the NWI maps would not significantly enhance their value, since their very complexity and extensive annotation make it difficult to separate out individual wetland types and categories.

Vector files can also be linked to attribute files so that each vector object, whether a point, linear, or polygon, can be linked to a large number of associated attributes. Thus items of information about vectors can be manipulated more easily than items of information about raster cells.

Tabular Data

Tabular data can be manipulated independently of any other kind of data. Relational data bases are the most popular method for manipulating tabular data. However, it is also possible to index tabular files and then use search algorithms to gain information contained within those files.

Further, tabular data may also be presented in a number of ways. Charting programs allow an analyst to view his data in a number of different ways, each possibly suggesting different strategies in a management context. Increasingly data exploration is enhanced by using the computer to chart in response to what-if scenarios that can be set up by the appropriate software.

In the case of non-tidal wetlands, tabular data that might be the basis for analysis would include such items as acreage statistics, measures of distance and proximity between wetlands and other known features, and change percentages for resource inventories. Rapid manipulation of tabular data and easy presentation of these data through graphing represent important tools in the management of natural resources, especially sensitive ones such as non-tidal wetlands.

Text

Text data can often be handled similarly to tabular data. However, it is often desirable to organize text by topic area and then provide the analyst with an opportunity to review the text on-screen in much the same way that he might use printed documentation.

Whereas tabular data must be readable at the element level, text data can be treated as an image and presented to the viewer in image form. Thus it is possible to scan text without concern for conversion into ascii form. The resulting image can then be treated in the same way as a photograph or map.

Although it might appear that it would be preferable to use optical character recognition techniques to automatically convert printed documents into true text files, there are some important considerations that would suggest the need for an alternative. When documents have been typeset it is far more difficult to recognize individual characters since proportional fonts and extensive kerning may impose fairly serious limitations on the success with which these documents can be scanned. In cases where text is heavily mixed with graphics it might again be desirable to simply store an image rather than an ascii document. And in some cases the quality of the original may be such that ocr software would simply not be able to cope adequately with the document.

How text is used in a management environment would depend on the specific arrangements decided upon by those involved in maintaining the system. Mention has been made of the possible use of legal landmark decisions, published regulations, and other documents that the manager might wish to consult in determining potential impacts on particular resources. The ability to include text files in a management and monitoring system is likely to be increasingly valuable as the size of the text database increases.

VI. Manipulation and Analysis of Multiple Data Types

Comparison of Multiple Rasters

There are many occasions when it is desirable to compare rasters to each other or to manipulate more than one raster simultaneously. One obvious case would be the creation of a false color infrared composite from separate data channels when using scanner data. Both Landsat and SPOT satellite data, for example, provide the opportunity to composite channels so that the result is a color composite.

Another case in which multiple rasters might be of interest is the comparison of similar data from different seasons or years. For example, a study of erosion processes might be meaningful only if two or more years of data can be examined simultaneously. Likewise the effect of episodic events, such as storms, can best be understood through a before and after comparison involving the manipulation of multiple rasters.

Again, non-tidal wetlands are subject to disturbance through a variety of activities and a multi-temporal comparison of different rasters may best illustrate the effect of these activities.

Overlaying of Rasters

Overlaying of rasters is an extension and special case of comparing multiple rasters. In this case we assume that the overlaying is done for the purpose of resampling one or more rasters belonging to different data sets to a common scale. For example Landsat MSS and Landsat RBV data were sometimes merged to provide the combined benefits of multispectral information of the MSS with the greater detail of the sharper resolution of the RBV. SPOT data may also be treated in similar fashion. 10 meter panchromatic data acquired at the same time as 20 meter multispectral data can be combined to achieve the joint benefits of spectral and spatial detail.

Insertion of one raster into another raster may also be considered a variation of this category. This technique may be useful in merging graphics or map data with satellite imagery or photography.

Generally raster overlaying is accomplished in two steps. First one of the two rasters is resampled to match the scale of the reference raster. Secondly, a slip-slide technique is used to move one raster over another so that an exact fit can be achieved.

Overlaying of Rasters and Vectors

The technique of floating vectors over rasters has already been discussed. There are other occasions, however, when the analyst may wish to manipulate a combined raster/vector image. The easiest way to accomplish this is to simply hardware zoom the combined set. The advantage is speed and reliability, but as the level of zoom increases, the vector lines begin to loose their precision and may, in fact, introduce errors into the representation of a particular feature.

