THE MISSISSIPPI HYDROLOGIC INFORMATION SYSTEM HARDWARE AND SOFTWARE IMPLEMENTATION

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INTRODUCTION

It was recognized by the technical staff of the Mississippi Department of Environmental Quality (DEQ), Office of Land and Water Resources (OLWR), that there was a need to implement a Geographic Information System (GIS) in order to better manage the hydrologic data of the state of Mississippi. There were many reasons that led to the decision to implement GIS technology at the OLWR, all of which were unified by the need to effectively access and manage geographic and hydrologic location related information. In the past, information critical to the mission of the OLWR was often inaccurate or incomplete, data sets were becoming increasingly difficult to manage because of the volume of paper involved, and maps were becoming increasingly difficult to interpret due to the quantity of attributes on each map. The need to resolve these problems into manageable assets was the fuel that drove the process of GIS implementation.

After determining the appropriate software and computer system hardware configuration, the Office of Land and Water Resources acquired the major components of the hardware and software necessary to answer many of the questions concerning the hydrologic cycle and the water use practices of the State. Human resource development is also a very important factor of GIS implementation and the addition of computer oriented staff members and the cross training of current personnel was essential to the development of the Mississippi Hydrologic Information System (MHIS). The digital data the OLWR is using for the basemap, along with the problems we anticipate in the conversion of hard copy media into digital data, are other factors that were given close attention because of mass storage requirements and other technical considerations. Implications for further growth are indicated by the projected size of the data coverages along with the equipment necessary to fully implement a digital cartographic mapping workstation with complete GIS capabilities.

Other factors influential to initiating the MHIS included a change in administrative perception at DEQ, as a function of technological advances. As the technological evolution of the GIS community continued, a change also took place in administrative awareness of these factors. Increasing manageability, improving quality, optimizing efficiency, and reducing costs were all factors that led to progressive changes. Finally, the most important factor in the equation was realized; there was newly developed technology available and economically attainable which could solve many of OLWR problems and that DEQ had a core group of scientists who understood how the newly evolved technologies interfaced.

OVERVIEW OF THE MISSISSIPPI HYDROLOGIC INFORMATION SYSTEM

Full implementation of the Mississippi Hydrologic Information System will be completed some time in the near future as soon as funding permits. In the time it will take for this process to occur, there will be, in all probability, new developments in GIS technology that will make some portions of the entire plan no longer technologically efficient. Emergent Geographic Information System technology is proliferating so swiftly that the original, carefully planned for MHIS will, in part, soon become out of date.

The process of GIS implementation at the OLWR was planned for in three phases that will, when complete, result in the full configuration of the MHIS along with the application capabilities desired.

Phase I - (Planning and Purchase)

This Phase has been successful to the point that the base software/hardware system configuration is operational and more software/equipment are being sought.

Phase II - (Hardware and Software Implementation)

The Mississippi Hydrologic Information System is now in advanced Phase II development and will continue to evolve as funding for further hardware/software upgrades and new equipment purchase become available.

Phase III - (Data Base Design)

The development of the data base is an ongoing process that began as soon as the MHIS hardware became operational. Partial completion is expected by July 1993.

The efforts made to achieve full implementation of the MHIS were made in response to needs to develop water management models as part of the State Water Management Plan (Mississippi Code of 1972, as amended, Water Laws, Section 51-3-21). Data gathered during these work efforts will become a permanent part of the State Water Data Base (Mississippi Code of 1972, as amended, Water Laws, Section 51-3-16). The MHIS, when fully configured, will enable the OLWR to develop water-management models and also provide complete GIS capability.

An important function of the MHIS is for the Office of Land and Water Resources to provide local water managers with more effective water-management tools to aid in decision making. With the development and implementation of the MHIS, this Office will be self-sufficient in providing this much needed information to local water managers and becoming independent from other agencies previously used for technical assistance.

