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REVIEW OF THE LATEST TECHNOLOGY IN CARTOGRAPHIC DATA ACQUISITION, MANIPULATION, STORAGE AND PRESENTATION, WITH SPECIAL EMPHASIS ON POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES: AUTOMATED MAPPING PROJECTS: DEVELOPMENT AND APPLICATION OF DIGITAL CARTOGRAPHIC DATABASES, INCLUDING DIGITAL TERRAIN MODELLING

A geographic data framework for economic development

Paper submitted by the International Cartographic Association**

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Abstract

For long-term economic well-being, it is important to make rational use of the best technologies available for resource management. Although these technologies will not be sufficient in themselves to ensure long-term sustainable prosperity, they can help reduce natural resource degradation and minimize its impact. This can "buy time" while national and international governing bodies take the appropriate steps to bring about behavioral changes that will result in stewardship rather than exploitation of natural resources. The human impact on the environment manifests itself at global to local scales. Population growth and legitimate attempts to improve standards of living are the major factors contributing to increased demands on the environment. Resultant environmental degradation can reduce the potential and real standards of living for all humankind. Short-term improvements in living standards, which can take place in years or decades, can exacerbate already existing problems, such as climate change, pollution, loss of soil fertility, and decreases in biodiversity.

Shortsightedness borrows resources from future generations to support current well-being. In many cases, there will be no way for current generations to repay future generations for using the resources. To understand the appropriate technological approaches and behavioral adaptations needed in our use of land resources, we must improve our knowledge of the resource systems. To do this, a basic set of data, analysis tools, and information must be available. The data are spatial and must represent physical, biological, and socioeconomic sectors of the environment. The tools, becoming increasingly sophisticated as computers become

faster and more powerful, include remote sensing, manned and unmanned field monitoring, geographic information systems, statistical analysis, and conceptual and numerical models. These are all components of modern decision support systems for natural resources. The information, a result of careful analysis of the data, is continually being improved as the scientific approach of questioning and testing the results is implemented. Adaptive management, a key to sustainabilty and improving living standards, depends on such an approach. The use of geographic information science can help developing nations exercise their legitimate right to improve the standard of living for their people while helping preserve natural resources for future generations.

Introduction

Garrett Hardin (1968) discussed three main topics in his paper, *Tragedy of the Commons*: (1) two variables cannot be maximized at the same time, therefore "the maximum good for the maximum number" is a nonsense statement, (2) there are some problems for which technological solutions are not sufficient and behavioral changes are required, and (3) common resources, when their use is not appropriately controlled, can be exploited to the advantage of individuals until they are overexploited and can no longer support the community or even those individuals.

An example of our inability to maximize two variables simultaneously is attempting to both increase population and increase standard of living in the same resource, technology, and behavior regime. If the population is held constant, the standard of living is increased until the capabilities and capacity of the regime are met. If the population increases, the demands on the regime may be such that the standard of living actually decreases.

Hardin's points are well illustrated by a community that holds land in common and allows grazing without restriction. Each member of the community attempts to increase his herd and so increase his wealth. This works well to a point, with the individuals and the community increasing in prosperity. Once the threshold is met, in this case the carrying capacity of the land, additional grazing animals diminish the resource until the carrying capacity of the land is decreased. At that point, the standard of living of the community and most, if not all, individuals in it begins to drop. That is the tragedy of the commons that Hardin discussed. The tragedy can be

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forestalled by technological means, such as changing the feed grown on the land. However, that is only temporary. For a permanent solution, a behavioral change is necessary; that is, to recognize the limits of the resource and manage its use.

