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GIS Applications to Wilderness Management:

Potential Uses and Limitations

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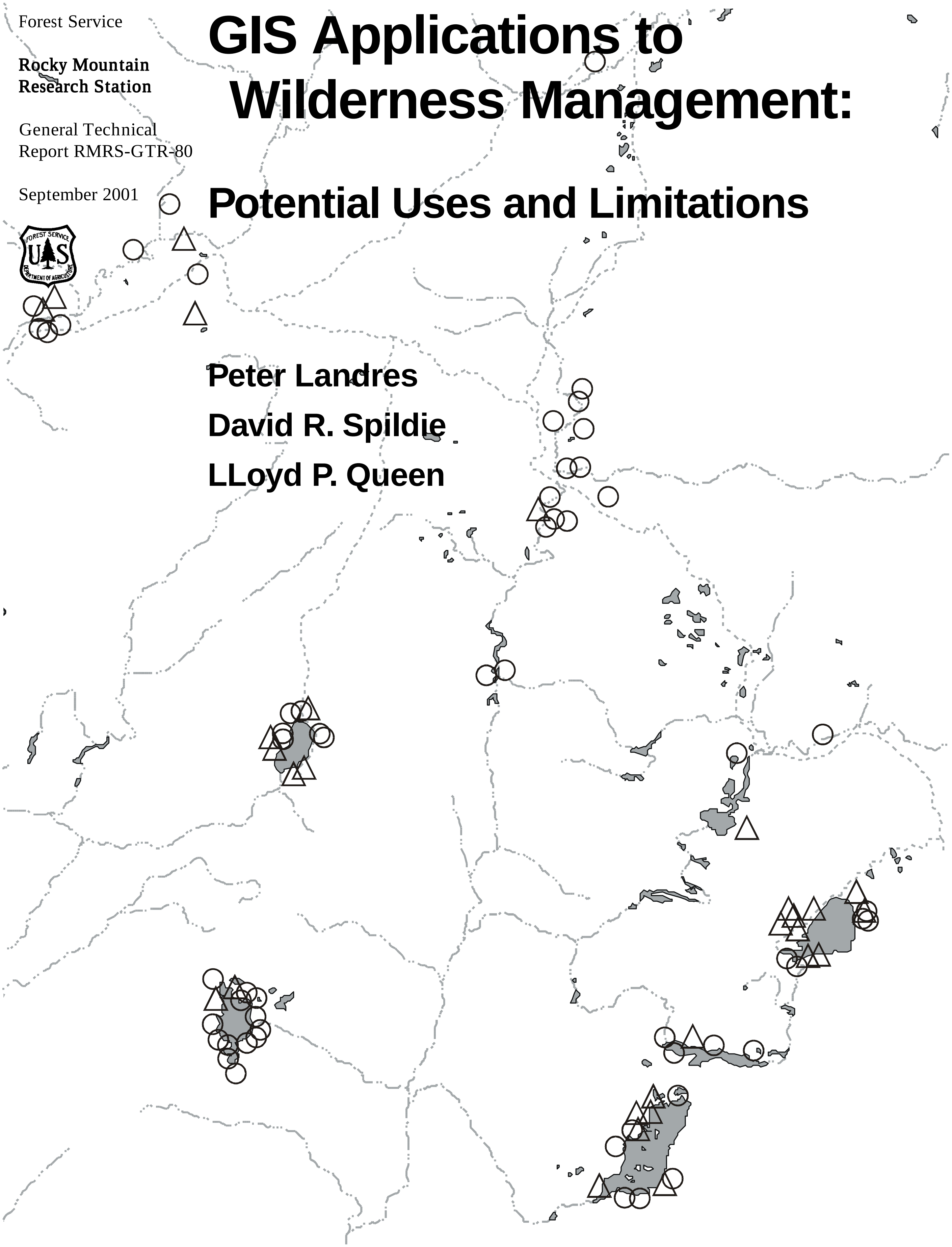

Abstract

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Geographic Information Systems (GIS) are increasingly being used in all areas of natural resource management. This paper first presents a brief primer on GIS, and then discusses potential applications of GIS to wilderness management in the areas of inventorying, monitoring, analysis, planning, and communication. Outlined are the limitations and pitfalls that could compromise the effectiveness of a wilderness GIS, and several suggestions are included for improving the chances of successfully using GIS in wilderness management.