The more desirable alternative would be to zoom the raster plane and redraw the vector plane simultaneously, maintaining the scale relationship. Since it is currently possible to use an elastic box to redraw the vectors and to use either hardware zoom or resampling to zoom the rasters, software implementation to permit the two processes to occur simultaneously will likely occur int he near future.

Overlaying of Multiple Vectors

Because of their relatively modest space requirements, multiple vector files, or files containing multiple levels of data, serve as the basic data form for most current GIS's. Superimposition of vectors, vector clipping, boolian operations on combined vectors, and generation of multiple vectors in one plane based on criteria derived from an examination of an associated database, are powerful procedures that increase the inherent value of registered vector data.

Although polygon format data storage might appear to be the most likely manner in which vector data can be handled by a computer, the arc-node format is ultimately more powerful since it allows assigning exclusive boundaries to adjacent polygons and requires less effort to support where changes might be made to the data set on a periodic basis.

Further, the support of multiple storage schemes for vector data creates the possibility to interface with other software packages. Cogo and Cad/Cam packages are increasing in popularity and add-in routines to make them suitable to either mapping or specific resource management needs will likely become more widespread in the future. The ability to handle different vector formats is as important as the ability to handle different raster formats.

Tagging objects defined as polygons is not only possible, but the basic technique used by all geographic information systems. The alternative is to define a raster cell of a known size. This alternative has shown to be cumbersome, often inaccurate, and difficult to manipulate. Vector tagging is done in the form of associating attributes with vector objects. These object most commonly are polygons, although they could also be linears or points. Multiple attributes can be assigned through the use of a database.

When multiple vectors are overlaid their associated attributes may also be examined. Conversely, specific combinations of attributes may be extracted and their associated vector objects displayed. These superimposed vector objects may then be subjected to set theory analysis in order to reduce them to common objects.

MIPS is currently being modified to permit linking a number of different databases, beginning with dBase III+, to the vector planes within combined raster/vector files. Because the raster/vector file structure provides an automated link between rasters and vectors, the potential for increasing the power of this system beyond current GIS's clearly exists.

Extraction of Text Data from Multiple Quads

In completing this overview of the strategy being laid out for the manipulation of multiple data types, it is necessary to reconsider the place of text and tabular data.

Text data can be supplied either in image or in character form and linked to graphically derived information through an external database. A more powerful approach, however, is to allow multiple text files to associate with multiple vectors and quads.

Thus, ideally, it would be possible to query a text database by example and relate the querying strategy to a graphic representation. dBase IV is designed to permit this kind of querying by example activity. The release of dBase IV should occur sometime in the first quarter of 1988.

The computerized non-tidal wetlands management system should be able to take full advantage of the enhanced dbase IV capabilities. The first step would be to test the querying by example feature. This should be followed by a structured linking to the graphics file structure.

Linkage of Graphic Wetland Representation to Tabular Data

Tabular data usually consists of a calculated extraction from a database. Acreage reports, for example, are often tabulated by political jurisdiction to give some indication as to the total resource component being considered.

Projections of increase or loss, threat or damage to a resource may also constitute a tabulation. Such tabulations may be derived in a number of ways, although it is anticipated that for the non-tidal wetland data most of the tabulations will be derived from the areal computations performed on specific wetland groups by quad and county.

Customarily, representations of tabular data are in the form of a table or graph. Additionally, the tabulation may be reflected by highlighting a representative map. This latter feature is of particular interest to resource managers since it provides a quick visual confirmation of a geographically known phenomenon.

The non-tidal wetlands management system contains a fairly extensive set of routines to provide graphic output capabilities, including the ability to enhance, highlight, and otherwise show a particular aspect of interest on a map or segment thereof. Tabular data, inasmuch as it reflects operations performed on the graphics planes, can be used to visually alter that graphics plane for better illustrative effect.

A number of drawing functions are available, as are lettering and other annotation features. Numerous fonts, and such drawing primitives as sized rectangles, circles, and polygons provide further flexibility in creating an attractive visual and output product that reflects tabular data.

VII. Conclusions

The work described in this report represents an attempt to assemble a combined hardware and software system that builds on past efforts and attempts to provide a platform for future development.