In situations where natural resources are being used, a sound information base is necessary to insure that human impacts are minimized or that the benefits are maximized. Although the information is necessary, it is not sufficient. A system approach has proven to be critical to determine what information is necessary for decision making (Scientific Assessment and Strategy Team (SAST), 1994; Kelmelis, 1995). For example, in response to the floods of 1993 in the Upper Mississippi River Basin of the United States, a simple input-output model was used to describe the system (see fig. 1). It addressed natural and human inputs to the river basin, how those inputs affected both the uplands and floodplains, how the uplands affected the floodplains, and how the changes to the uplands and floodplains affected the natural and cultural systems in which they reside. This conceptual model allowed for external inputs (the weather, grain prices, and national flood and crop insurance policies, for example), internal events (upland and floodplain floods, for example), systemic conditions and changes (river channelization, addition and removal of levees, land cover change, for example) and feedbacks (changes in demographics, land use patterns, and habitat variability, for example). Taking this system approach ensured that the data were gathered and analyses were conducted in such a way that the major policy and management issues were addressed (SAST, 1994; Interagency Floodplain Management Review Committee (IFMRC), 1994; Kelmelis, 1995).

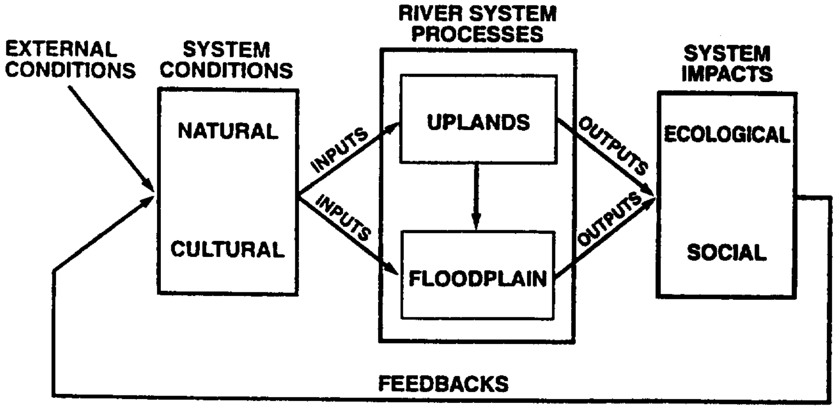

Figure 1. A simple system diagram showing the relationship of river basin system components when considering flood dynamics (from SAST, 1994).

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This paper identifies (1) major issues in development, (2) major natural systems about which development decisions must be made, and (3) the basic spatial data needs and potential sources. Three examples of analyses and the data that were used for decision making are discussed; they are water retention practices in upland areas, natural habitat conservation in floodplain areas, and the impact and location of river training structures on a floodplain.

Major Development Issues

In both developed and developing countries, the principal development concern is to improve the health and well-being of the population; that is, raise its standard of living. Each nation uses a different strategy based on many factors to achieve this goal: its physical, biologic, economic, and human resources, its cultural biases, its state of development, its institutional and political framework, and its relationships with other nations. As a general rule, using basic economic sectors helps define the issues of concern. These sectors include agriculture, forestry, mineral resources, transportation, industry, commerce, tourism, communications, and information.

Examples of the physical resources include minerals, water, soils, climate, terrain, hydraulic potential, navigability, and geographic location and proximity. Examples of biologic resources include fish, animal, and bird stocks, timber stands, grazing lands, biodiversity, and so on. Human resources include the number, distribution, age profile, education, and physical condition of the population.

Development requires tradeoffs. They can include exchanging current resources and productivity for current benefits. If a long-term view is taken, development can also include the exchange of future resources and productivity for current or future benefits. Thus, any development that is undertaken has opportunity costs. An important issue of concern is that the current benefits may exhaust future opportunities; that is, current generations develop at the expense of future generations. In addition, there are spatial and socioeconomic tradeoffs. One region can develop to the detriment of others, and one segment of the population can develop at the expense of others.