Keywords: Geographic Information Systems, GIS, remote sensing, wilderness, wilderness management, spatial data, geospatial data, monitoring

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Introduction

This paper introduces wilderness managers to the potential benefits and limitations of using a Geographic Information System (GIS). Although some wilderness managers are familiar with and routinely use GIS, there have been only a few published accounts showing how GIS could be used to improve wilderness management. For example, Kliskey (1994) used GIS to explore how visitor perceptions varied from one area to another, and Gimblett and others (2001) combined GIS and simulation techniques to examine how alternative trail systems would affect use by different groups, and the resulting potential conflicts among these groups. Brown and others (1994) used GIS to assess how well the prescribed natural fire program matched the presettlement fire regime in the Selway-Bitterroot Wilderness in Montana and Idaho. In a broad use of GIS, Loomis and Echohawk (1999) assessed ecosystem representation within the National Wilderness Preservation System.

The use of GIS in all areas of natural resource management is increasing dramatically, but our experience suggests that the people who manage wilderness may not fully understand the benefits and limitations of this rapidly developing technology. Likewise, the people who know this technology may not understand the needs and constraints of wilderness and wilderness managers. This mutual lack of understanding results in lost opportunities to improve wilderness management.

This paper links these two disparate disciplines of GIS and wilderness. Specifically, we discuss what GIS is, highlight potential applications where GIS may substantially improve wilderness management, and briefly discuss general approaches and limitations that should be considered in developing a wilderness GIS. We conclude that GIS offers a new way of thinking about and improving wilderness management, a new way that offers much promise but also poses substantial hurdles and limitations. We do not discuss the technical issues of how to build a wilderness GIS because every area has a unique set of goals, conditions, threats, available data, and computing environment (the hardware, software, and computer expertise); instead we offer a selected set of references for people interested in these technical issues.

Background

Wilderness management decisions and actions are based ideally on an intimate knowledge of the natural landscape, its use, and the multitude of internal and external threats to wilderness. In reality, most wildernesses have insufficient information about current resource conditions, uses, threats, and the interrelationships among these. This lack of information likely results from the perception that these areas are intact ecological systems with little need for active management, and there are no commodity values within wilderness, both suggesting that there is no need for new or better information. In addition, the large area and general inaccessibility of wilderness contributes to the perception that collecting new information would be too costly and time-consuming. Exacerbating this lack of information is inadequate staffing in proportion to the area of wilderness managed, and traditional reliance on "shoebox" recordkeeping and paper maps. These traditional means for keeping records and analyzing issues worked well in their day, but in comparison to computer-based methods, paper-based records are difficult to analyze and easily lost, especially as staff relocate or retire. In addition, interactively demonstrating the effects of different management options to the public on paper maps is difficult or impossible. Furthermore, understanding complex spatial relationships among different types of variables, such as the influence of trailhead location on the availability of solitude and the influx of exotic plants, is difficult with paper maps, especially for issues that cross traditional administrative boundaries.

GIS and other rapidly developing computer-based technologies, such as remote sensing and spatial analysis, offer the means for overcoming some of the problems mentioned above. The availability of large amounts of geospatial data and powerful analysis tools to help understand relationships among these different types of data, and being able to manipulate these data over large areas for different planning goals, allow new ways of thinking about wilderness. For example, programmatic questions about wilderness and other natural areas that could be asked with these new technologies include: What is the contribution of wilderness to municipal water supplies? What is the contribution of wilderness to the protection of wildlife? Where are the greatest opportunities for primitive recreation and solitude? At the local level of managing a wilderness, questions might include: Where are weed infestations the greatest and how are these changing over time? Where are campsite impacts the worst and how might a quota system affect these impacts? Where could trails be routed to minimize soil erosion and impacts to wildlife habitat? Readily answering questions such as these is the hope of GIS application to wilderness management. Fulfilling this hope, however, requires understanding what GIS is and what it isn't, and its limitations.

GIS: A Primer

A GIS is a computer application that stores, retrieves, manipulates, analyzes, and displays *geographically referenced* information or *geospatial data*. Geographic referencing ties objects to a known location on the ground and can relate this object to all other objects or features on the ground. Two basic types of data are managed by a GIS: *geospatial data* that define the location of a feature or object on the ground, and *attribute data* that describe the characteristics of this feature. Table 1 illustrates different types of spatial objects and describes potential attribute data for each. GIS offers the unique ability to link spatial and attribute data, and then to manipulate and analyze relationships among them.

