Environmental Assessment Sourcebook
UPDATE

Environment Department
The World Bank

January 1995
Number 9

# Implementing Geographic Information Systems in Environmental Assessment

*In EA Sourcebook Update no. 3, Geographic Information Systems (GIS) were presented in conceptual terms and through case examples as a potentially powerful tool in project development and environmental assessment (EA). Building on that introduction, this Update discusses in practical terms how GIS might be introduced institutionally and technologically in the project context.*

## GIS and environmental assessment

Most EA experts and planners, even in some developed countries, do not fully realize how difficult the generation and management of environmental information can be. Typical problems are lack of reliable data, poor compatibility between different data sets, weak coordination among agencies or units responsible for different types of data, and low capabilities for collecting, archiving, processing and analyzing data. These kinds of problems become all too familiar to environmental practitioners trying to *determine the baseline environmental conditions* at and around a project site and, subsequently, to *assess impacts* and *analyze alternative project sites or designs.* Although GIS is not a miracle solution to these problems, it has become an increasingly attractive answer to the difficulties in collating, organizing, coordinating and analyzing spatial data. And its usefulness is widely recognized by natural resource managers, environmental specialists and EA practitioners in governments and donor agencies.

Backed by more than fifteen years of research and development, modern GIS technology is considered to have reached maturity in many applications (although, as is true for any emerging technology, some refinement will continue to be needed). Two of the mature applications are of particular interest to environmental assessment:

- Project-based GIS that is designed to address specific problems associated with a particular project.

- Program / institution-based GIS where the capability for environmental information management at a national or regional level is to be developed.

In the first application GIS may be part of the EA process for a project or, more broadly, of project design and implementation. It is most appropriate in projects that cover relatively small geographical areas and do not require very extensive databases. The second application may be developed in conjunction with an institutional-strengthening project, a regional natural resource management project, or very large energy, urban or infrastructure projects. GIS may also be helpful in building collaborative information management efforts between two or more countries.

The GIS technology needed for the project-oriented application is relatively inexpensive and is usually PC-based, although sometimes manual systems are used (e.g., map overlays). These systems may, nevertheless, be used in relatively complex activities such as impact assessment. The actual implementation of the GIS is relatively straightforward and would not require prior experience with GIS. Very little training during installation would bring the EA experts up to speed in operating the system. Training in GIS for EA practitioners, either in-country or in short-term courses overseas, is recommended in cases where technical capabilities are weakly developed.

The second type of application of GIS requires more-elaborate technological and institutional capacity and is more costly to implement and operate. However, once in place, this application is more cost-effective than implementing several isolated project applications.

## Components of GIS

### *Hardware and software*

GIS systems are available already packaged, or can be custom designed, with varying degrees of sophistication and capabilities and with a range of hardware and software options. At one end of the spectrum are a number of systems that rely on simple microcomputers running small and inexpensive programs, primarily for project-related activities. At the other end are complex mainframes supporting large and expensive packages of programs associated with massive databases, typically maintained for programmatic purposes. Care needs to be taken in selecting appropriate GIS solutions to a given application.

With the recent advances in microcomputer technology, a number of functional, PC-based GIS packages are available that have many of the capabilities of the larger systems. These new systems may be particularly attractive in complex settings such as large hydroelectric, large urban, and rural roads projects or regional forest management operations. The microcomputer usually requires, at a minimum, a high-resolution graphics monitor and a hard disk with at least a few hundred megabytes data storage. Most systems operating on PCs require at least an 80386 or 80486 (or equivalent) processor. Similar systems work on Apple Macintosh computers. In addition, some software packages operate only when a coprocessor is installed. Typical costs of such a system (including referrals such as digitizers and simple plotters) would currently cost less than US$10,000.

Hardware configurations, which are somewhat more sophisticated and powerful than the PCs, include what has become known as “workstation” computers. These systems are able to handle 3-D modeling and real-time analysis and process quickly large volumes of data. However, they are more difficult to manage and operate than PCs, and require at least some staff with specialized skills for even routine file maintenance and system operations. Depending on the size of the workstation computer, costs may range from US$10,000 to US$100,000. These options are therefore more suitable for programmatic uses. For very large, programmatic applications, very specialized computers are required along with specialized services. Such systems may cost from several hundred thousand to several million dollars.

The major GIS software vendors, as indicated in the 1993 GIS Sourcebook (this list is not inclusive and does not indicate an endorsement by the World Bank), are Intergraph, ESRI (ARC / INFO), Electronic Data System, GeoVision Systems Inc., ERDAS Inc., MAPINFO Corp., GENASYS II Inc., Tydac Technologies Corp., Generation 5 Technologies Inc., PMAP Technologies Inc., and Digital Resource Systems Ltd. There are many public domain software programs (such as GRASS, IDRISI, etc.) now that cost nothing or very little to use.