Incorporating spatial scientific and socioeconomic data into the decision making process does not address all the issues, but it is relevant to most of the decisions on industry and natural resources. Although there are obvious economic benefits to

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industrial and natural resource development, there can be long- and short-term economic and environmental costs as well. Some examples of these are described below:

- Expansion of agricultural lands. Intrusion of agricultural lands into forested areas raises concerns of soil erosion, loss of carbon dioxide sequestration potential, fragmentation of ecosystems, loss of biodiversity, and loss of future timber harvests. Establishing agricultural activities in wetlands and on floodplains can eliminate the natural function of the wetlands to (1) store water and reduce peaks of floods, (2) provide natural filters that clean water, and (3) provide habitat for wild species that may be critical components of the environmental web.

- Extraction of minerals. Mineral extraction can cause erosion, affect surface and ground water quality, mobilize toxic minerals, and alter land surface characteristics. As a result, resources must be expended in the future to stabilize the land surface disturbed by mining, to improve the quality of the water that may be affected by disruption of ground and surface water sources, and to establish more intensive medical treatment for people with illnesses related to toxic substances that may have been mobilized during mining.

- Development of hydroelectric power. Hydroelectric dams alter flood regimes resulting in loss of habitat for aquatic species, and they alter sediment flow patterns, resulting both in loss of habitat and reduction in sediment available to maintain deltas and also in obstruction of pathways for migration of fish upriver and downriver and the flow of debris downriver.

- Establishment of controlled river transportation routes. This includes the channelization of rivers, establishment of extensive floodplains, and incorporation of river training structures, such as wing dikes, levees, locks, and dams. These controlled routes alter the flow characteristics of the river, which in turn can reduce or increase available habitat, depending on the particular implementation, and can encourage human occupancy and development in the path of floods.

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Although this list of development activities is far from exhaustive, it illustrates the potential impacts of development activities if they do not incorporate a long-term spatial view in their planning. To support planning and design of development projects that meet current needs while maintaining adequate resources to meet future needs, decision makers must understand the natural and socioeconomic systems involved. They must also have access to data with which to conduct analyses of potential alternatives and their likely impacts.

Major Natural Systems

Natural systems can be defined physically or biologically. The method of definition is principally a function of the variable of interest and spatial distribution. For instance, a river basin system is defined by the river and the area that contributes water to its flow, the drainage area; a boreal forest system is defined by the aerial extent of specific species of trees. In reality, however, both physically and biologically defined systems are physically driven. The river basin's spatial extent is defined by topography and the extent of the rivers within the system. The boreal forest exists in a particular place with its particular boundaries created by climatic factors, soils, cultural history, and so on, which, if changed sufficiently, would cause the demise of the species that compose a boreal forest. The place would then support another type of ecosystem, more or less desirable than the previous one (Kelmelis, 1996).

Systems vary in size and scale, can overlap, intersect, or abut, and can influence or be influenced by processes that operate at different spatial and temporal scales. A geographically based strategy for Earth system analysis is effective for resource planning in a global change environment. The global strategy described in Kelmelis and Ragone (1992) is modified here to address development issues from regional to local scales: (1) identifying management, policy, and stewardship concerns relevant to environmental change and the information needed to intelligently analyze them, (2) identifying regions on the basis of aggregates of topically relevant variables, (3) identifying the scientific research that must be conducted to understand how the system is affected by internal and external changes, (4) identifying the feedbacks and forcing functions from the system to the external system, (5) developing a management strategy to ensure that the research is effectively coordinated to gain the maximum result for the least cost, and (6) managing the data and information so that they reach management and policy decision makers in a timely manner and a usable form.

A geographic focus is used to implement a strategy to consider the high variability of the terrestrial environment over different spatial and temporal scales. The variability is due to quantitative and qualitative differences of such factors as climate, terrain, land use and cover, cultural attitudes, political boundaries, and others, at specific geographic locations. Each set of variables can be aggregated to define regions. For instance, topographic features define physiographic regions (Fenneman, 1946). Aggregates of ecosystems define ecoregions (Baily, 1983, 1995; Omernik, 1987), and aggregates of vegetal types identify biomes (Udvardy, 1982). Climates can be defined regionally (Thornthwaithe, 1933; Trewartha, et al., 1967). Hydrologic units are catchments of various sizes where it is relatively easy, for the most part, to account for the mass and energy balance (Seaber and others, 1987). Human communities define political, economic, and land use regions. All of these regions operate as systems at some scale and contain subsystems that are significant at other scales. Development planning must consider the relevant systems to reduce the likelihood of unhappy surprises at some future time.

