SPATIAL DATA HANDLING SYSTEMS FOR NATURAL RESOURCES

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I. Introduction

This paper presents several ideas for the application of automated geographic information systems (GIS's) to the resource, planning, management and public information needs of the National Park Service (NPS). It is our view that, because of the great diversity of functions performed by the Service and because of the variety of problems it faces, there is no single system which can meet all its needs. Therefore we shall discuss several "levels" of system that should be examined carefully.

II. Automated Geographic Information Systems

The common connection among the various possible GIS systems usable by NPS is that the information contained in each of them is referenced geographically (i.e., containing data which describes spatial variation or is associated with some event, or enumeration tied to geography). In a GIS the basic data are acquired, automated, filed, retrieved, analyzed and displayed with reference to their spatial or geographical location. Geo-referencing techniques such as x, y coordination or grid is used to technically accomplish the abstraction of data to location. Often the source data and the final displays of processed data are in the form of maps.

The employment of the GIS involves a series of rather special tasks. These are necessary to properly create, use and maintain GIS's. They include, in a typical GIS "system cycle": analysis of user needs or decision analysis; data base design; system design; data acquisition; data reformatting; data automation; and creation of automated outputs. These outputs include creation of atlases of basic data variables; data analyses and modeling (i.e., capability/suitability analysis, site selection studies, route selection, environmental impact modeling, etc.); display of the resulting information (often as maps); statistical analysis; and report creation. For certain systems there is also the ongoing work of system maintenance and updating. This paper is too short to permit discussion of each of these work tasks in any detail, but we shall mention some which are of special importance to particular NPS problems.

III. The National Park Service as a Potential User of Automated Geographic Information Systems

There are potentially enormous benefits possible to NPS in the application of GIS's to its day-to-day operations, planning and management decision making at levels from the individual park* through the region to the national level. GIS's can also help the NPS provide appropriate information about parks and the NPS to the public, to the congress and to various government agencies at all levels.

We base this belief on several points. First, there

* In the paper we shall generally refer to the "park" as the basic land unit under the jurisdiction of the Service; it should be understood that "park" here refers to any of the various kinds of NPS System units: National Parks, National Recreation Areas, National Monuments, etc. Similarly, we shall refer to the park as the basic "local" level unit within the NPS system; in some cases this local level should be a part of a park, in other cases it should include one or more parks and portions of their surroundings, or even the entire region in which one or more parks are found. Nevertheless, for simplicity, we shall refer to the park, asking that these related levels of complexity also be kept in mind.

are now a large number of federal agencies which are using GIS's in support of their functions. They include the Geological Survey, the Fish and Wildlife Service, the Soil Conservation Service, the Bureau of Land Management, the Forest Service, and the Census Bureau, to name only a few. Many states and local governments throughout the United States are also creating their own GIS's as are various private businesses -- utilities, land holding companies, and forestry products firms, among others. These users have many similar information needs as NPS indicating that GIS's can play an important part in an organization like the NPS.

The second point we want to make is that agencies are increasingly committed to the use of automated GIS's for their own work and also in support of cooperative efforts with other agencies. Often geographic information is chiefly shared between agencies in an automated form. This means that for those functions in which the NPS must work with other federal, state and local agencies, the GIS may be the medium of exchange.

Finally, we believe there are a whole range of problems to which the NPS can apply the technology of the GIS. At this point it is important to point out that GIS technology goes far beyond the capability to efficiently store, summarize, and retrieve geographic data. It can provide a context or framework for communication of general planning and management information.

IV. National Park Service Information Processes to which Automated Geographic Information Systems can be Applied

In this paper we suggest four kinds of processes within NPS where we see GIS's technology would be useful. They are park resource assessment, planning, management, and public communication.