There are also two distinct GIS data structures or ways that data are represented and stored within a GIS: *vector* and *raster*. In a vector data structure, geospatial data are represented as *points*, *lines*, or *polygons*. As examples, fire rings or campsites would be stored as points, trails or streams as lines, and forest stands or recreation opportunity classes as polygons (fig. 1a). In contrast, a raster data structure represents geospatial data in a regular grid of *cells* and the attribute applies to the entire cell (fig. 1b). Raster data provide continuous coverage of an area. For example, a Digital Elevation Model showing slope, aspect, and elevation in a grid for an area is a raster data structure (fig. 2). A discussion of vector and raster data structures and their specific benefits and limitations is beyond the scope of this paper; readers wanting more

Table 1. Examples of spatial objects and potential attributes for each type of object.

Spatial object	Type of data	Attributes
Administrative structures	Point	Name and condition of buildings, bridges, or culverts
Campsite	Point	Bare area, tree damage
Trail	Line	Name, amount of use, length, maintenance needs
Stream	Line	Name, intermittent or perennial
Lake	Polygon	Name, amount of accessible shore line, number of peak season users
Recreation opportunity class	Polygon	Class
Grazing allotment	Polygon	Leaseholder, (animal unit months)
Patent claim	Polygon/point	Type of patent and activity status
Exotic plant	Polygon/point	Species, date of detection, density

a.

b.

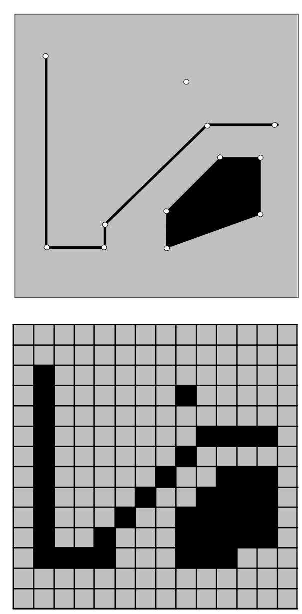

Figure 1. The same geospatial data can be represented by vector (a) and raster (b) data structures. Vector geospatial data are organized as x,y coordinates. In contrast, raster geospatial data are organized as cells in a matrix of rows and columns that cover the entire area.

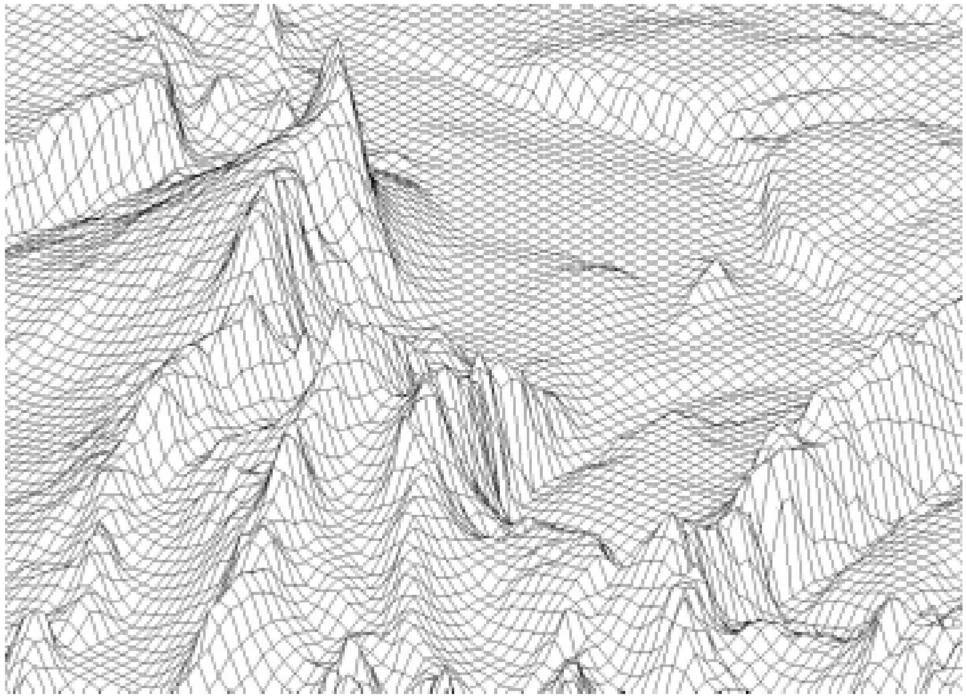

Figure 2. A Digital Elevation Model showing continuous coverage of slope, aspect, and elevation in a raster grid across an entire area. This area is the east side of the Cascade Mountains in west-central Washington State. Each regular grid cell is 1 km on a side. Figure developed and provided by Steve Brown at the University of Montana.

technical information should refer to the references in the Appendix. All of the uses, benefits, and limitations of GIS discussed below apply equally to both vector and raster data structures.

