TVA'S GEOGRAPHIC INFORMATION SYSTEM: AN INTEGRATED RESOURCE DATA BASE TO AID ENVIRONMENTAL ASSESSMENT AND RESOURCE MANAGEMENT

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ABSTRACT

The Tennessee Valley Authority (TVA) has implemented a computerized Geographic Information System (GIS) to aid a wide range of environmental assessment and resource management activities. These activities vary in scope from region-wide to site-specific considerations. A major area of application is the administration of reservoir land. There are 23 multipurpose reservoirs in the 7-State TVA system with a combined total of 300,000 acres of land, 660,000 acres of water surface, and 10,000 miles of shoreline. These land and water resources are managed for multiple uses such as forestry, wildlife, fisheries, recreation, and navigation. In addition, TVA annually receives more than 1,500 external requests for the use of reservoir land for a diversity of activities from commercial and industrial development to private boat docks. This paper describes how the data storage, selective retrieval, analysis, and display capabilities of the GIS are being used to aid development of overall reservoir land use plans, formulation of detailed land management prescriptions, and assessment of environmental impacts related to requests for the sale, transfer, or other use of reservoir land.

INTRODUCTION

TVA is a regional resource development agency. In 1933 TVA was envisioned by President Franklin D. Roosevelt as an agency to be "charged with the broadest duty of planning for the proper use, conservation, and development of the natural resources of the Tennessee River drainage basin and its adjoining territory for the general social and economic welfare of the nation." It was a novel approach to the organization of Federal programs: a single Federal agency responsible for encouraging the unified development of all resources in a specific region of the Nation, headquartered in that region, and directly responsive to the needs of its citizens. In pursuit of this goal TVA undertook a broad range of resource development activities, chief among which was the multipurpose development of its reservoir system for flood control, navigation, and electric power production.

A significant base of land was acquired by TVA in conjunction with the development of its reservoir system. The system now spans seven States and includes 23 multipurpose reservoirs with more than 10,000 miles of shoreline and about 300,000 acres of public land.

Consistent with its regional mission, TVA has continuously used its reservoir shorelands to meet a variety of needs in the Tennessee Valley. Because these shorelands include many high-quality sites for various uses and control access to the inexpensive transportation offered by the Tennessee River system, they have traditionally been a catalyst for the development of the region. They are used for a wide variety of TVA activities, ranging from nuclear power plants to recreation sites, forestry, and wildlife management. In addition, they are made available for many other public and private uses, including industrial development, agriculture, parks, and commercial recreation development. To manage effectively the growing demand for development on these lands, TVA has initiated a formal planning process intended to balance competing demands for public and private uses, environmental considerations, and local and regional values.

This planning process depends upon an accurate inventory of the resources existing on the land base and an extremely diverse set of evaluations regarding their suitability for various types of development. To help TVA planners manage and interpret the tremendous volumes of basic resource data necessary for this process, TVA acquired and implemented a computer-based geographic information system (GIS) in 1981. The GIS was purchased from Intergraph Corporation after an extensive evaluation of the ability of available systems to meet TVA's diverse needs. This paper describes TVA's experience in using this system to support land use planning and administration of its reservoir properties. Specifically discussed are the technical problems and the payoffs of this use of geographic information systems.

RESERVOIR LAND MANAGEMENT APPLICATIONS

The data storage, selective retrieval, analysis, and display capabilities of the GIS are used to support a variety of TVA reservoir land management activities. These include (1) resource inventory; (2) development of overall reservoir land use plans; (3) formulation of detailed land management prescriptions; and (4) assessment of environmental impacts related to requests for the sale, transfer, or other use of TVA reservoir land. These applications will be described in detail through the use of a case study.

Guntersville Reservoir, the second largest reservoir in terms of water surface area in the TVA system, will be used as the case study. It is a multipurpose reservoir operated for navigation, flood control, power production, recreation, and other uses. The reservoir is located in northeastern Alabama with a small portion extending into Tennessee. It includes 67,900 acres of water surface, 950 miles of shoreline, and 36,000 acres of TVA-owned land.

Reservoir Inventory

An integrated digital data base consisting of both mapped and alphanumeric attribute data linked internally within the GIS was developed for Guntersville Reservoir. The data base covers the reservoir, TVA-owned land, and a zone extending approximately 1 mile behind TVA-owned land.

Two kinds of mapped data were collected: (1) resource and (2) capability data. Resource data identify the nature and extent of existing landrights, physical features, biological resources, and cultural resources in the reservoir area. Twenty-six data types were integrated into a common geographically referenced data base (Table 1). These data were stored in the GIS as point, line, and area (polygon) features. Most of these data were collected by TVA resource specialists and then entered into the GIS. However, some resource data such as erosion hazard and prime farmland were derived using the data manipulation capabilities of the system.

Capability data, indicating the relative ability of the land to support various uses, were derived by analyzing combinations of selected resource data. Seven categories of capability data were developed by TVA staff using a variety of manual and computer-assisted methods and entered into the GIS (Table 1). This technique was used because these analyses required consideration of transportation, demand, labor, market, or other factors that extended beyond the 1-mile zone behind TVA-owned land.