### *Data*

A detailed database design is a critical component of any GIS system design (see box 1). The database design depends on the hardware and software configuration and functions, and vice versa. This requirement, however, may not be important in the future when the data transfer and transformation softwares now being developed are operational. The system functions include graphic presentation, database manipulations and other analytical functions. By defining these functions, the character of the system takes form and the cost estimates become possible. The cost of database development and maintenance is several times more costly than all of the other GIS components. Defining the database content and accuracy, while maintaining applications priorities, is therefore one of the important first steps in system design.

The database is normally composed of data generated by means of satellite remote sensing (including radar), areal photography and radar, field studies, and use of existing data. Experience shows that use of images from satellites can only complement areal photography and field studies such as ground surveys and questionnaire. For example, while remote sensing techniques have dramatically increased our ability to map trends in land use patterns and natural resource depletion, they leave unaddressed the socio-economic and political forces underlying these trends (see Box 1).

### *Human resources*

Perhaps the most underrated step in GIS development and implementation is that of organization and human resource development. Approaches to human resource development vary from project to project, but a well-trained and organized staff, with a clearly defined mandate, is the key element of success in any GIS application (see box 2). The GIS organization component should define the authority, responsibility, chain of command, and staffing level, including staff development. The complexity of the system,

**Box 1. Development of the database**

A GIS database can be of two basic types: geographic and non-geographic. Geographic data are manual or digital representations of spatial features. They may include coordinates, rules, and simples (explained through certain keys) that define the specific cartographic elements on the map or image. GIS uses geographic data to generate a graphic display on the computer screen or on paper. Non-geographic data are expressions of the characteristics, qualities, attributes, or relationships of features and their locations. They are stored in conventional alphanumeric formats, but are cross-referenced to the geographic data.

Building the database is typically the most expensive, time-consuming, and problematic part of implementing GIS. Not surprisingly, the data cost often becomes a driving concern. Data generation and preparation usually runs up to 70% of GIS implementation cost. For development projects, the cost of data collection usually runs at about 6% of the total project cost. Generally, the cost increases as a function of the scale, precision, accuracy, and type of data collected and the extent of area covered. Thus, large-scale information gathering for urban environmental assessment and engineering development has perhaps the highest cost per unit area. Sometimes cost considerations force a compromise between the ideal and the acceptable.

Easy access to existing databases, or developing new data, is the heart of any information system. Large volumes of environmental data at local, national, regional and global levels already exist, but unfortunately a great deal of these databases are essentially inaccessible. In many developing countries, access to topographic maps and aerial photographs is restricted, because it is seen as a potential security threat. Many accessible databases are not very reliable and are mostly outdated. The need for timeliness is often overlooked in assessing the quality of data. For example, maps of land use in urban and semi-urban areas that are more than five years old may have historic value only and are probably not very useful in environmental assessment of current projects.

number of users, and sophistication of the applications dictate the number and level of skills of staff needed for the specific GIS.

## Implementing GIS

Over the last few years some generalized models for the design and implementation of GIS capabilities have emerged. Most of the models are similar to those used in development project planning. The process can be divided into five broad stages, as shown in chart 1. The more detailed steps involved in this process are presented and discussed in a recent World Bank publication entitled *Natural Resource and Environmental Information for Decisionmaking* (Hassan and Hutchinson, 1992, pp. 58-63). In the following discussion, the process is presented in a more condensed form and is illustrated with project examples.

### *Identification and conceptualization*

In implementing a GIS for project-specific EA work or for more-programmatic uses, various issues have to be considered up front. These can be targeted by assessing user needs, the degree of geographic information culture, and the kind, scale, resolution, and volume of the data needed.

A thorough and early assessment of the *users' needs* for data will help ensure the development of an efficient operation. The supply and use of environmental information is a whole process that starts with the producers of the raw data and proceeds to the processors who collate, treat and aggregate the data, the analysts who analyze the data and produce the information, and the users who rely on the information for making decisions. The number and type of users will influence how the data is collected and how the information system is to be designed and managed. An analysis should be made of the existing and proposed activities within relevant agencies that rely on spatially referenced data, both graphic and non-graphic. Systems should be built on existing capabilities as much as possible.

An important part of the local capabilities will be the level of *geographic information culture.* Many institutions that oversee the EA work in developing countries have little or no exposure to the management of spatial information, even as hard copy maps. It is very important to develop a basic sense of geographic culture within these institutions before attempting to establish sophisticated, computer-based GIS systems.