Not surprisingly, when analyzing Earth systems, basic sets of data are important regardless of the system and other sets of data are critical to analyzing specific issues within the system.

Spatial Data Needs

Although modeling the Earth system to address particular issues could require enormous amounts of data, there are a several initial core data sets that should be acquired because they are useful in many types of analyses. These may be augmented by improved and special data sets as time and resources allow or as required to answer specific research and policy questions. The International Symposium on Core Data Needs (ISCDN) for Environmental Assessment and Sustainable Development Strategies (Estes, Lawless, and Mooneyhan, 1994) identified 10 high-priority data sets that are central to many types of analyses necessary to produce sound development strategies. They are climatology, topography, soils, hydrology, land use and land cover, demographics, economy, infrastructure, air quality, and water quality. In

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addition, data sets for specific resources and conditions are important. For instance, geologic information, such as mineral resources and surficial geology, and spatially referenced biological data are critical for many decisions. In many places these data do not exist or are not adequate. Although acquiring some of these data sets is becoming easier by remote sensing or remote monitoring networks as technological capabilities advance, direct field observations are necessary to (1) validate the interpretations of the remotely sensed data, (2) acquire data that cannot be sensed remotely, and (3) improve the quality of many data sets. Establishing acceptable standards and specifications is also necessary to ensure that any data acquired are suitable for the intended application. Data standards should be designed to ensure compatibility among the data categories. Consideration should also be given to ensure that the data have other broad applications as well, thus decreasing the long-term data costs.

Case Studies

During the late spring, summer, and early fall of 1993, devastating floods occurred in a large part of the Upper Mississippi River Basin (UMRB) in the United States. This flooding was the result of a persistent atmospheric pattern of excessive rainfall that occurred over much of the UMRB, which was already saturated from precipitation that began in mid-1992 after years of drought. A stable upper-level atmospheric pattern with a deep trough to the west of the upper Mississippi River valley and a strong ridge along the East coast of the United States sustained the excessive rainfall events through July. Then the trough shifted eastward, bringing drier conditions to the UMRB; however, localized flooding continued through October (IFMRC, 1994). The 1993 flooding in the UMRB was a devastating event resulting in the loss of 38 lives and between 10 and 18 billion dollars in damages.

The flood raised many questions, including these: How could a flood of this magnitude have happened? Did our policies contribute to the devastation? Will such an event recur? How can we reduce the risk to society in the future? If this is a natural event, are the natural parts of the system that are being hindered by our attempts to control it?

The Federal Government, recognizing the high cost of this flood and of possible subsequent floods, established the interdisciplinary, interagency Scientific Assessment

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and Strategy Team (SAST) to help answer the above questions, to provide scientific advice and assistance to Federal officials responsible for making decisions about flood recovery in the UMRB, and to support the decision making process with information regarding both nonstructural and structural approaches to river basin management. The SAST was made up of senior scientists and engineers from throughout government and represented disciplines such as hydrology, hydraulic engineering, civil engineering, geology, geomorphology, geography, cartography, biology, ecology, economics, disaster management, soil science, and agricultural engineering. The team was assisted by other scientists throughout Federal, State, and local governments, private industry, not-for-profit organizations, and universities. It may be necessary to obtain support for this type of activity from donor nations or organizations.

Taking an interdisciplinary approach, the SAST evaluated the river basin system and its components. Using a geographic information system (GIS), the SAST built a 240-gigabyte digital data base. Using GIS, computerized mathematical models, and in-depth environmental system evaluation, the team conducted preliminary analysis and provided information and recommendations to policy makers and program managers. Data and information were gathered from numerous sources, including existing digital data, digitized maps, statistical tables, textual information, remote sensing analysis, interpretation of aerial photography, field observation and analysis, numerical modeling results, time series analysis, global positioning system, meteorological and stream gage networks, and others. The result is not only a data base useful for river basin management but also the beginnings of an integrated river basin management system that incorporates the needs of society and the natural environment.