Water management is vital for Mississippi in order to provide long-term reliable sources of water for future agricultural, municipal, and industrial development. In order for the OLWR to accomplish its goal of providing technical information to local water managers, a system was needed to store and disseminate the available data and to act as a repository for future data requirements. The Mississippi Hydrologic Information System will meet this need by providing the hardware/software capabilities that will enable the development of water-management tools for use throughout the State of Mississippi.

APPLICATION EXAMPLES

The following section has brief descriptions of application examples for the Mississippi Hydrologic Information System. These examples are not intended to be extensive but include typical computerized water-management applications possible to develop with the MHIS. These management tools will be of great benefit to analyze hydrologic problems in Mississippi and assist in formulating appropriate management practices.

As an integral part of our normal operations, the Office of Land and Water Resources employs complex computer software, such as MODFLOW (groundwater modeling software), to assist in accessing questions concerning the future of groundwater resources for the State. The numerical/statistical output from MODFLOW has been utilized in both 2D and 3D graphics presentation software as a methodology to visually display the data.

Extensive internal evaluation determined that PC systems were not powerful enough to adequately resolve the State's groundwater problems, even if a Local Area Network were to be developed. The OLWR also found that the graphic peripherals currently in use at DEQ were not entirely adequate for map construction and production purposes. Several alternatives were investigated to temper these inadequacies, including PC upgrades and the evaluation of numerous sophisticated graphics peripherals. As a result of these investigations and exhaustive literature reviews of both hardware and software, the OLWR decided to explore more powerful computational alternatives including minicomputers and ARC/INFO software.

Ground Water Modeling

The growth in the use of management models in the United States stems from a series of ever more stringent and comprehensive environmental statutes developed since the early 1970's (National Research Council 1990). Because the subsurface environment is not easily observed or accessible, computer models have become the tools employed to better understand ground-water systems. Models can be used to simulate and predict the behavior of ground-water systems. Using models, the amount of stress that a system can safely withstand can be empirically calculated. For example, the withdrawal effects concerning the volume of water pumped from the Mississippi coastal aquifer can be analyzed as well as the influence on underlying and overlying aquifers. In addition, the simulated hydraulic gradient can be examined and the effects investigated concerning the rate of change concerning the salt water/fresh water interface.

Numerical models used in ground-water studies are computer programs that can be applied to a variety of hydrogeological conditions. Through the use of numerical models, staff hydrogeologists can approximate "real world" conditions by calibration techniques and then utilize the model results for realistic forecasting.

Surface Water Modeling

Programs to model surface water flow can be used to compute and plot the water surface profiles of river channels of any cross-section configuration for either subcritical or supercritical flow conditions. The effects of in-place or proposed hydraulic structures such as bridges, culverts, weirs, and dams may be considered in the computation. Computer programs are now available which will determine river profiles for various frequency runoffs under both natural and modified conditions. These analyses can be used by water planners to develop management schemes for controlling runoff and storage, thereby maintaining a balanced hydrologic system.

Modelers of ground-water and surface-water hydrologic systems have found GIS ideal for preparing their data and displaying their results. New techniques for representing terrain features, such as streams and drainage basins, are producing surface-water models with spatial resolutions unimaginable a few years ago. Visual, interactive displays make finding and retrieving water-resource data easier than ever. The basemap for the MHIS will be the 1:100,000 DLGs that have been enhanced by MARIS, along with a raster soils data set and selected Landsat satellite coverages. These data sets and additional coverages are foreseen as new information for the MHIS and include well locations, surface water withdrawal points, geologic unit contacts, hydrologic characteristics, sand and clay thicknesses, volume of water withdrawn, and land use. This information combined with predictive modeling results will form a technical basis for water-resource management in Mississippi.

Permitting

The primary issue faced by water planners today is the need to reliably forecast future water demands; however, in order to provide accurate forecasts the water planners must have access to reliable data to support past and present water use. A major function of MHIS will be to provide a state-wide water management data base that is continually updated as additional information becomes available. The data base file for water-consumption data will be designed according to beneficial use, place of use, and volume of use. Developing such a comprehensive data base will be very useful in making accurate short and long-term projections of water-supply requirements. The more accurate and complete the data utilized are, the more reliable and useful the forecast will be and the more efficient and productive the plans and projects based on the forecast will prove to be. Development of this data base is scheduled as Phase III (Data Base Design) and is being constructed by MARIS in part. A portion is scheduled for completion in June of 1993.