The attribute data of a GIS are stored in a relational database and the geospatial data are stored in what are commonly called *map coverages*, *map layers*, or *themes*. These layers, geographically referenced to one another, are the core of the GIS (fig. 3). Each map layer typically represents distinct features of interest. For example, topography, trails, campsites, opportunity classes, sensitive species habitat, and soil erosion potential all could be map layers. The most important criteria used to choose which map layers should be in the GIS are the desired goals and the availability of data with the appropriate *content* and *data resolution*. Management goals determine everything else, from the types of data that are used to the analyses performed and the maps that are finally produced. The *content* of a map layer refers to both spatial and attribute data; the spatial data should be accurately located on the ground, and the attribute data should be accurate, up-to-date, and appropriate for the intended uses. *Data resolution* is dependent on the scale of the map (for example, 1:24,000 or 1:100,000) and refers to the accuracy of the depiction of the map elements. While a GIS can zoom in or out to magnify or reduce the view, no GIS can improve data quality, or increase the amount of detail once it is entered into a GIS. As is true for any information-based tool, if poor quality information is put into the GIS, misleading information comes out. Also, as layers are added and merged throughout the analysis process, errors are compounded. These problems are especially acute in a GIS because many different sources of information are assembled into the final GIS database, and poor quality attribute data are difficult to discern on a map that otherwise "looks good."

There are several different methods for entering data into a GIS database. One method is to digitize (or convert into electronic form) already existing maps us-

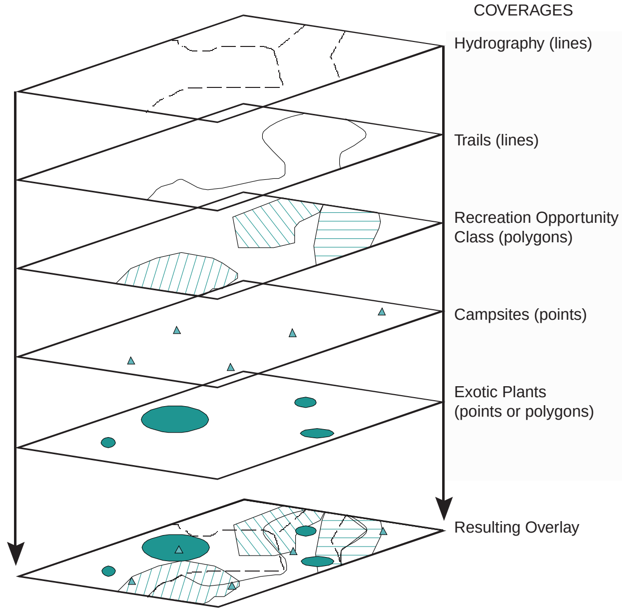

Figure 3. A GIS is composed of individual coverages, all geographically referenced to one another.

ing a manual digitizer or a scanner. Manual digitizing can be laborious, depending on the complexity of the map layer, and may introduce significant errors depending on the skill of the operator. Scanning is quicker and provides a more objective electronic rendition of a paper map, but requires access to a large scanner and is also subject to several sources of error. Scanning errors include linework that varies in width and continuity, inadvertent smears or smudges, and incorrect or missing registration marks. For a complete discussion of scanning and scanning errors, see references cited in the Appendix. Both manual and scanned data must be proofed and edited to correct inevitable errors that occur.

One alternative to map digitizing is acquiring digital data files from a GIS data clearinghouse, such as the U.S. Geological Survey, the USDA Forest Service, or other government agencies that have many different types of digital map coverages, such as political boundaries, topography, and hydrography (streams and lakes). Other alternatives to digitizing include processing satellite images to obtain vegetation cover, and, while in the field, using a Global Positioning System (GPS) to directly record digital data on features of interest, such as the location and condition class of campsites. Digital files of map layers derived from satellite and other remotely sensed images, as well as from a GPS, can be directly entered into a GIS. A key consideration when acquiring any digital data from other organizations is to review data content and format standards in what is referred to as a *metadata record* (literally, "data about data"). These metadata records help users evaluate whether data format, attributes, and source data resolution are appropriate for their intended purpose.