A few of the studies are described here to indicate the types of analyses that can be conducted using spatial data for restoration and river basin management purposes.

Upland Land Treatment Flooding and erosion are problems that originate in the uplands before being concentrated in floodplains. Analysis of structural and nonstructural techniques to control them throughout the river basin is important. Studies conducted in sample watersheds in the UMRB have shown that the effectiveness of different land treatments varies depending on physiography (SAST 1994; Nicolini et al., 1997; Jorgeson and Johnson, 1997; Miller et al., 1997; Cooper, 1997). The watersheds used for land practice and land use studies were

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selected to represent three distinct areas of the UMRB on the basis of the U.S. Department of Agriculture Major Land Resource Areas (MLRA). These were Boone River, West Fork Cedar River, and Whitebreast Creek. A fourth watershed, Redwood River, was used for a more detailed evaluation of the effect of wetlands on flooding. All watersheds were selected, in part, because of available data. The following alternatives were analyzed for the first three watersheds were:

1. maximizing wetland storage in upland and (or) floodplain areas as applicable,
2. converting cropland to Conservation Reserve Program[1] (CRP) as available,
3. maximizing infiltration by using all applicable land treatments, such as conservation tillage, terraces, and permanent cover,
4. installing flood prevention structures as applicable, such as small water detention structures designed to temporarily store water and release it slowly,
5. combining all nonstructural practices (a combination of 1, 2, and 3), and
6. combining all possible alternatives (a combination of 1, 2, 3, and 4).

The fourth watershed was specifically selected to determine the effect of wetlands; therefore, no CRP or maximum infiltration methods were analyzed.

The analysis proved that physiography is important in determining the effectiveness of various land management practices. No one technique was uniformly effective among the different physiographic regions. Applying different land management techniques in different geographic locations could improve water retention and infiltration, alter flood stage and flow, and, as a result, control erosion and deposition of topsoil. This is important to the long-term productivity of agricultural lands, maintaining the appropriate flood flow regime, managing the risk of flooding, and managing the erosion and sediment regime to maintain a dynamic geomorphology on floodplains and ensure the viability of delta regions.

Although several hydrologic and hydraulic models can be used to conduct this type of analysis, they depend on a standard set of information that is contained in

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The Conservation Reserve Program (CRP) was introduced in 1985 to provide payments to farm operators who agreed to temporarily protect highly erodible lands. As of 1995, 36.4 million acres enrolled in the CRP were scheduled to begin coming out of the program (IFMRC, 1994).

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selected cartographic data sets described above. The data sets are climatology and meteorology, topography, soils, hydrology, land use and land cover, and infrastructure. Pseudo data (hypothetical data that are developed for and by models to test various scenarios) are also used to test potential changes to the real world conditions described in the cartographic data sets.

Floodplain Levee Placement Levees, dikes, wing dikes, maintained channels, dams, and locks are river structures that alter the flow characteristics of a river. As a class, they are designed to allow specific activities to take place in an area that is not capable of sustaining them in the natural state. For instance, maintained channels are designed to allow navigation of a river by vessels of a larger size than would be possible under natural conditions, dams can be used to control flow on a river by attenuating peak and low flows, locks allow navigation up a river whose gradient is too steep for navigation in its natural state, and levees allow use of floodplain lands for dry land activities even when the river is at a certain flood stage. All of these structures can be effective within design limits and can provide significant economic benefits if planned, designed, and used wisely. However, if the population using the resource does not understand the limits, catastrophic results can ensue. Long-term maintenance costs can also be significant and can exceed benefits.