Water Use

The use of ground-water flow models in simulating the effects of ground-water withdrawals will be invaluable in water supply planning. Future water demands can be simulated at existing well fields or may be simulated at other proposed locations. Access to this type of information provides the water planner with an eye into the future upon which to base his decisions. If water planners are to have some role in managing the future rather than just witnessing its arrival, they must have the technical tools available to them to properly manage the resource. The implementation of the MHIS will provide State water planners with the equipment with which they may base their decisions. Therefore, regular communication with the MHIS will be fundamental to the permitting process involving ground-water and surface water withdrawals throughout Mississippi.

In addition to traditional water use studies, the OLWR has initiated a Landsat Agricultural Crop Analysis in the Delta that will correlate crop types with pumpage data from irrigation practices to further analyze water use and changes in the potentiometric surface of the alluvial aquifer.

Technology Transfer

One of the most valuable aspects of MHIS implementation for water planners in Mississippi is the role it will play in data dissemination throughout the state. The available technology will enable the mutual transfer of data to all agencies involved in water resource management. This process will not only aid the agencies involved but will also assist in avoiding costly duplication of effort.

As previously stated, one of the long-range goals of the OLWR is to use the MHIS to assist other agencies, especially the existing Water Management Districts, in their analysis of local water management areas. This can be accomplished through technology transfer including data transfer, hardware and software selection for compatibility, interagency expertise, and analytical training. With an interactive MHIS in operation at the State level, this assistance will prove to be the most effective means of water management in Mississippi.

End Products

Traditionally, the OLWR has published reports based on data gathered from field measurements. Maps have been hand generated that illustrated the potentiometric surface of the aquifers being studied. The data collection procedures are well established and serve an ongoing purpose. The only change to the current program will be an enhanced capability to input and analyze these data by staff scientists due to the increased efficiency of the MHIS to manage the relational dabases and synergistically display map data.

Map products will become increasingly more abundant, along with increasing in data content and precision. The ability of the MHIS to graphically display and output hardcopy products of hydrogeological data will mean greater utilization of the data generated for water management purposes.

Digital data will be kept on an electronic bulletin board for public access. Graphics and statistical data will be kept in directories for the public to access with modems. It is hoped that this will provide local water managers with access to previously difficult data to access along with graphics never before available. Private consultants and academicians will also have access to these data and will hopefully assist in providing new information on the hydrologic cycle because of the new availability of information.

SOFTWARE STRATEGY

Careful evaluation of all aspects of the operations of the OLWR was required during Phase I (Planning and Purchase) in order to acquire a system that would fulfil the needs of this Office. One of the primary reasons for the intense evaluation was due to the immense quantities of data required for OLWR applications. Current estimates suggest 10 Giga Bytes as the size of the mass storage equipment necessary to load the entire data base. In order to manipulate the data base several GIS packages were evaluated, and ARC/INFO, because of its superior technology and statewide acceptance, was chosen. Additionally, other software packages were needed in order to fully meet the application needs of the Office. Finally, much thought went into acquisition of the appropriate hardware necessary to generate the specific end products (reports, maps, digital data) that were anticipated. When Phase I planning was complete, hardware and software were purchased and Phase II began. Data was gathered from many disparate sources, and the complex system software was loaded for application needs. Extensive plans were put into motion that were necessary for generating and outputting the desired end products.

Vector Data

Acquisition of vector data will come from several sources including in-house generation of data from digitizing, raster to vector conversion software, and gathering digital data from various government agencies. The basemap for the MHIS was originally acquired from the USGS in the form of 1:100,000 Digital Line Graphs (DLGs). These data were then enhanced by MARIS and provided to the OLWR in coverages consisting of a county by county format. There are many other digital data sets the OLWR needs in vector format in order to analyze the complex dynamic variables of the hydrologic cycle. One of the most important is the contour information from 7.5 minute quads. With over 800 quads in the state, whichever route taken for acquisition will prove to be expensive and time consuming. Other data sets that the OLWR plans to include in the MHIS are listed in Table 1.