Map coverages from a GIS database, and results from GIS analyses, can be displayed and printed in different forms—maps, figures, and tables—and can also be shared between different GIS software packages. Some types of maps that are difficult to create using traditional cartographic methods can now be easily produced using GIS. For example, within a GIS program it is usually a simple operation to *overlay* different coverages on top of one another to illustrate relationships, or derive an entirely new coverage resulting from the combination of two or more coverages. Similarly, modeling tools available in GIS software packages can easily produce map measurements and analyze attribute data. There are many technical issues related to GIS and readers can refer to the texts listed in the References and sidebar for more information.

GIS Applications to Wilderness Management

What can GIS do for wilderness management? The unique ability of a GIS to store, manipulate, and analyze spatial and attribute data provides one of the best means for assessing and understanding the status and trends of resource conditions, threats to these resources, and the consequences of different proposed management actions on these resources. In the past, this resource information was stored in hard-copy documents and on maps. With GIS, this information can be stored digitally, making it readily accessible for evaluation and analysis, and it can be shared among wilderness managers, other staff, and the public. Specifically, GIS offers the potential to significantly improve the accuracy and long-term cost-efficiency of five basic actions of wilderness management: inventorying, monitoring, analysis, planning, and communication.

Inventorying

Inventorying is simply identifying things of interest, their location, and their current condition, and is unarguably one of the earliest uses of GIS and now one of the most common uses. Campsites, fire rings, trails, recreation opportunity classes, common vegetation types, exotic plants, and vegetation types used by threatened and endangered species can all be inventoried and mapped into a GIS. If GIS and other digital technologies such as GPS receivers are not currently available for use in a wilderness, it will take time and money to buy these new technologies and learn their use. In the long-run, inventory tasks will be easier and quicker with these new technologies. For example, inventory data can be directly entered into a GPS during field surveys and then into the GIS. Finding particular maps, and particular dated versions of maps, would take less space and be far quicker on a computer than searching storage rooms for paper maps. Computerized maps are also easily updated as new or more accurate information becomes available. Most important, within a GIS all inventoried attribute information about map features is readily available for tabulation, analysis, and graphical display.

Monitoring

Monitoring is the process of repeatedly measuring an attribute over time to determine changes in location or condition. Nearly all of the resources traditionally monitored by wilderness staff can be assessed within a GIS, including the amount of use an area receives; campsite location, condition, and size; the location and condition of official and social trails; the location and density of exotic plants; or the location and condition of structures. By facilitating the storage, retrieval, and comparison of any attribute data over any time frame, a GIS can simplify the process of monitoring, assessing change, and determining trends.

Still in various stages of development, some inventory and monitoring needs may be accomplished by bringing satellite imagery and other remotely sensed data for a wilderness directly into a GIS. For example, assessing vegetation types, wildlife habitat types, and establishment of exotic plants or exotic insect pests or pathogens within a wilderness could be accomplished by purchasing appropriate satellite imagery, classifying the various components of this image, and loading this information into a GIS. With sufficient development, this process could significantly decrease the time and funding needed to inventory and monitor valued wilderness attributes in large and remote areas. A major trend to watch for are spatial data from NASA's Earth Observing System satellite, which will provide frequent, high resolution data directly to the GIS user.

Analysis

GIS is much more than a tool for making maps. It is the analytical capabilities of GIS — the ability to integrate and overlay any number of data layers limited only by the imagination and experience of the user — that offer the most promise to wilderness managers. A GIS can explore relationships and determine trends and consequences of potential or planned actions. The analytical capabilities of GIS allow wilderness managers to pose "geographic questions" (Falbo and others 1991). These questions include: (1) What objects occur in a specific location? (2) What are the attributes of certain objects in certain locations? (3) What are the spatial patterns of certain objects? Specifically related to wilderness management, one could ask "Where are campsite standards exceeded?" and determine if there are patterns in where these standards are exceeded by examining the relationship of these campsites to other attributes such as elevation, soil erosion potential, and proximity to lakes, streams, or trailheads (fig. 4). One could ask, "What trails and