Each of these information needs should be addressed by the NPS at the local or park level, at the regional and at the national level; GIS's can be of use at all these levels. (see Figure 1) Ideally the information system developed for each of the boxes of Figure 1 would be functionally independent yet capable of using and supplying information of the other systems. For example,

Figure 1

	COUNTRY	REGION	PARK
PUBLIC COMMUNICATION			
MANAGEMENT			
PLANNING			
RESOURCE ANALYSIS			

resource information collected as part of the operational function of a park can often provide information to both planning and management functions as well as focused communication to the public. Likewise, the summary and movement of information from the park to the region and on to the national level provides efficient information collection and consistent reporting. The key is providing the linkages enabling this data to be aggregated and to flow. An automated framework can provide these linkages with spatial as well as numerical generalization and statistical summary.

In discussing the four kinds of information problems we shall describe the functions that the GIS can perform, the steps to create a GIS -- at least in summary form -- and the required resources which are required to support the use of such a GIS.

Before taking these four information problems up, we want to first discuss what we see as important considerations and constraints which should be kept in mind as we talk about the use of automated geographic information systems by NPS.

V. Operating Considerations and Constraints on the Use of Automated Geographic Information Systems by the National Park Service

The National Park Service contains more than 300 parks scattered throughout the United States, ranging in size from less than an acre to millions of acres. For these and other reasons we believe that a single, optimally designed GIS to serve all the needs of the NPS is impracticable. Furthermore whatever system(s) are ulti-

mately evolved they must maintain some diversity of structure and function to permit tailoring to particular mission requirements.

We believe that the kinds of geographic data variables to be included in the GIS's cannot and should not be specified in advance of the analysis of the needs of the system's users. There is, for example, such diversity in the size, natural features, function, staffing, etc. of the various parks that the resource information about each one might well differ from all others or most others. We believe tailoring of the data bases will be appropriate in many cases.

We believe the designs of the various GIS's used by the NPS should include provision for considerable flexibility. The NPS has diverse and often conflicting interests, and it faces almost yearly changes in budget, staffing and organization. Such a changing pattern of organization and function seems to us to require that any GIS's created for NPS use must be made flexible. We think it will be unwise to make long term plans for GIS use within the NPS; rather than five or ten year plan for development, we recommend two to three year plans, with frequent review of the results in each case. This pattern should help maintain the flexibility we feel the NPS needs.

The use of the automated GIS not only permits more rapid and inexpensive decision making and planning, it also permits decision and planning criteria to be made explicit -- indeed, for the computer to apply decision criteria, the criteria must be explicitly spelled out. The computer applies these criteria uniformly in analyzing the geographic information with which it works. The effect of these characteristics of the GIS is that planning and decision making and even day-to- day operations, are more rational. Moreover, because this is so, it is easier to explain to the public how plans and decisions were made; it is easier to be open about these processes because they are clearer and better defined. This means that public participation--of ever increasing importance in government affairs -- is easier to effect.

While we shall shortly be describing four kinds of GIS's which we think the NPS may find useful, we want to emphasize again that the design of each individual

example of such a system -- such as the resources GIS for a particular park -- should be preceded by careful analysis of the decision making or planning which the GIS is to support or the other needs of the people who will use the GIS. The hardware and software available for use in GIS's is of almost bewildering variety; the output of such a system can be in the form of reports, tables, maps (the maps in line form, grid cell form; in black and white or in color; in two dimensions or three dimensional projection form; etc.). Decisions about each of the aspects of the GIS should be made with its function and objectives in mind -- especially with its users in mind. We shall make more comments on this matter as we take up the four functional classifications of GIS's useful to the NPS.

VI. Four Kinds of Automated Geographic Information Systems of use to the National Park Service

We will discuss the four types of information processes which can use GIS technology successfully within the NPS: Resource Information, Planning Information, Management Information and Public Information. We have pointed out that within each category there is considerable need for flexibility in design; in use, structure and function; and in tailoring a specific system to the needs of its users. What we describe here, are general characteristics and features; the specifics of any particular example of each type of system will be defined during its design.