TABLE 1. VECTOR DATA SETS

Enhanced DLGs:

State Lines
Counties
Coastline
Rivers
Lakes
Roads
Railroad
Permits
Administrative Boundaries

Other Data Sets:

Precipitation
Topography
Surface Lithology
Steam Gages
Well Sites
Well Gages
Well Permits
Water Table
Potentiometric Surface
Aquifer Thickness
Subsurface Lithology
Structure Maps

Raster Data

The largest anticipated source of raster data will come from construction of the well log repository. Over 15,000 well logs of both petroleum and water wells will be scanned with a large format scanner and stored in an off line repository. Another large source of raster data will come from satellite data. Meterolologic satellites will provide the MHIS with information concerning the atmospheric moisture in the environment and will yield important information on precipitation events. After image processing algorithms have manipulated both Landsat and SPOT satellite data, they will generate information for the MHIS on Land Cover/Land Use. Aerial photographs, once scanned and interpreted, will provide high resolution information on a variety of subjects pertinent to hydrological studies. Finally, the Soil Conservation Service has compiled a state wide data set on the soil classification that can be used for studies on infiltration rates. There is a very large quantity of information available in raster format, and it is going to be a long and time consuming task to acquire, access, and assimilate it into the MHIS. Table 2 was constructed to give examples of the data sets anticipated.

TABLE 2. RASTER DATA SETS

* Meteorological Satellites
* Landsat
* Spot
* Aerial Photography
* Well Log Repository
* Soils

Data Bases

Data-Base management is a systematic way of electronically organizing and accessing tabular data. One of the most powerful features of a GIS allows digital map elements to be linked with the tabular data in data bases. The relationship exists so that the digital map or the data base may be manipulated in order to adjust and update either data set while maintaining the relationship between them. Several agencies have provided the OLWR with digital data bases that are going to be used in constructing the MHIS. In addition, there are other data bases that have been developed internally and will also be used in the MHIS. Table 3 gives a full accounting of all of the data bases currently being considered for use in the MHIS.

One of the most important features of a data base is the spatial discretization of available data. These data may be well locations, surface water withdrawal points, river courses, land use, as well as many other attributes. Using the data from a data base the computer can electronically map and store these data in discrete data layers for manipulation and integration into a final map product accomplished by a process known as overlaying or layering. Each attribute of a series of maps to be overlaid is represented at the same scale and registered to a set of common benchmarks and combined through software manipulation. The result is a new map with regions corresponding to the combination of the source maps. By digitizing this information and storing it in a file, any map attribute can be recalled independently or in combination with other attributes for map generation. It is the capability to select attributes, manipulate, and analyze data in both spatial data sets and tabular data bases that makes the MHIS such a valuable water resource management tool.

TABLE 3. DATA BASES

* Stream Discharge Data
* Dams
* Water Use
* Water Quality
* Water Levels
* Drillers' Logs
* Formation Tops
* Water Well Contractors
* Aquifer Parameters

SYSTEM SOFTWARE

The primary function of the software will be to allow the OLWR to fully automate all activities that were previously recorded on paper and to utilize graphics peripherals for high quality output. Other important utilization of these capabilities will allow the Office of Land & Water Resources to upgrade the quality of presentations in meetings with other agencies (Federal, State, County, and Local) and to the public. In addition, the data and graphics will be uploaded to MARIS as required for dissemination to other state agencies and/or the public. These efforts will be accomplished with modems and tape backups.