Analysis of levee breaches along the lower Missouri River indicates clearly that the physical environment plays an important role in the location of breaches. Examining the history of levee damage for the levee districts revealed many repeat breaches. One levee district, Lisbon Bottoms, has been breached or overtopped on the average of once every 3.9 years since 1943. Thus, approximately every four years the people and property protected by that levee were adversely affected by flooding. Further analysis of levee breaches showed that most occurred where the current channel crossed historic river channels, in high-energy reaches, and near tributaries and chutes. The following factors contributed to the levee breaks:

1. highly permeable substrata composed of channel sand, with or without a thin silt-clay cap;
2. channel banks subject to high-energy flow conditions at
   a. downstream banks of meanders between points of initiation and inflection and

    b. channel banks opposite deflecting cross flows on a tributary, chute, or flood channel;
3. levee irregularities and (or) discontinuities at
    a. high-angle junctions between levee segments and
    b. repaired levees that ring old levee scour holes;
4. inadequate levee design, construction, and repair; and
5. inadequate levee maintenance.

Geomorphic mapping showed that catastrophic levee failure most frequently occurred at the following places:

1. areas of high-amplitude and short-wavelength meanders (loop bottoms),
2. long-bottom areas where remnants of historic channels intersect the upstream end and extend along much of the length of the long bottom, and
3. areas with significant floodplain constrictions (artificial structures, such as bridges, powerplants, and so on).

This analysis indicated that a decision model for rational placement of levees could be designed to minimize risk of (1) people and property being placed in harm's way, (2) frequent levee breaches and costly levee repairs, (3) catastrophic failure causing destruction of critical infrastructure, and (4) a downstream hazard caused by mobilization of hazardous material stored behind levees.

Although historic data are not available for all places, much information for making decisions can be gained from recent data, including topography (to support hydraulic models and geomorphic analysis, and identify current high energy zones); surficial geology (to identify soil and surficial material types that indicate the location of historic channels, engineering properties of surface materials and their suitability for use as levees or the area on which to construct levees, and identification of previous high-energy zones); land use and land cover (to identify the types of biological and infrastructure resources that are at risk and may need special protection); infrastructure (to identify constrictions on the floodplain and critical cultural resources that may be at risk); hydrology (to provide an understanding of potential flood flow characteristics); climatology and meteorology (to provide an understanding of the potential frequency of extreme events that may cause flooding); and economics (to evaluate the existing and potential value of the lands being placed under protection, as well as the opportunity costs of altering the flood flow characteristics). Combining the appropriate data from these data sets will identify the active floodway; that is, the area of highest risk on the floodplain. Avoiding that area can help reduce risk to people and property and help prevent frequent costly repairs. The active floodplain is critical to ensuring the existence of viable aquatic habitat.

Aquatic Habitat Maintenance Many benefits accrue to societies that maintain viable aquatic habitats on their rivers and streams. These include subsistence and commercial fishing industries, higher quality water, improved aquaculture, aquatic ecosystems as a support for other wildlife groups, and attractive resources for tourism.

Important aquatic habitat restoration objectives were outlined by the National Research Council (1992). Briefly, they consist of (1) restoring the natural sediment and water regime, (2) ensuring that the natural channel geometry is maintained, (3) ensuring that the natural riparian plant community is a functioning part of the channel geometry and floodplain/riparian hydrology, and (4) restoring the native plant and animal community if it does not restore itself. Those objectives are also guidelines for ecosystem maintenance because they represent a dynamic equilibrium of the floodplain ecosystem and the geomorphology on which it is based.

Protecting the active floodway from manmade obstructions is an excellent way to ensure the dynamic equilibrium; however, at times such obstructions are necessary for economic development, Also, there may be river reaches whose floodplain cannot be fully maintained. In those instances, selecting high-priority sites for restoration or maintenance may be an acceptable approach to ensuring a sustainable level of aquatic habitat. The SAST members and scientists who worked with them prepared a data base of high-priority aquatic restoration sites on the middle and lower Missouri River. SAIC (1994) reported the criteria used by SAST to develop that data base. Further examination of those criteria indicate that they fell into four categories: physical, biologic, biophysical, and economic.