A. Resources Information

A NPS's Resource GIS would contain basic geographic data on the parks under NPS control. These data will include both natural and cultural features as well as the numerical aerial unit (i.e., administrative, watersheds, etc.) that are maintained on each National Park. The system would perform several functions. Among the most important of these is providing information for use in the Planning, Management and Public Information GIS's.

The Resource GIS's would also supply information of use to the various levels of the NPS in its day-to-day operations. The system could provide displays of basic natural and cultural data variables. Derived variables such as aspect, ecosystem type, watershed, etc., can be

displayed; or basic variables can be combined for mapping, to produce more complete mapping systems.

NPS system-specified data would also be included in the Resource GIS; it might include, for example, data on the condition of campgrounds, location and condition of burned over areas, traffic count and visitor use statistics by road, campground or park, and so on.

Because of automation, this GIS and all the other GIS's can be readily updated, maps can be produced in a wide variety of formats and scales, maps and other outputs will be inexpensive and readily obtained.

GIS Creation

The source of the data for this system include, first of all, existing automated data, already part of the GIS's of other agencies. The designers of a particular Resource GIS will need to carefully search for such data since if it is available its use will speed up the GIS creation process and save considerable resources as well. Among the kinds of automated data which may be available for a particular Resource GIS are digital terrain tapes from the Defense Mapping Agency, LUDA tapes, and a variety of already automated information from particular Census, Bureau of Land Management, Soil Conservation Service, and other projects. State and local governments and private businesses may also be suppliers of automated data.

Mapped data, which will need to be automated can also readily be included in the Resource GIS; such data can include an extemely wide range of natural and cultural variables. Data from aerial photography and other forms of remote sensing can be incorporated into the Resource GIS, after suitable automation procedures. Geophysical data, field survey data, can also be included.

Reformatting of these data would be required in many cases to resolve differences in scale, age, classification systems etc. Often this process is best accomplished if done in connection with the interpretation of recently acquired remotely sensed imagery. (With satellite imagery approaching nominal resolutions of ten meters, with diverse sensors on board, with new imagery acquired of an area about every eighteen days

and with considerable progress being made in both change detection and image interpretation, we think the use of satellite imagery as a data source and to provide a base to which other data can be referred, is an increasingly attractive option for NPS use.)

Automation of data can be accomplished by means of digitizing, which also preserves the original point, line and polygon format of the data. Data can also be acquired by hand coding into grid cells, or can be automatically converted between the two different formats. The automated data are then gathered into carefully designed file structures, each arranged to meet the needs of a particular project and to provide for efficient computer storage and processing.

Information display of these basic Resource data can take many forms; on graphics terminals or in hard copy form; in black and white or in color; one variable or many variables; single copies or the means for making many copies; and so on. Tabulated statistical data, three dimensional views, and a wide variety of other map-related displays are also possible. These displays can be used for research work, for day-to-day monitoring, for operational purposes, and in connection with the use of the other three kinds of NPS GIS's we have mentioned.

Required Resources

ESRI has created a good many systems of this type. Creation usually requires six to eighteen months, the service of a production oriented staff of technical specialists, and a variety of compter hardware and software. Costs vary greatly: from under $10,000 for a simple system covering a small area to several hundred thousand dollars for more elaborate systems covering large areas. These costs only include the actual development of the automated information; they do not include hardware and software costs.

While the NPS might very well create its own technical facilities and staff to perform these services, we think that at least initially the Service would be well advised to make use of commercial firms for doing production work of this kind.

B. Planning GIS's

The NPS Planning GIS's are used for planning and planning-related work at various levels within NPS and for interfacing with planning organizations and efforts outside the NPS.

Functions

The functions of the Planning GIS's vary considerably, depending on the level -- park, regional, national-- at which they are used.

At the park level we envision the Planning GIS's used for: formulation of a comprehensive plan carrying capacity estimation; analysis of fire hazards; selection of routes for trails, roads or alternative methods of transportation, environmental impact analysis of proposed actions; planning for joint development of NPS lands and those adjoining the park; visual quality analysis in connection with design work; studies of ecological succession or recovery of ecosystems in connection with planning for resting or rotating campgrounds; and so on. We want to mention again that in performing these analyses or in doing various modeling exercises, the use of the GIS requires that objectives and analysis criteria be stated clearly and explicitly. This means that the results of these analyses are rational and can be referred directly back to the criteria which produced them.