Arc/Info (Geographic Information System)

The first priority consideration given to the development of the Mississippi Hydrologic Information System was what type of software was needed in order to manipulate and manage geographic and hydrologic data. It was recognized several years ago that a Geographic Information System (GIS) was necessary for this office's complex and diverse applications. A GIS is described as "An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information." (ESRI, pp. 1-2). The recognized industry standard GIS package at this time is Arc/Info and it is also the GIS standard for the State of Mississippi. In addition, there was a great deal of digital data available from the Mississippi Automated Resource Information System (MARIS) that was already in an Arc/Info format. Current plans for statewide implementation of GIS systems for government agencies will also use Arc/Info. A Geographic Information System combines two computer software technologies: data-base management and digital mapping. The key feature of a GIS is that the digital map elements are linked with the tabular information in such a manner that when either the map or the tabular data are manipulated both sets of data are updated and adjusted to maintain the relationship between them. For example, a GIS can be used to identify wells having increasing rates of water-level declines and then search land-use maps for potential heavy water users located near these wells. It is this ability to select, manipulate, and analyze data in both a spatial and a tabular sense that makes a GIS so powerful.

AutoCAD (Digital Cartography)

In addition to the GIS software, we decided to use AutoCAD, the industry standard CAD package, as our front end digitizer. AutoCAD will be used to digitize map data from hard copy media because it is so much easier to use than Arc/Info. To this end, we have trained thirty-five scientists and technicians over the past two years at DEQ. Another advantage of using AutoCAD is that there are numerous third party add on packages that exist which allows AutoCAD to be used in a wide variety of applications.

ELAS (Image Processing)

As an integral part of the MHIS the OLWR decided to use remotely sensed data as a part of its environmental analysis software. The OLWR is testing the utility of satellite data in a water use study in the Mississippi delta. There are of course many software packages that are available for image processing, but the most powerful package available is ELAS (Earth Resources Laboratory Analysis Software) from NASA. ELAS is a geobased information subsystem originally designed for analyzing and processing digital imagery data such as those collected from multispectral scanners or digitized from maps. The other deciding factor in this decision is because there is a built in user's community at Stennis Space Center which is dedicated to using ELAS for advanced applications. We may receive training and assistance in problem solving from them.

MODELING SOFTWARE

The decisions that led to certain hardware acquisitions were in part based on the software necessary to analyze the specific types of data collected in the field. One of the primary applications that this office deals with is the forecasting of groundwater availability. Ground water modeling begins with a conceptual understanding of the physical problem and then translates the physical system into mathematical terms. The software package the OLWR uses to accomplish this is MODFLOW. This powerful analytical tool is a three dimensional finite- difference numerical groundwater modeling package. "A mathematical model consists of a set of differential equations that are known to govern the flow of groundwater." (Wang and Anderson, pp. 2). Inputs from the field in the form of water level measurements are entered into the model and "Ground water flow within the aquifer is simulated using a block centered finite difference approach" (McDonald and Harbaugh, pp. 1). The potentiometric output from MODFLOW is in a numerical tabular format and, while very useful, is not yet in a graphic format.

SURFER (2D/3D Graphic Visualization)

When the numerical/statistical data from MODFLOW is processed, the final product is in the form of gridded tabular data. When used in the proper format these data files can be renamed and used with another software package called SURFER. This package can manipulate the gridded data using a series of algorithms that transform the data into two and three dimensional graphical figures. Extreme care must be taken when using any graphics package to represent a visual image of the numerical data because it is very easy to manipulate the data in ways that give it the appearance of multiple meanings. As you can see from Figure 1, it is much easier to visualize the groundwater in a 2d/3D presentation rather than try to mentally extrapolate the potentiometric surface using tabular data sets. In addition to SURFER the OLWR has recently acquired QuickSurf which runs under AutoCAD and is also investigating the purchase of ARC/INFO's TIN package.

TRALAINE (Coordinate Conversion)

Modflow does not assign a real-world coordinate system to the digital data output, nor does SURFER have any capability to translate the MODFLOW coordinates into anything that can be utilized by a GIS. After the generation of the 2 and 3 dimensional maps the graphic output is manipulated by another package called Tralaine which has the capability of generating the coordinate system that is needed by the MHIS. After this process the graphic images are then ready to be uploaded into our GIS Software.