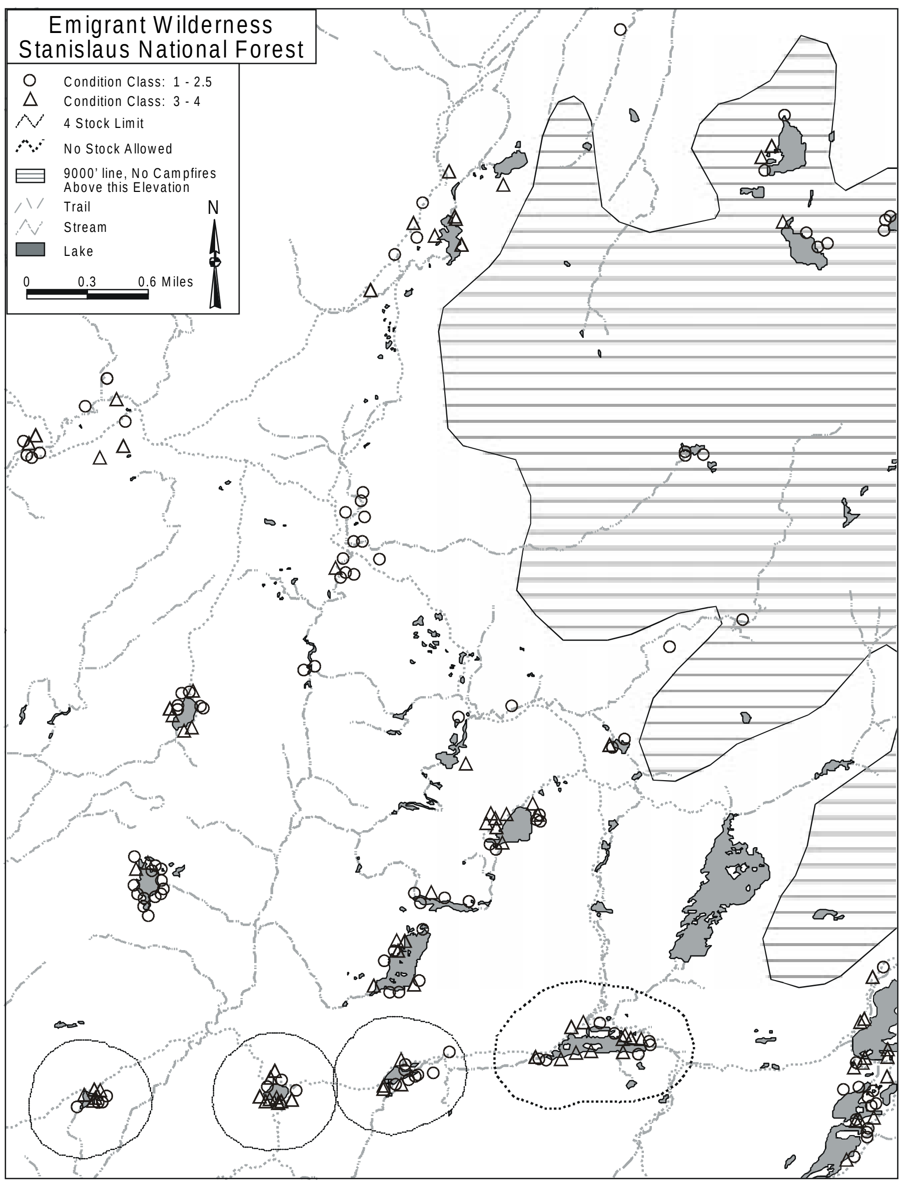

Figure 4. Campsites and areas that are monitored in the Emigrant Wilderness, Stanislaus National Forest. Campsite condition class 1-2.5 is low impact (O), 3-4 is high impact (Δ). Campsite condition class is monitored to assess change over time. Stock areas are monitored for compliance and campfire rings above the 9,000 ft line are identified for removal. The GIS analysis allows wilderness rangers and support crews to easily identify monitoring areas and sites where campfire rings will be removed. Figure developed and provided by Marty Gmelin.

campsites occur in habitat areas or corridors important for species of special concern?" These areas could then be monitored more frequently and trail rerouting planned. Using time-series analysis, it would be possible to understand how campsite and trail conditions are changing over time. Or, one could ask "How would the paving of a new road close to a wilderness influence that area?" Using a GIS-based analysis, a wilderness manager could examine whether that new road might create habitat problems for threatened, endangered, and sensitive (TES) species, or overburden existing trails, and even predict potential reduced impact on some areas of the wilderness caused by the new road displacing use from one area to another. In this case, the analyst has the ability to build virtual roads within the GIS, analyze the outcomes from alternative road networks, and assess the comparative advantages and disadvantages of these alternatives. GIS modelers often refer to these as "scenario-building" exercises.

Many wilderness managers intuitively know the answers to these questions. In these cases, a GIS may not provide new information. Instead, the GIS provides a long-term record of these relationships and how they are changing over time. As work duties become more filled and fragmented, and as personnel change, such long-term records will be invaluable. GIS tools also allow the decisionmaker to frame questions in alternative ways to examine the sensitivity or efficacy of a given "answer" to such questions. In addition, this computerized information allows other individuals who may not be as familiar with a particular area to examine potential relationships and analyze changes over time. If GIS is applied over entire management areas, the cumulative effects of land management decisions could be analyzed (Queen and others 1995).