Physical criteria

1. Proximity to river. This is determined by topographic and hydrologic information. Is the parcel of land located sufficiently near the river to provide accessible and protected habitat and spawning areas during critical times in the life cycle of target

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species, yet sufficiently close to other critical parts of the ecosystem?

2. Structural diversity (for example, sand bars, islands, and cliff faces). This information is found by analyzing the topographic, geologic, and hydrologic data bases.
3. Structural uniqueness (for example, oxbows, sloughs, and side channels). This information is determined by analyzing topographic, geologic, and hydrologic data bases.
4. Connectivity or "linkability" (that is, can the parcel be linked with others to form a more ecologically functional pattern?). This information is obtained by evaluating the map of the parcel of interest in conjunction with other parcels of interest or others that have already been acquired. This is derivative information from other data bases and the current analysis.

Biological criteria

5. Number of species present. The biologic data bases provide this information. Spatial and temporal characteristics of the life cycle, species and community productivity, and vulnerability of the population, are important as well as species type and counts.

Biophysical criteria

6. Parcel size. The parcel should be large enough to meet the habitat maintenance or restoration criteria. The target parcel is identified and outlined on the basis of the other criteria. Ideally the parcel is owned by one individual or organization for ease of acquisition; however, more often several pieces of land owned by a number of individuals or groups must be acquired to make a parcel of sufficient size.
7. Rarity of habitat. This information can be derived from the biologic and land cover data bases.
8. Presence of critical habitat. The biologic, topographic, and land cover data bases provide this information. Evaluation of the relationship of species' life cycles with land characteristics and

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available habitat types helps ecologists and biologists identify critical habitat locations.

Economic criteria

9. Willing sellers. The willing sellers are identified in the local economy through indirect or direct inquiry. This is a highly dynamic variable, both temporally and spatially, and must be assessed on a case-by-case basis.
10. Targeted area. (That is, is this parcel already in a plan for acquisition for another reason, and can it be used simultaneously for the habitat maintenance or restoration purpose? Is there a possibility for multiple, nonconflicting land uses?)
11. Threat of development pressures. (That is, do plans for long-term management of the river identify this area for development? If so, the future land use should be adjudicated in advance to prevent conflicts and loss of critical habitat in the future.)

These criteria are based on an analysis of data bases, plans, local interests, and knowledge of the aquatic ecology. Proper decisions early in the planning and development process can ensure the maintenance of aquatic habitat and the attendant environmental and economic benefits it provides.

Information Availability

Providing the results of management and policy relevant research to the decision makers in a timely manner takes a concerted effort. It is important not only to provide the information, to make it available in a form that the decision maker can use. Although printed maps and reports have been the standard for many years, the digital information age has provided opportunities to supply information to managers faster than ever before. These opportunities are greatest in the developed countries where the information infrastructure is more mature. However, developing countries will obtain significant benefits as they acquire greater access to stable power sources, adequate telecommunications capabilities, and more sophisticated hardware and software. Dropping prices for these items combined with an obvious need for

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international interdependence in development can accelerate an improving intrantional and international information infrastructure.

Already there are a number of data bases and clearinghouses serving available data and technology on the Internet through the World Wide Web (WWW) including the following:

- Environmental Information System for the Upper Mississippi and Lower Missouri River Basins (often called the SAST data base) was established by the SAST in response to the floods of 1993 in the UMRB to provide data and information to managers, policy makers, researchers, and others for flood recovery and river basin management. It contains more than 240 gigabytes of data; some can be served online and some must be served offline because of size. The clearinghouse links Federal agencies, States, nongovernment organizations (NGO's), and similar clearinghouses in the international community. The WWW address is <http://edcwww2.cr.usgs.gov/sast-home.html>.
- Mojave Desert server is a point of distribution for data that have been assembled to help managers and policy makers make decisions with respect to ecologic recovery and sound environmental management of current and future projects in the Mojave Desert. Its WWW address is <http://mojave.army.mil/>.
- The United Nations Environment Programme (UNEP) maintains a series of nodes throughout the world to improve access to data that nations can use for environmental analysis. The Global Resource Information Data Base (GRID) for North America is maintained by the U. S. Geological Survey at the Earth Resources Observation System (EROS) Data Center (EDC) and can be accessed on the WWW at <http://grid2.cr.usgs.gov/>.
- The Inter-American Geospatial Data Network (IGDN) is supported by the U.S. Agency for International Development to encourage environmentally sound, broad-based economic growth and free trade in the Western Hemisphere through improved access to geospatial data for business, NGO's, and governments in the region. The project promotes implementing Internet capabilities internationally and has international cooperators in both the public and private sectors. Its WWW address is <http://edcintl.cr.usgs.gov/igdn/igdn.html>.

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- The Africa Data Dissemination Service (ADDS) has been established to improve access to and use of geographic data and data communication on the African continent by linking continental, regional, and national data sets served by various organizations through a distributed clearinghouse. The home page and links to participating file servers can be accessed at <http://edcintl.cr.usgs.gov/adds/>.
- The Famine Early Warning System (FEWS) is a multi disciplinary project that provides subnational information to decision makers about potential famine situations in Africa. It can be reached at WWW address: <http://edcintl.cr.usgs.gov/adds/general/project.html>.
- The National Biological Information Infrastructure (NBII) is designed to increase access to and application of biological data and information from a distributed network of numerous domestic and international sources. It can be reached on the WWW at <http://www.nbs.gov/nbii/>.

Examples of how available data have been used to make management decisions include following: data from the SAST data base have been used for many purposes, including locating habitat restoration sites that have been purchased as part of the Big Muddy Wildlife Refuge and identifying sites containing toxic materials that were inundated by the flood of 1993, thus identifying which toxic substances might have been mobilized by the flood waters.

Making the data and information available is not sufficient. A practical approach to facilitating data use by decision makers includes providing data and analysis results in various formats so they can be understood and used by many clients. Some formats are fact sheets (one- or two-page documents that describe a technical analysis and results in non-technical terms), management reports, scientific reports, maps, data bases, demonstrations, and presentations. Some of these may be provided in hard copy or on a digital information network like the Internet. These products must be presented in such a way that decision makers can understand them. Timing is also important. For instance, there is heightened awareness of the natural hazard for a short time after a natural disaster. Usually decision makers and the general public are more receptive to using scientific information to help reduce current and future losses at that time.

Conclusion

Managing the environment as a system rather than as a series of independent projects is more effective in the long run. Experience has shown that the long-term maintenance of ecosystems provides important economic benefits and that the degradation of ecosystems has ongoing costs. Developing multi scale, spatially referenced data bases of critical variables that can be used to help make resource management and development decisions is a wise investment in the future. Certain identifiable variables should be part of the base data available to researchers, planners, policy makers, and managers. If those data are readily available to a wide segment of the population, it is likely that more in-depth and creative analysis will take place.

Data from the data bases are being used by decision makers within the United States for land use and resource planning, recovering from disasters, and biophysical analysis. For example, more than 750,000 digital data files were transferred from the Environmental Information System for the Upper Mississippi and Lower Missouri River Basins between June 1995 and January 1997. During that 18-month period, many of the data were used for research but many were also used to make decisions on the management of the river basin.

There are several things that can be done to make the data and information more valuable:

(1) Improve the data and information infrastructure and make it more accessible to the general population, as well as to the managers and policy makers. This is particularly important in the developing nations, where sound decisions in the early stages of development can prevent costly corrective actions in the future.

(2) Make the infrastructure compatible with inexpensive, readily available equipment.

(3) Improve the availability, ease of use, and understandability of the tools used to apply the data.

(4) Present the analytical results in such a way that they are easy to understand and apply.

(5) Ensure the data and information upon which the analysis must be based exist and are readily accessible.

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