The specific *issues and problems to be addressed* will depend on the project and its setting. For example, an urban infrastructure project will require a different set of variables from those of a forest management project. Sometimes soil data, topography and hydrology are the more important variables; at other times, flora and fauna or demographic indicators take precedence. However, any of these information variables

**Box 2. Guinea-Bissau: Agricultural Land and Environmental Management Project**

The idea of introducing GIS technically and institutionally in Guinea-Bissau emerged from recent collaborative efforts between the government, the World Bank, and other donors in developing the National Environmental Action Plan (NEAP) and the Tropical Forestry Action Plan (TFAP). As one of the poorest countries in the world (with per capita income of US$190), Guinea-Bissau has had difficulty managing its natural resources effectively, maintaining sustained growth, or addressing deep-seated problems such as population growth, resource depletion, and inequities in income distribution. As one part of a broader attempt at changing these patterns, the government is currently collaborating with the Bank in implementing an Agricultural Land and Environmental Management Project, which includes a component aimed at developing in-country capability for collecting, storing and analyzing environmental and natural resource data across space and time. More specifically, the component will establish a National Geographic and Cadastre Institute (NGCI).

Because of its scarce financial and human resources and small geographical size, it would be difficult and economically undesirable for Guinea-Bissau to develop separate and parallel sectoral units dedicated to collecting and managing natural resource and environmental information, as is being done in some other African countries such as Ghana, Nigeria and Uganda. The proposed new institute, NGCI, would consolidate the staff and functions that are now dispersed among several government agencies and create a critical mass of experts that could service the needs of all agencies at minimal cost. The early preparation stage of the project included an assessment of Guinea-Bissau's information management needs related to environment and natural resources, as well as a feasibility analysis of putting the proposed institute into operation.

The long-term objectives of NGCI include the development of a competent, multi-sectoral, demand-driven institute that would provide geographic and cadastral information to satisfy the data needs of all the natural resource and development sectors in the country and that would operate on a sustainable semi-commercial basis. The institute would replace and take over the mandates of all the natural resource and environmental information collection and management units scattered among several ministries. NGCI would be sector-independent and semi-autonomous and would be located in the Ministry of Finance and Planning.

may be useful across a broad range of sectors. The functional processes, kinds and characteristics of data, and existing hardware, software and databases should be considered for each activity.

*Scale and resolution* are the fundamental properties of information that describe the probable level of detail and degree of aggregation they contain. The scale suggests the level of absolute precision of the map and the amount of generalization in compiling the information. Resolution indicates the smallest detail that can be identified. Covering large areas in low resolution (i.e., by satellite imagery) may be appropriate for national and regional planning or for projects with impacts that extend over a large area (watershed management or irrigation projects), but may not be useful for site-specific project planning and detailed design work (see box 3). However, collecting detailed, high-resolution information is more costly and time-consuming than expected.

Finally, determining the amount of *data availability* and data needed will be a crucial step in the early stages of building the system. If a relatively small amount of information is needed for proper analysis, simple manual techniques will probably suffice; however, if larger volumes of data and complex analysis are needed, computerized management and analysis systems may be required.

Box 4 provides an example of how this initial stage was handled in the context of a Bank-supported project for national environmental management.

### *Planning and design*

This stage normally consists of three separate but interconnected parts: the implementation plan, system design, and database design and development.

The *implementation plan* identifies the roles, responsibilities, and relationships of all the agencies and individuals involved. It outlines the fiscal and human resources that are to be committed for the program and identifies tasks and products to be achieved according to a time schedule.

*Database design and development* would accompany the overall system design. The design would contain descriptions of the content, specifications and standards, relationships, and sources of data to be incorporated into the database. The comparability and compatibility of data from different sources must be evaluated.

The *system design* includes a detailed description of the system configuration, defining the hardware and software capabilities. The compatibility between hardware and software and between the existing da-

## Chart 1. Steps in GIS implementation

**Identification and conceptualization**

- *Assessment: User needs/Geographic information culture/Feasibility*
- *Scale and resolution*
- *Data availability*

**Planning and design**

- *Implementing plan*
- *Database design and development*
- *System design and specification*

**Procurement and development**

- *Acquisition*
- *Organizational structures*
- *Operational procedures*
- *Site preparation*

**Installation and operation**

- *Installation of hardware and software*
- *Pilot project*
- *Application and database development*
- *Quality control*

**Review and audit**

- *System management*
- *Expansion/Updating/Upgrading*
- *System operation and maintenance*