HARDWARE STRATEGY

After an intensive effort (Cash 1991) to isolate the most efficient hardware platform to host the MHIS, a SUN minicompter was selected. A SUN SparcStation 2 with all of the file server options is currently being utilized by the OLWR as a host for two other SUN workstations (IPX,IPC-GX). In the future all of the PCs in the OLWR will be networked into the SUN system with ethernet cards and TCPIP software. The HI& R (ground water division) is planning to use a SUN IPX networked into the system along with an SUN IPC/GX for Surface Water. All of the peripherals will be networked into the SparcServer and will have the capability of communicating with all of the workstations and peripherals. In addition the Sparcserver will be the primary workstation of the GIS. A design format for the current and proposed MHIS hardware is provided in Figure 2.

SUMMARY AND CONCLUSIONS

The decision to acquire and implement a GIS was a long and drawn out process going through multiple iterations of scientific investigation and bureaucratic paperwork. Full implementation is a highly desirable goal, but it will be some time before it is fully realized. Other institutions who have pursued GIS implementation have also realized the same difficulties that the OLWR has encountered. Hardware and software acquisition was only the first part of the painful process of converting from previous operations. Learning how to set up and use the hardware necessitated sending staff members to system administration schools and UNIX classes. In addition, consultants were brought in to set up and streamline the operating system for the specific OLWR hardware/software system configuration. Upgrades to the system hardware and software inevitably cause problems in overall system operational efficiency, resulting in down time while the system is being fine tuned. Constant care must be given to the system in order for it to work properly. When considering changing from a distributive processing, personal computer environment to a more centralized UNIX based system, it must be realized that a dedicated system administrator must be ready to take charge of the system maintenance and that extensive training of the staff must occur in order to be productive with the system. Everything about using UNIX seems more complicated, and many of the staff will have a hard time adjusting even with training.

The MHIS Phase II, Hardware and Software Implementation procedure, while partially complete is still in a state of growth. New hardware is anticipated, especially RAM and mass storage. In addition new graphics input/output devices are being considered. Software upgrades are inevitable, as well as widening the base of current operations with additional software.

Phase III, Data Base Design is currently in progress. New data sources are being considered from a variety of governmental agencies along with data creation from internal sources including digitizing and scanning. The primary hydrologic data base design has been contracted to MARIS and is currently under construction. It will take an unspecified amount of time to finally develop the data base design into a final form, and in all probability it will undergo numerous revisions in an effort to streamline the entire system efficiency.

The anticipated results from the MHIS are expected to yield benefits that will stretch far into the future and provide efficient maximum utilization of the complex information/variables that are associated with understanding the hydrologic cycle and the water use practices for the State of Mississippi. Given the difficult nature of managing a dynamically changing system that must out of necessity be studied in four dimensions in order to be understood, there was no other reasonable solution other than to implement a GIS for the OLWR application requirements. It will be an ongoing process of ever increasing complexity to utilize all of the new technological advances foreseeable in the future, and the OLWR staff must continue to grow and increase in technological awareness in order to meet the pervasive demands necessitated by the information explosion.

REFERENCES

Cash, S.C. 1991. Software and hardware considerations for a graphics workstation. Mississippi Water Resources Research Institute.

Munter, J.A., and M.P. Anderson. 1981. The use of ground-water flow models for estimating lake seepage rates. Ground Water. Volume 19. No. 6: 608-616.

National Research Council. 1990. Ground water models - scientific and regulatory applications/committee on ground water modeling assessment.

ELAS - Science and Technology Laboratory Applications Software. 1989. National Aeronautics and Space Administration, Science and Technology Laboratory. Stennis Space Center.

McDonald, M.G., and A.W. Harbaugh. 1984. A modular three-dimensional finite-difference ground-water flow model. U.S. Geological Survey, Open File Report 83-875.

Wang, W.F. and M.P. Anderson. 1982. Introduction to groundwater modeling. W.H. Freeman and Company, San Francisco, CA.