Past efforts have focused on the evaluation of various remote sensing techniques and data sources for general resource management and specifically for non-tidal wetland evaluation. It has become clear that the greater the integration of a varied database, the more powerful the tools are that can be developed to manage this database.

Thus, the creation of the computerized non-tidal wetlands monitoring and management system is dedicated to the concept that every conceivable form of data that might be of interest to the wetlands manager should find a place within one or more of the related databases that constitute the total system. Map products, digital products, photography, vectorized plots, text and tabular data can all be integrated under the system being implemented under this project.

What is provided here is both a concept and a capability. The concept is one of using a computer to organize diverse data, present it in a meaningful manner, whether through text or graphics or both, and allow the analyst or manager to use the computer as an interaction tool. To this end state-of-the-art hardware and software have been coupled in what we believe, is a unique and exciting system that is applicable not only to non-tidal wetlands management concerns but to a broad spectrum of resource management tasks. The hardware capability is matched by a software capability. Among the most important and innovative of these capabilities is the ability to "view" data in a form familiar to the photogrammetrist, to make measurements, enhancements, annotations, and data layer overlays. The easy, intuitive interface is another major feature of the software, requiring a fairly short learning curve for casual use. Powerful features such as three-dimensional modeling and raster filtering require some knowledge of the nature of the data and some skills in remote sensing, but it is expected that every-day use of the system will be easy, intuitive, and productive.

During the course of testing the hardware and software it became clear that the system would mature well beyond the scope of the non-tidal wetlands project. Some of the capabilities developed as incidental to the project have since been tested as part of other projects and are reported on elsewhere. For the present it is appropriate to return to a discussion of the resource that the project was to help serve: non-tidal wetlands.

There are both sound ecological and legal reasons for protecting non-tidal wetlands. In Maryland, all local jurisdictions are required to afford protection to non-tidal wetlands that meet any of the following criteria (as published in "Guidelines for Protecting Non-tidal Wetlands in the Critical Area", 1987:4):

1. All palustrine non-tidal wetlands classified as Aquatic Bed, Emergent, Scrub-shrub, or Forested ... of one acre or larger in size that are shown on the National Wetlands Inventory Maps or which may be found by onsite survey;

2. Such palustrine wetlands not shown on the Maps that are hydrologically connected to streams, tidal waters, or tidal wetlands, and
3. Such palustrine wetlands not shown on the Maps that have special importance to fish, wildlife, or plant habitat.

Guidance Paper No. 3 of the Chesapeake Bay Critical Area Commission, "Guidelines for Protecting Non-tidal Wetlands in the Critical Area", 1987, provides information on the identification of non-tidal wetlands and the means to be used to establish required setbacks. The paper also discusses the circumstances and conditions under which alterations to a wetland may be allowed, and guidance on appropriate mitigation measures and techniques. It is hoped that the computerized system as it becomes implemented will enhance the purpose of the Guidance Paper and expand the capabilities of the analyst in a fashion consistent with the goals of the guidance paper.

The computerized system provides, at best, a concept for handling large amounts of diverse but related information, and a capability to explore this database quickly and productively. What the system does not provide is the intelligence to interpret the information it contains. There is no substitute for the experience and skill of the human manager. Although some expert-system capabilities are inherently a part of the expanded system, such capabilities pale when compared to the sophistication of the experienced wetlands manager or field knowledge of the dedicated naturalist. The system described here is a tool, not a solution, and to that end it can be used with great success or abused to the detriment of the resource being managed. This is not intended to be a caveat, but rather a challenge. Tools can be sharpened and honed, applied to new tasks or picked up regularly to perform old and familiar tasks. The computerized system which has been described here and which has been installed as part of the non-tidal wetlands program, should be seen as a tool. In the future it is hoped that refinements, enhancements, changes, and other applications will be found to broaden the effectiveness of this tool and that his project represents a beginning to a solution for non-tidal wetlands monitoring and management, not a definitive and final solution.

VIII. Appendices [provided as Supplements]

A. System User's Guide

B. Technical Details - Hardware

C. Technical Details - Software

D. Reference Data Sets (on optical disks)

E. dBase III+ files (on Bernoulli cartridges)

F. National Wetlands Inventory Map Preparation