**FUNCTIONING GIS**

**Box 3. Satellite remote sensing and GIS in urban planning**

The Urban Management Program (UMP) was begun in 1991 as a joint undertaking by the United Nations Development program (UNDP), United Nations Center for Human Settlements (UNCHS), and World Bank. The project aims to develop and promote appropriate policies and technologies for land management, infrastructure management, urban poverty reduction, and municipal finance administration. One of the components of the project is the development of a practical guide to show how remote sensing and GIS technologies can be used in urban management and to demonstrate the benefits of geographical analysis of data. This component's report focuses on operational applications in cities in developing countries, based on a comprehensive review of experience. The report introduces the technologies, available range of products, and various methods of analysis offered by satellite remote sensing and GIS. The cost estimates reported for satellite products range from US$0.37 / km2 (for Landsat TM image at 1:100,000 scale) to US$10 / km2 (for enhanced SPOT image at 1:25,000 scale). It should be noted that the scale of 1:25,000 almost approaches the limit of SPOT resolution.

According to the report, high-resolution satellite data have great potential for providing the needed current, reliable and cost-effective information on cities in developing countries. However, satellite data do not replace but rather complement other, more-detailed, information-gathering techniques such as aerial photography, ground surveys, and questionnaires.

Satellite data are useful for fast and inexpensive mapping and updating of urban land use / land cover, road design and implementation and other services networks (traffic management). Land cover information can be used together with data from other sources in applications such as the identification of hazard-prone areas. Satellite data are particularly useful for analyzing changes over time by comparing images of the same area taken at different dates. Image analysis can be greatly improved when remote sensing is used with GIS. Applications of such an integrated system include evaluation of urban growth scenarios, planning of new facilities, environmental zonation, and contingency planning for and mitigation of natural hazards.

The report recommends that remote sensing and GIS be integrated into capacity-building efforts to optimize the use of personnel, equipment and the information generated.

*Source:* Paulsson 1994.

tabases and the proposed new technology needs to be closely examined. Some flexibility in system specifications would enable vendors to take advantage of rapidly changing technology and to propose capabilities that are superior to the original design specifications.

### *Procurement and development*

This stage of building the GIS involves the acquisition of the system and database, establishment of the organizational structure and staffing arrangements, and preparation of the operational procedures, physical site, and infrastructure needed for proper operation of the hardware and software.

*Acquisition* would be based on the system and database design prepared previously. It is strongly recommended that the implementing agency acquire a previously tested commercial system rather than attempt to build capabilities from scratch, which would normally require many staff years. For systems that will have large databases, it is often desirable to contract the initial database development and data conversion activities to specialized firms. For smaller installations, the conversion may be done in-house.

There are no blueprints of *organizational structures* for GIS, because conditions surrounding implementation vary from country to country and from project to project. The structure for a single agency, limited purpose system can be quite simple. Systems supporting multiple agencies must consider how individual agencies would participate and share responsibility for system management and operation, policy and system procedures, staffing and skill levels, and so on.

The *operational procedures* should relate to both the management and the operation of the system including aspects such as allocation of resources to users, authorization of user access to the system, day-to-day operating practices, system maintenance, and data archiving. *Site preparation* includes providing space for the computer facilities and data storage, temperature and humidity control (in very hot, dry, and humid areas of the world), and—perhaps most importantly—a stable and sufficient supply of electricity.

### *Installation and operation*

This phase begins with the actual installation of the GIS system *hardware and software*, including the commissioning and testing of all components before final payments are made. It might be useful to begin operations by executing a *pilot project* for a small geographic area (but involving a wide spectrum of system functions) to verify that the system works as intended, test procedures, and

**Box 4. Planning an environmental information network in Ghana**

A major element of the Environmental Management Project in Ghana is the development of an environmental information network based on the environmental problems and priorities identified in the National Environmental Action Plan for Ghana.

The network is designed on the premise that the role of the central Environmental Protection Council (EPC) should be to ensure that relevant and required environmental information is used in environmental decisionmaking and economic development planning, rather than to be directly involved in the collecting, maintaining, processing, and analyzing of environmental information. The physical establishment and actual management of the information should be left to more-specialized agencies.

In this context, an assessment of the roles of the various agencies that collect, process and analyze environmental information was conducted as part of project conceptualization and preparation. In the assessment, it was found that most of these agencies independently have adopted technologies from different donors, with the result that formats are not compatible and the exchange of data is almost impossible. The assessment therefore recommended that an environmental information management system be established as a main component of the project to ensure that information be made available in compatible formats. It was further recommended that EPC coordinate this effort.