Planning

GIS could facilitate wilderness planning in several ways. Once relationships among wilderness resources and threats to these are understood, managers could play "what-if" scenarios within the GIS, varying different aspects of wilderness conditions and threats (Wing and Shelby 1999). For example, the location and intensity of different types of uses such as recreation, mining, or livestock grazing could be altered one-at-a-time to discern the effects of alternative management options. GIS could also allow greater integration of wilderness planning across administrative units if these units are using a common, shared GIS database (Queen and Arthaud 1994). The ability to share information across spatial scales, from a single wilderness to an entire forest, State, and region, would facilitate and enhance landscape-level planning (Landres and others 1998). Shared and integrated data would also allow administrative units to more efficiently allocate budgets, time, personnel, and responsibilities related to wilderness management. A GIS may also compel collecting better quality information and new types of information because of the potential for improved analysis and planning (Coppin and Queen 1995).

Communication

GIS is an effective tool for public outreach, communication, and education (Blinn and others 1993). GIS is effective because most people understand information more readily when it is portrayed graphically, and one of the principal outputs of GIS is a map, combined with other data in graphical form. Land management issues are often contentious, requiring a good understanding of several variables and their interrelationships, and where impacts and potentials occur within the wilderness. By graphically showing these interrelationships and locations, GIS-produced maps can improve communication among management personnel and the public, as well as among different stakeholders (Lime and others 1995). Further, a GIS can be set up in public meetings to allow immediate exploration of "what-if" scenarios to illustrate potential effects and outcomes of different decisions. For example, if one user group wants to improve road access to a wilderness trailhead, a GIS could be used to show the likely impact of a greater number of recreationists on campsite conditions, density of people around lakes, and effects on trails. This information would be useful for managers to communicate to various stakeholders the potential impacts and tradeoffs of different management alternatives, as well as to improve communication among the different stakeholders.

Problems and Limitations in Developing a Wilderness GIS

GIS is one tool among many that wilderness managers can use. While GIS may be a valuable and unique tool, there are basic issues in developing a wilderness GIS that must be resolved before any action is taken, and several practical issues can prevent or compromise the use of GIS (see sidebar 1 on Potential Problems with GIS). These basic issues include determining if GIS is appropriate for the situation and which data layers are necessary and sufficient to accomplish the intended task.

Assessing whether GIS is appropriate is crucial because there are substantial ethical issues about using this sort of technology in wilderness, as well as significant costs in terms of time, effort, and money in developing a GIS. Borrie (2000) discusses the philosophical and ethical concerns about using such technology as GPS receivers inside wilderness, as well as using this technology to manage wilderness. One of Borrie's chief concerns is the "loss of the unknown" and all that wilderness stands for in a world increasingly circled, studied, and mapped by our technological devices. Borrie concludes by asking: “How does technology irrevocably change us and our views of wilderness, and how do we weigh the advantages and disadvantages of technology?” Parsons and Graber (1990) raised similar questions about the role of scientific activities in wilderness, and the necessity of understanding the relative benefits and costs of acquiring knowledge about wilderness.

Sidebar 1 -- Potential Problems with GIS

* Poor planning
* Poor training
* Poor documentation
* Data compilation is too involved and costly
* Overemphasis on technology
* Unrealistic expectations

Although every situation is different, GIS practitioners have developed recommendations for initiating these types of projects and ensuring that costs are controlled. One recommendation is a systematic planning and design process prior to GIS acquisition, startup, or the initiation of a new project on a GIS that has already been established (Blinn and others 1993). Somers (1990) developed the GIS Lifecycle planning and design framework, consisting of a “data core” and four cyclical phases of GIS adoption (fig. 5). At the center of the Lifecycle are the spatial data that are to be managed and analyzed by the GIS user. In this framework, data appropriate to the desired analyses are the core of the GIS effort. Also, with the growing role of the Internet and local networks in connecting different GIS users, data sharing and consequent liability are issues that should be anticipated (Freimund and Queen 1996, Blinn and others 1993).

The four cyclical phases of the GIS Lifecycle are common-sense steps in project design and analysis that are often overlooked in the “technical” arena of GIS.