An extensive alphanumeric attribute data base was developed and linked within the GIS to the mapped data. Attributes are textual and numerical data that describe the characteristics of mapped features. For example, attributes stored for each existing recreation area included: (1) name of the recreation area (e.g., Lake Guntersville State Park), (2) owner, (3) type of recreation area (e.g., public park), and (4) acreage. The number of attributes for each data type ranged from 2 to 40. The GIS is capable of storing over 1,000 attributes for every point, line, or polygon stored in the system. The attributes can be used to retrieve selectively all or a subset of the mapped data, in accordance with combinations defined by the user. Conversely, the user can point to a mapped feature and request a report of all or a subset of its attributes. The link between mapped and attribute data is a powerful tool for selective retrieval, analysis, and display.

Many conceptual and technical problems were encountered in developing an integrated digital data base for Guntersville Reservoir. The data existed on a variety of source documents including unrectified aerial photographs and maps with varied scales, projections, and coordinate systems. For example, the landrights data for the Alabama portion of the reservoir were mapped at 1" = 500' on an Alabama East State Plane Coordinate base. The same data for the Tennessee portion of the reservoir were also mapped at 1" = 500' but on a Tennessee State Plane Coordinate base. Many of the descriptive data were mapped on USGS 7½-minute topographic quadrangle maps. These maps have a scale of 1" = 2,000' and use a polyconic map projection. Soil survey data were mapped at 1" = 1,667' on uncorrected aerial photographs. Integration of these sources into a common base would have been extremely difficult using manual graphic methods.

Table 1. Guntersville Reservoir Digital Data Base

(A) RESOURCE DATA:

Physical and Biological Data

1. Air Quality
2. Aquatic Plants
3. Fisheries and Molluscan Resources
4. Flood Elevations
5. Forest Resources and Research Areas
6. Prime Agricultural Land
7. Potential Erosion Hazard
8. Threatened or Endangered Species Habitats
9. Unique Biological and Geological Features
10. Water Quality
11. Waterfowl Habitats
12. Wetlands
13. Wetland Wildlife Habitats
14. Upland Wildlife Habitats

Social and Cultural Data

15. Archaeological Sites
16. Architectural and Historic Sites
17. Existing Forest Industries
18. Existing Industrial Areas
19. Existing Navigation Development
20. Existing and Planned Power Facilities
21. Existing Recreation Development
22. Water Intake and Discharge Facilities

Landrights and Political Boundaries

23. State, County, and Municipal Boundaries
24. TVA Reservoir Land (plan tracts)
25. TVA Reservoir Land (developed tracts)
26. TVA Reservoir Land (easements, leases)

(B) CAPABILITY DATA

1. Agricultural Capability
2. Barge Facility Capability
3. Forest Management Capability
4. Industrial Development Capability
5. Recreation Capability
6. Upland Wildife Habitat Capability
7. Waterfowl Habitat Capability
8. Wetland Wildife Habitat Capability

The World Mapping System (WMS) portion of the Intergraph software was used to integrate these data into a common digital data base. The Universal Transverse Mercator (UTM) coordinate system on a transverse mercator projection was selected for geographic referencing. UTM coordinates were selected instead of latitude/longitude coordinates because accurate acreage calculations were required. State plane coordinates could not be used because the reservoir covered portions of two States. The WMS software was used to transform all of the data from their source coordinates and projections into the common system. Differences in map scale were handled automatically by the software during data entry.

A more difficult problem was encountered when the same earth feature was represented in different geographic locations on different source maps. A prime example was the definition of the reservoir shoreline, particularly in shallow embayments. Significant differences were found in the shoreline location among the maps of surveyed property ownership, USGS 7½-minute topographic quadrangle maps, and Soil Conservation Service (SCS) county soil surveys. The differences were caused by a number of factors, including: (1) map scale, (2) mapping date, (3) reservoir water level at the time aerial photographs were taken, (4) natural processes of erosion and deposition over time, and (5) differences in human collection and interpretation of data.

For the Guntersville Reservoir data base, the TVA property ownership maps were considered to be the most accurate overall and were, therefore, used as the base to which all other data were registered. In addition, the ownership maps are legal documents used in daily land administration matters, which adds to their credibility. In some cases islands were adjusted to reflect changes that had occurred over time. The flexibility of the GIS was invaluable for registering all data to the selected base and inserting updated shoreline definitions where appropriate. In addition, the GIS served as a vehicle for recording and updating changes in land use, environmental conditions, and TVA landrights over time. These changes were made quickly and inexpensively.

Once the resource inventory was completed, it was used to support a range of reservoir land management activities.

Reservoir Land Use Plan

The purpose of the Guntersville Reservoir plan is to provide a decisionmaking tool that will enable TVA to better meet its responsibilities as a public agency and land manager and to expedite handling of requests for the use of its lands and waters. It is not a rigid "master plan." Rather, it is intended to have the flexibility to guide development, facilitate on-the-ground land management, and offer alternative sites for specific proposed land uses around the reservoir. The plan designates Guntersville Reservoir land for a variety of single and multiple land uses, guided primarily by views expressed by private groups and citizens, TVA land use policies and program objectives, and the inherent capability of the land to support various uses.