Based on needs and financial considerations, priorities were set for establishing or improving the databases and systems for processing and analyzing data. The most pressing information needs were in topography, land ownership, land use and soil degradation. More-detailed assessments have since been made of the current status in these areas.

EPC was asked to begin standardizing data formats to make them compatible and comparable, even though data and system exchange facilities are now available in the market. EPC will also take a leading role in ensuring the consistency and coherence of all environmental information collection and management efforts in the country. Finally, EPC will develop general capabilities for managing the information related to its activities and for receiving the information generated by other agencies.

provide on-the-job training for staff. The pilot is also useful for identifying, debugging, and solving any remaining technical and procedural problems.

A major step in this phase is the *development of the database* through conversion of existing data. Basic information may be gathered from old surveys, maps, plans, statistical tables, textual reports, and other analogue and digital databases. *Quality control* procedures must be in place to ensure a sufficient degree of data reliability, precision and accuracy. Development of applications and the conversion to automated operations may also take place during this phase.

### *Review and audit*

The final phase in GIS implementation includes system review and consideration of future system expansion. The review should examine both *management* and technical aspects of the system. An independent reviewer might consider, as appropriate, the original statement of objectives, policies, procedures, and operational plans and recommend adjustments where needed. *System expansion and update* can be considered as the GIS matures and becomes an integral part of an organization's regular work program. New technologies can also spur consideration for expansion or upgrading of the system. In addition, the review will consider the system *operation and maintenance*.

## Institutional challenges

Most of the time, different departments and agencies are responsible for different types of environmental and resource information. There frequently is a reluctance to share this information among agencies, as it is often seen as "power." Even within the same agency, there are often difficulties in collaborating in data collection and management activities.

In some cases, the establishment of a technical steering committee, composed of senior representatives from the various agencies involved in information collection, management and analysis, may be an effective way to ensure free and easy access to information. In this way, the interests of all agencies may be expressed, giving each agency a stronger sense of ownership and involvement in the program. This can also help to ensure consistency and comparability in the various data collection and information-handling efforts.

In addition to developing administrative and technical capabilities for environmental and resource information programs, it is necessary to review the supporting legal framework. Official topographic and geographical survey data are often the responsibility of a national surveying and mapping department; the military and defense departments often control aerial photography work. Sensitivity issues need to be clearly understood. It is critical to ensure the availability of proper legislative authority for environmental and resource information management activities.

The level of technology needed for environmental information management typically is not found in most developing countries. To ensure success when introducing or transferring such technologies into resource management or environmental planning agencies, several issues should therefore be addressed:

- The whole process needs to be demand-driven, noting that initial prefinancing will be necessary.
- Long-term financial sustainability needs to be ensured through building mechanisms for cost recovery into the operation of the GIS.
- A well-planned and well-executed training program is needed; twinning arrangements or partnerships with agencies from developed countries may be essential.
- Adequate post-installation service and maintenance and good quantities of supplies need to be provided.
- Strong leadership and the desire for coordination between agencies and donors need to be achieved.

## For further reading


Antnucci, J., K. Brown, P.L. Croswell, M.J. Kevany, and H. Archer. 1991. *Geographic Information Systems: A Guide to the Technology*. Von Nostrand Reinhold. New York.

Cummings, R.W., Jr. 1977. *Minimum Information System for Agricultural Development in Low-Income Countries*. Report 14. Agricultural Development Council Inc. New York.

Hassan, H.M., and C. Hutchinson. 1992. *Natural Resource and Environmental Information for Decisionmaking.* The World Bank. Washington, D.C.

Heit, M., and A. Shortreid, ed. 1991. *GIS Application in Natural Resources.* GIS World Inc. Fort Collins, Colorado.

Paulsson, B. 1994. *Urban Application of Satellite Remote Sensing and GIS Analysis.* World Bank, Urban Management Program. Washington, D.C.

Peuquet, D.J., and D.F. Marble. 1990. *Introductory Readings in GIS*. Taylor & Francis. New York.



This *Update* was prepared by Hassan M. Hassan. The *EA Sourcebook Updates* provide up-to-date guidance for conducting EAs of proposed projects and should be used as a supplement to the *Environmental Assessment Sourcebook.* The Bank is thankful to the Government of Norway for financing the production of the *EA Sourcebook Updates.* Please address comments and inquiries to Olav Kjørven and Aidan Davy, Managing Editors, EA Sourcebook Update, ENVLW, The World Bank, 1818 H St. NW, Washington, D.C., 20433, Room No. S-5139, (202) 473-1297. E-mail: eaupdates@worldbank.org.