Simulated potentiometric surface of the Mississippi River Alluvial Aquifer in the delta for the year 2003, assuming pumpage rates of 670 million gallons per day .

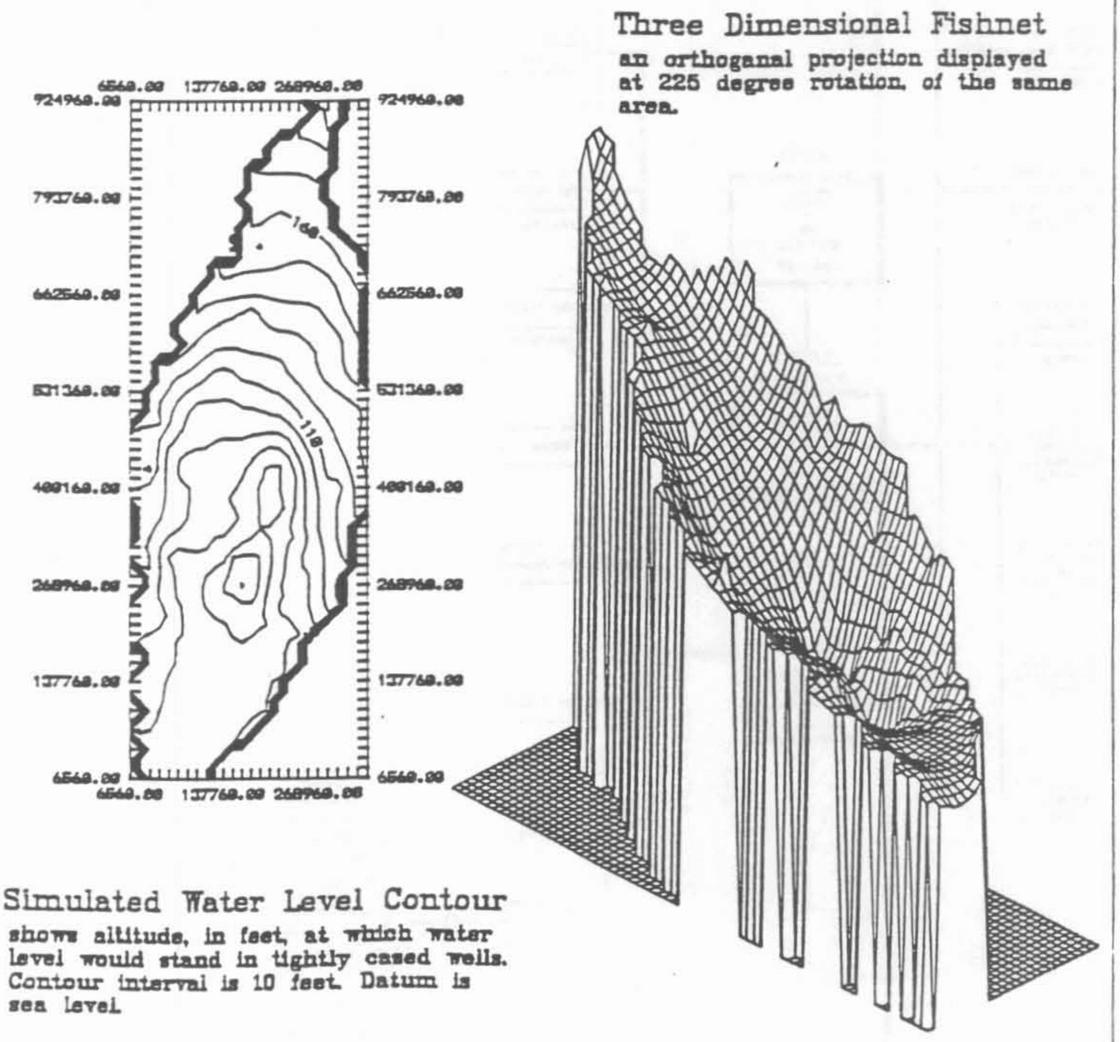

FIGURE 1. A combination of MODFLOW, SURFER and AutoCAD was used to create this graphic.