The GIS was used to support many activities during the reservoir land use planning process. The selective retrieval, analysis, and display capabilities of the system were used to manipulate the digital data base to aid land allocation. This included developing data interpretations such as prime farmland from detailed soil survey data, overlaying capability data with selected resource data to produce suitability maps for various uses, developing composite suitability maps that identified competition for land and potential compatible and incompatible uses, providing graphic and textual material related to mitigation of the effects of incompatible use conflicts, updating the TVA landrights data to reflect new tract boundaries that resulted from the land allocation, and using the system's extensive graphic display capabilities to facilitate development of the plan map for the draft and final project reports.

Manipulating the data base by means of traditional manual overlay techniques would have been considerably more difficult and time consuming. To develop a manual data base would have required redrafting over 350 source documents into a set of 200 hand overlays, each covering four 7½-minute topographic quadrangle maps. Selectively retrieving subsets of data types (for example, separating those sites on the National Register of Historic Places from the overall historic resources data and combining them with other data) would have been impractical by manual techniques.

Land Management Prescriptions

The reservoir plan provides an overall context for the use of TVA-owned land. However, land management prescriptions must be prepared to guide on-the-ground land management activities consistent with the reservoir plan. For example, various tracts were allocated for forest and wildlife management. On these tracts TVA foresters and wildlife biologists work cooperatively to determine detailed site conditions and develop a management strategy for those resources while adhering to strict environmental quality standards. This process usually requires an identification of forest stands accompanied by a detailed forest inventory; analysis of existing and potential wildlife habitats; and analysis of erosion potential, visual sensitivity, and site accessibility. The data management and analytical capabilities of the GIS can be used to store these data and conduct needed analyses.

Assessment of Environmental Impacts

Each year TVA receives hundreds of requests for the sale, transfer, lease, license, or other use of its reservoir land. Requests include such uses as road, pipeline, and transmission line easements; commercial boat docks, piers, and launching ramps; public and private recreation facilities; navigation; industrial development; and municipal facilities. Assessment of potential environmental impacts associated with each proposal requires an intensive interdisciplinary review that often involves field investigations (especially for archaeological and wetland resources) and public involvement.

The GIS can reduce costs and expedite this review process by rapidly developing a package of mapped and tabular information related to any particular request. The information contained in the package forms the basis for a formal environmental impact statement (EIS) or other assessment document. With this package TVA program staff can rapidly assess potential impacts and respond quickly to land use requests. Staff attention can be devoted mainly to changes in conditions since the last update of GIS and to interpreting the consequences of proposed uses rather than to recompiling resource data. In addition, TVA field staff that have direct access to the interpretations on GIS made by resource specialists can respond immediately to some preliminary requests (by telephone, etc.). In this way it is possible to assist applicants in modifying or redirecting clearly undesirable requests before initiating the formal review process.

By using the GIS as a data integration tool, each reviewer can examine all aspects of the situation, not just those directly related to his or her specific expertise. The result is a higher level of understanding and concurrence among the specialists reviewing each action. GIS can also exhibit particular proposed uses in the context of surrounding land and water use. Reviewers must no longer look at these requests as independent, isolated entities; they can address the important question of cumulative effects caused by numerous actions in proximity to one another on TVA reservoirs. High quality GIS graphics custom-tailored to each review highlight important issues much more effectively for consideration by all reviewers and also communicate the results of the review to field staff, TVA management, and the applicant.

COSTS AND BENEFITS

The most expensive aspect of implementing such a system for reservoir land administration is development of the digital data base. The total cost of using the GIS for Guntersville Reservoir was $100,000. Of that total, 65 percent, or $65,000, was required to build the digital data base. Landrights data alone accounted for $30,000. As such, the cost effectiveness of using such a system for reservoir land administration is dependent on the multiple use of the data base for planning, land management, and environmental assessment. To maintain the system's usefulness over time, the data base must be constantly updated to reflect changes in conditions. The cost of updating the data base for Guntersville Reservoir is less than $5,000 per year.

One-time use of the system--to aid development of the reservoir plan only--is more costly than using comparable manual techniques. However, when GIS is used to support a full range of reservoir land administration activities over time, it becomes a very cost-effective tool. For example, selective retrievals, analyses, and graphic displays of data in response to requests for the sale, transfer, or other use of reservoir land cost $50 to $350, depending on the nature and extent of the proposal. This cost is well below that of comparable manual methods.

CONCLUSION

Computer-aided geographic information systems such as the one used by TVA offer an effective tool for integrating and interpreting the large amounts of basic resource data necessary for sound planning of multiple-use land management. Cost effectiveness is further increased if the data bases developed for planning are also designed and maintained to support long-term land management and administration activities. Use of geographic information systems for land management will become more commonplace as managers discover the long-term economic benefits of their application.