At the regional park level the unit of analysis and planning is more likely to be an entire park or several parks. This means that filtering will be necessary so that regional planners will not receive excessive or irrelevant information. Some of the kinds of planning done at the park level will also go on at the regional level. In addition this will probably be the level at which coordination with other agencies takes place and interfacing with these agencies will have to be done. There are a number of kinds of planning in which coordination between federal, state and local agencies is mandated by federal law: energy planning, wastewater management planning, recreation planning, highway construction planning and river basin planning, to name a few.

Where this kind of coordination is required--whether at

the regional or the national level -- we think that the NPS may not have to create new GIS's in order to participate. It may be possible to supply existing information created and maintained by other agencies, with NPS information in a suitable form. We expect that in these cases, the agencies would then also supply the NPS with information useful in making plans for the development or maintenance of its parks.

The NPS is constantly involved in planning for the acquisition of new parks and in planning for helping to meet the recreational needs of all Americans. The processes involved in such planning efforts usually involve obtaining a good deal of information about the existing parks and other recreational resources and then comparing these with NPS needs and with the recreational demand. Much of the data involved in these analyses is geographic in nature, and the Planning GIS is a suitable vehicle for working with it. Several states have GIS's which are used for planning to meet recreational needs and for park acquisition planning; the California Parks and Recreation Information System (PARIS) is but one example of such an automated system. Where these exist, the NPS might well cooperate with other agencies in their use. Such systems require rather complete data on existing parks and recreation resources in order to evaluate "supply"; on the "demand" side they consider such information as census data, transportation, estimated travel times from urban areas, and population projections. For reasons of consistency alone, the NPS may wish to cooperate with agencies in gathering and using these data.

So far as we are aware, a completely automated national GIS for recreation planning does not exist. If the decision were made to create one we would certainly favor cooperative efforts in its creation.

We also believe that data displays showing the geographical distribution of NPS staff, park traffic loads, visitor days, incidence of crime, and a host of other variables would be of use to NPS planners at the regional and national levels. Analysis of the impacts of new NPS policies and directives might also be performed using the Planning GIS in some case (e.g., the production of maps showing the number and location of campgrounds affected if a new policy on carrying capacity is implemented nationally). The above list is by

no means exhaustive of the possibilities.

GIS Creation

The source of the data for the various Planning GIS's is, first of all, the various Resource GIS's within the NPS. These GIS's will provide basic resource data which will be manipulated for analysis and planning purposes.

Additional data will come from the various agencies with which the NPS will need to cooperate in its planning efforts.

Some data will come from the NPS's various Management GIS's; in paricular these GIS's will provide information of NPS objectives, resources (money, staff, equipment, etc.), and policies and regulations.

Some data may need to be acquired in addition to these listed above; non-spatial data is likely to be of particular importance for various planning efforts.

Analysis of the data can take many forms. Capability/suitablity analysis is used to determine the best locations for various activities such as creating campgrounds, building roads, locating nature trails, preserving ecologically important communities, and so on. Environmental impact analysis can make use of geographic data by applying a policy or procedure to parks and modeling what the consequences are likely to be. Route selection combines capability/suitability analysis, visual analysis, environmental impact analysis and other kinds of modeling and analysis to select optimal corridors and routes, using automated techniques. These are but a few of the many kinds of planning related analyses possible with GIS's.

Information display can include maps, map related statistics, three dimensional views and other formats. Special display formats which compare different routes by means of graphs and charts, report generation, and a variety of other information displays are also relevant and useful in planning.