Phase 1—planning—begins with the crucial question “why consider a GIS?” Many planning, monitoring, and assessment tasks can and are effectively accomplished using methods other than GIS. Users need to be aware of what a GIS is and is not designed to accomplish (see sidebar 2 on What GIS Is. What GIS Is Not). The substance of phase 1 is a systematic assessment of (1) who the GIS users are, (2) what their goals are, (3) what the anticipated products are, (4) what data and analyses are needed to provide these products, and (5) how decisionmakers will use this information. Also during this phase it is critical that all users assess their roles and responsibilities in GIS adoption because most “users” will not be GIS technicians trained to use the software. Rather, they will provide data to be entered into the GIS, will use the products created by the GIS, or will work with a GIS technician to pose questions during “what-if” scenarios.

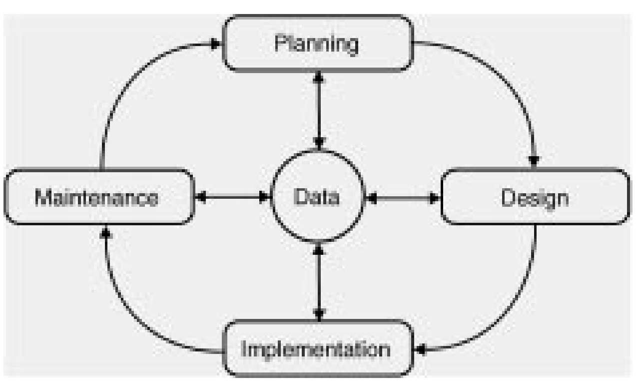

Figure 5. The GIS Lifecycle denoting four distinct phases shown in boxes (from Somers 1990). See text for explanation of this figure.

Phase 2—design—matches user needs and expectations to the appropriate GIS functions. Included in this phase are tasks of software selection, allocation of resources to training and education, and staging or scheduling tasks and outcomes so that progress toward planning goals can be measured. Phase 3—implementation—is where many users assume that GIS projects actually begin. During phase 3, data are compiled, maps digitized, metadata records compiled, analyses conducted, and output products (for example, maps, tables, charts) are generated. Phase 3 is the realization of the planning and design goals (see sidebar 3 on Requirements for Successful GIS Implementation).

Finally, in phase 4—maintenance—data must be kept current and up to date. Users may require additional training in use of software, system upgrades may be needed, and the overall effort may be expanded from a pilot to a full implementation. These maintenance tasks clearly are necessary to support ongoing GIS use but may also be required even if the project has no longer term programmatic use. That is, even if user needs are met at the close of phase 3, the data compiled for the project may have real utility for other uses or users. Maintenance of data and expertise developed earlier in the GIS Lifecycle guards that investment and provides the opportunity for a longer term return on the original investment.

Users need to be aware of the limitations and added costs of selecting GIS-based data management and analysis. The success of a GIS project will ultimately be measured against the abilities of the system to meet and respond to user needs and expectations (see sidebar 3 on Requirements for Successful GIS Implementation). The structured planning process should carefully consider the design and adoption of GIS, with the setting of clear, reasonable design goals that can be used to measure the return on a GIS investment. In many instances, users may decide that pilot or prototype projects are useful for testing the feasibility and costs of a GIS solution.

Conclusions

Increasing use of GIS in many areas is insufficient justification for developing a wilderness GIS: time and funding are in too short a supply for wilderness managers to

Sidebar 3 -- Requirements for Successful GIS Implementation

* Funding and administrative support
* Willing users
* Knowledgeable staff
* Cost-effective applications
* Appropriate hardware and software
* Adequate and appropriately scaled GIS data
* Implementationplan that includes how GIS products will support decisionmaking
* Monitor and evaluate effectiveness of GIS improving resource management
* Clear protocols for data handling operations

jump on bandwagons or adopt the newest tool in search of a problem. Experience has shown that selecting an appropriate GIS solution that meets user needs and expectations can be challenging. References in this paper (and in the appendix) will help the reader understand the issues and the "learning curve" associated with new or expanded GIS projects. GIS projects can flounder on poorly defined goals and the use of poor quality or inappropriate data. Without clearly stated goals and precise questions or objectives, GIS can be easily mired in costly details of technology and data. If anything, the lack of clearly defined goals and adequate planning is exacerbated by using GIS.

Despite these concerns, GIS can bring significant benefits to wilderness management, and we firmly believe that wilderness managers need to be proactive in understanding what GIS is, how it can be used, and its limitations. Introducing GIS into wilderness management may fundamentally change the way data are compiled, analyzed, and shared. Ultimately, GIS is not so much about a new technology as it is a stepping stone for a new way of thinking about and improving our understanding of wilderness and its management.

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