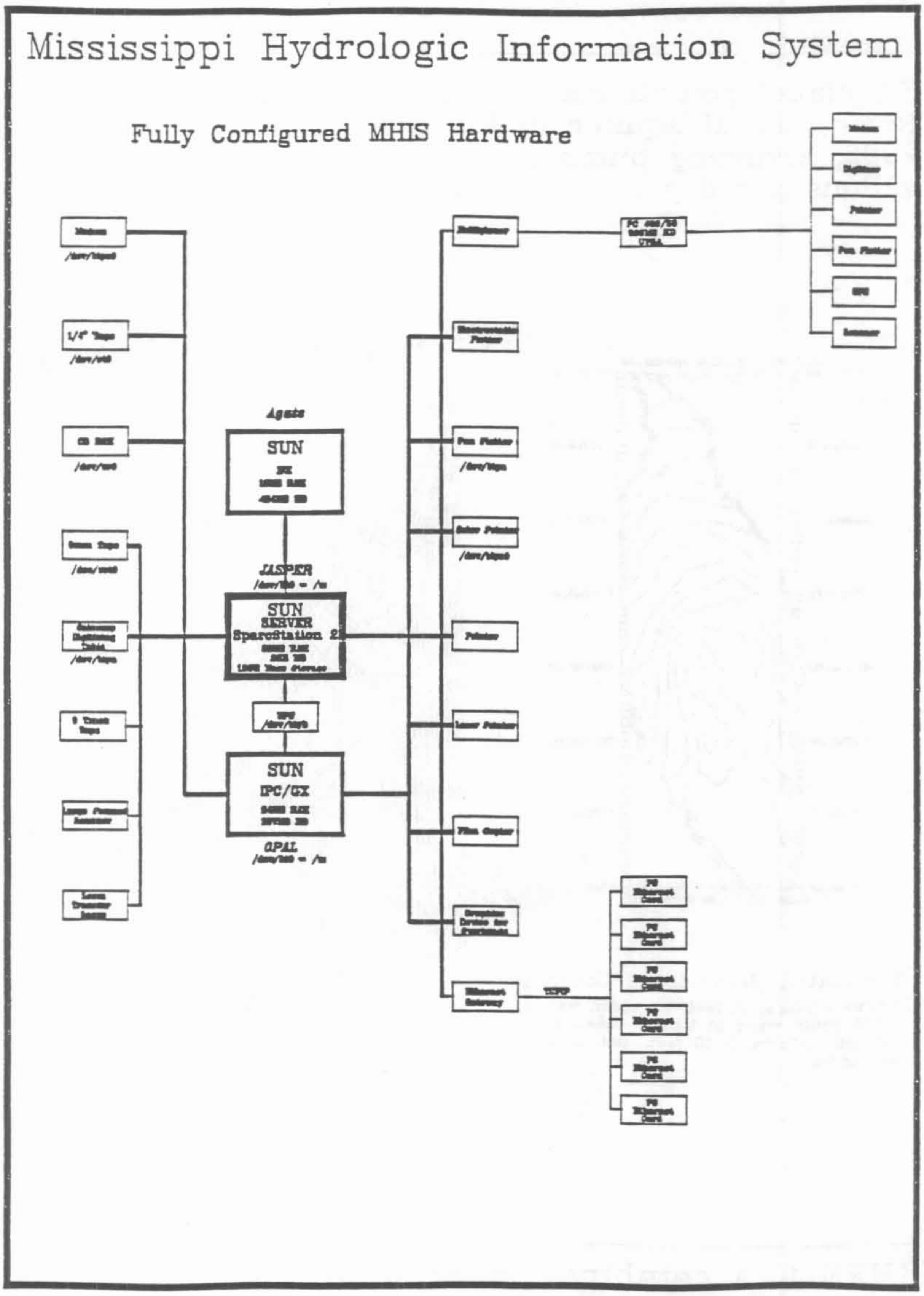

FIGURE 2. Diagram of the Current and Proposed Hardware Configuration of the MHIS.