Required Resources

At the park level the planning function will usually be

able to be supported by the same system which supports the Resource GIS so that few additional resources will be required. At the regional level we think that cooperative efforts may considerably reduce the NPS resources required to support a Planning GIS; costs might be chiefly for the acquisition of NPS-specific data which would then be transmitted to the shared system. At the national NPS level such sharing may also be possible for some planning purposes -- such as recreational planning; but for other kinds of planning, such as for the acquisition of inholdings in parks, budget planning, and the like, special NPS GIS's would probably have to be created. Their costs would vary considerably, depending on their function and the amount of data they needed to contain to perform adequately.

C. Management GIS's

The NPS Management GIS's would provide managers and decision makers at all levels with a spatially referenced management information system. This would supplement whatever management information systems the NPS now has in place.

Functions

We see the Management GIS's as especially valuable in a management by objectives environment; the GIS will permit managers and decision makers to compare their objectives with actual performance and to see the results of this comparison displayed in readily understood, mapped form. The displays could be produced at any level of refinement, with filtering to reduce the amount of data displayed or without it, and in a variety of formats. Among the kinds of data which might be displayed are: visitor days, visitor days per staff member, facilities conditions, traffic counts, incidence of crime, campground status, ecological condition and so on. Data variables could be combined in various ways also: ecological condition as a function or traffic counts and visitor days; facilities conditions as a function of staffing levels, budget levels, and visitor days, by park; and so on.

With basic resources data on the park system in the Resource GIS's and with the Planning GIS's containing information on possible alternative decisions, the possible ways of using the Management GIS's would be

limited only by the imagination of the managers and decision makers.

We particularly want to point out the value of such a GIS in an environment where there are multiple objectives, some of which are in conflict. We believe this is the situation in the NPS at present. The Management GIS's will allow various decision criteria to be programmed into models and analyses, producing displays showing the effects of these decision criteria at any selected level of detail. Where conflicts arise (as between conservation and providing recreation) it will be easy to explore alternative approaches since changing the decision criteria, relaxing constraints, altering the policies modeled, are all easily done; feedback about the results of each such alteration can be provided rapidly -- often in a matter of minutes.

We want to mention again that the GIS approach tends to force the use of rational methods: decision criteria must be explicit and often quantitative; decision makers know the criteria will be applied uniformly and fairly so they must carefully consider "exceptions" in advance; where discussions of a decision take place all the parties will have a clear idea of what the decision criteria were and what the results of the decision were, since the format will be stated in the computer programs and the latter displayed as maps and statistical tabulations or the like.

GIS Creation

The source of the data for the Management GIS's is both the Resource and the Planning GIS's. Additional data may be incorporated from other NPS management information systems and from data resources outside the NPS (as, for example, when a joint project is undertaken between the NPS and another federal agency).

The analyses used in the Management GIS's resemble the kinds used in the Planning GIS's and can involve a very wide variety of possibilities. A fairly common approach, we believe, might be to compare -- by mapping - an existing condition with either a proposed condition or a condition set as an objective; the resulting map would then display areas where the compared conditions differed.

Information displays produced by the Management GIS's are of particular importance, in our view. We see the need for colored displays, capability for interactive graphics displays, the need for producing final graphics for publication or display, and so on.

Required Resources

We believe that there are important similarities between the Management and Planning GIS's. We think that at the park and regional levels, at least, these similarities would permit overlapping systems use, thus reducing costs. Since much of the data needed will be generated in connection with the creation of the Resources GIS's, the cost of data for the Management GIS's will probably be moderate. Hardware and software costs can be shared with the Resource and Planning GIS's in most cases.

At the national level of the NPS it may be necessary to create some special features -- particularly in terms of display options - in addition to those found in the national level Planning GIS. We particularly have in mind the provision for interactive color graphics, rapid processing times to permit immediate feedback about decision alternatives, and probably increased amount of memory for storing a large national data base. Such additions might well increase costs by many tens of thousands of dollars beyond that for the Planning GIS.

We think that special training would probably also be necessary for those managers and decision makers who will be using the system; without it they are unlikely to be efficient users and may, in fact, ignore the possibilities of the system completely, preferring to continue with their present methods. This training could be quite informal, in the form of computer supported tutorials, "examples" and the like. If this approach is not taken we think well trained staff will need to support decision makers in their use of the system.

D. Public Information GIS's

The Public Information GIS's are a family of GIS's which are used to provide the general public and specific NPS publics with a somewhat restricted range

of information: availability of recreational opportunities within the National Park System (and perhaps in areas surrounding parks), certain general information about the NPS, and information which is part of the NPS's environmental education and park interpretation efforts. Under some circumstances, and with augmentation of hardware and software, the same system could be used as a reservation system for the National Park System.

Functions

The Public Information GIS, first of all, is designed to interface directly with a using public; the interface would presumably be initially in large urban areas whose residents are known to frequent nearby NPS parks. The system would permit the public to query a computer directly about the availability of campsites, parking spaces or the like, at the nearby parks; a national system would provide this information for the entire National Park System.

By controlling the daily content of this information the NPS would be able to more effectively guide the using public to NPS parks which are able to meet their needs and away from parks which are already too heavily visited. Combined with a complete reservation system the Public Information GIS would give the NPS almost complete control of this problem.

By including information on recreational opportunities for areas near parks or for facilities which are alternatives to parks, the NPS could assist recreationists to more enjoyable experiences and at the same time reduce overloads on the parks themselves. Where suitable alternative camping, for example, has been cooperatively developed outside National Parks but nearby, the Public Information System could help guide recreationists to these specially prepared sites.

Because of the almost immediate editing which can be done on information in an automated GIS the Public Information GIS could include data on road conditions, water and snow conditions, fire hazard and other matters which vary rapidly.

The system concept is that the public can query this system about a paricular range of information: what

opportunities are available within a particular driving range; what opportunities for a specific type of recreation (boating, backpacking, touring, etc.) are available within a driving range; what special events are scheduled in the area on a particular week-end; what facilities are available at a particular park, at a particular campground, etc.; how much traffic should be expected at a park on a given holiday week-end; has campground X, which was closed last year, been opened, and if so what was done about the condition of the latrines; where can I expect to see bears in Park X; and so on. The range of this information depends only on the sophistication of the system and the raw data which can be made available.

With electronic funds transfer coupled to the reservation system the Public Information GIS could complete reservation transactions and insure proper payment as well. With hard copy and graphic devices at user terminals the recreationists could be provided with marked maps showing the information they wanted, complete directions, fee schedules, lists of facilities, etc.

The public information system could also play a role in both the NPS's interpretation programs and in environmental education. Depending again on the sophistication of the Public Information GIS's hardware and software , the public could be given interpretive presentations about specific parks or parks sites before they make their plans; this would lead to more satisfying experiences for them and confidence on the NPS's part that they were reaching the public even outside the boundaries of the parks themselves. Similarly, by providing various kinds of information displays, reports, accounts of important natural features, or the like, the Public Information GIS could be a central part of the NPS's environmental education efforts.

GIS Creation

The source of the data for this system would be chiefly the Resource GIS. If information on park-related areas or on an entire region were included then these data would need to be separately incorporated into the data files. Specific interpretive information would have to be generated by the NPS especially for the system. Reservations information would need to be supplied by a special system designed especially for the purpose.

The query-response system would require special hardware and software as would the reservations system and and electronic funds transfer system. These systems would presumably work through terminals located in urban areas, along transportation routes, in parks, or elsewhere.

The information displays could include CRT screens for alphanumeric data, graphics displays, hard copy devices and voice communications.

Required Resources

For small, in park Public Information GIS's with only a few terminals, the system design would resemble that of a Resource GIS for the same park and the resources would be similar, too. For regional or national Public Information GIS's costs would be considerably higher, especially for the greatly increased storage required, the networking costs, and the costs for the larger number of public use terminals. It is our view that the users of such a system should not, at least initially, bear the costs of its creation, which will be high, since this would discourage or eliminate system use.