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Development and Assessment of a Spatial Decision Support System for Conservation Planning

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DEVELOPMENT AND ASSESSMENT OF A

SPATIAL DECISION SUPPORT SYSTEM

FOR CONSERVATION PLANNING

By

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Land conservation is frequently cited as the most effective means of limiting the detrimental effects of anthropogenic forces on natural resources. Because governmental entities can be hampered by fiscal and political concerns, land trusts are increasing relied on to protect habitat. However, these groups often lack the analysis and research tools necessary to meet their mission.

Geographic Information System (GIS) technologies such as Spatial Decision Support Systems (SDSS) offer the promise of allowing decision makers to explore their decision space at a landscape level of analysis. But critics have charged that research in this arena is largely anecdotal in nature. This research explores the validity of this contention and presents two applied empirical studies of user satisfaction with an SDSS.

In order to assess the overall maturity of the GIS discipline, articles in four journals from 1996 to 2001 were analyzed based on the scientific rigor of the research strategies employed. The results showed that, while there was an increase in the breadth of methodologies employed, the majority of studies employed qualitative ("hypothesis generating") rather than empirical ("hypothesis testing") designs. The findings showed need for scientifically rigorous studies in applied settings.

An operational SDSS was designed that identified and prioritized suitable land parcels for protection given multiple criteria and user values. The SDSS was customized for a single land trust in Maine and four theories of user acceptance of technology were tested using a modification of the traditional case study methodology. The Relative Advantage theory provided the best explanation for user acceptance of the technology. The research design also overcame the hurdles to conducting case study research in an empirical manner.

In the next stage of research, the SDSS was distributed to eighty-one land trusts for testing. An analysis of the twenty-four returned surveys indicated strong support for the User Competence theory. To the author's knowledge, these two studies represented the first experimental SDSS research in an applied rather than laboratory setting.

PREFACE

This research began with a simple objective: to develop an appropriate tool or tools to support land conservation activities. Traditional "command and control" techniques to limit anthropogenic sources of environmental degradation were being increasingly regarded as inadequate, particularly for the protection of habitat and water quality. Permanent protection of land resources appeared to be the most efficient means of ensuring these resources remained viable and so it was deemed critical to provide land conservation groups such as land trusts with the means of accomplishing their objectives.

Drawing upon previous work involving the integration of the spatial functionalities of Geographic Information Systems (GIS) with Multi-Criteria Evaluation theory, the initial stage of this research was the design and implementation of a Spatial Decision Support System or SDSS (as detailed in the first portion of Chapter 2). At the time this research was initiated (circa 1996), the term SDSS had primarily appeared in the literature as a conceptual model with only a few instances of existing software. The research design followed the typical framework for the majority of SDSS and GIS studies at the time: identify a problem, develop a spatial tool to address these issues, and then perform an evaluation of some sort.

However, as the time for the evaluation drew near, it became clear that this research still did not have a specific and quantifiable hypothesis. The difficulty with answering such commonly utilized questions as "Is it possible to build a system that meets certain criteria" or "Does the system produce the expected benefits" was that the results were not easily quantifiable. More importantly, their proof or rebuttal did not offer any significant contribution towards understanding the nature of the use and implementation of these technologies. Yet it was difficult to escape the impression that much of the applied GIS literature revolved on this type of questioning.

As a result of these realizations, the focus of this dissertation shifted from the design and evaluation of a spatial tool to an exploration of the nature and means of GIS research. In order to ascertain if the anecdotal evidence that most GIS studies focused on "hypothesis generating" rather than "hypothesis-testing" research designs, a review and categorization of the literature in four bellwether journals was conducted in order to quantify the nature of scientific GIS research. Chapter 1 presents the results of this inquiry, which draws significantly upon the discourse that the Management Information Systems field underwent at a similar point in its scholarly development. While there has been a rise in the use of empirical studies in recent years, the results in 1999 indicated that there was a need for more rigorous GIS studies.

Having identified this need, it became incumbent on the author to suggest means of conducting applied research in an empirical manner. The case study has long been held to be richest way of exploring the organizational, socioeconomic, and political context of technology implementation. In Chapter 2, a case study methodology, previously suggested in the literature, was applied to the evaluation of an SDSS adopted for the needs of land trusts in Maine, USA. While the case study methodology was presented in

1993, this study represents the first attempt to utilize it for evaluating an SDSS and is one of the few studies for a GIS application in general known to the author.

In Chapter 3, the traditional survey design is modified to allow for a field level evaluation of the factors influencing user satisfaction with the SDSS. The SDSS was distributed to a sample of land trusts and a survey instrument employed to quantify user satisfaction as well as other user characteristics. While surveys have been used in the past for GIS studies, this research methodology is unique in its attempt to draw out the effect of different factors on user satisfaction in a quantifiable manner. Collectively, the final two chapters represent the first attempt to evaluate empirically an operational SDSS in a field setting and join a small group of studies that have attempted to conduct applied GIS research in a scientifically rigorous manner.

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The intellectual genesis of this work began during my time at the Yale School of Forestry and Environmental Studies. Dr. Dana Tomlin, Dr. Paul K. Barten, and Dr. Jared Cohen each provided a piece of the initial puzzle. Special thanks goes to Dr. William Halteman, who served as the statistics guru for this project. My fellow members of the Maine Spatial Analysis Laboratory also provided intellectual grist for this project, especially Jeffrey Hepinstall, Jake Metzler and Renee St. Amand.

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Funding for this project was provided by the Maine Space Grant Project, as well as the Association of Graduate Students. Mike Phoenix of ESRI generously provided demo copies of ArcView software, which allowed land trusts without access to this technology to participate in the study. My current employer, Jeffrey E. Noyes of Heindel and Noyes, allowed me the time necessary to finish this writing.

While it would be impossible to list all of the people who made my stay in Orono the enjoyable experience it was, there are a few who stand out: Edwin Nagy, Thomas Molloy, Sally Dixon, Simon Krugoff, Tina Roberts, Steve Peary, Pamela J. Keef, Theresa Grove, Steve Lawson, Genevieve Pullis, Peter Reavey, Scott Delcourt, and Mark Torres. I am particularly grateful to Dawn Cameron, who provided encouragement both at the beginning and the end of the writing process.

Last, but not least, this dissertation would not have been possible without the love and support of my family. At long last, I can answer that inevitable and often annoying question posed at every family gathering: "So, are you done with that big paper yet?" Thanks to you all and many others, yes, I am.

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CHAPTER 1: ASSESSMENT OF EMPIRICAL RESEARCH IN GEOGRAPHIC INFORMATION SYSTEMS

INTRODUCTION

Over the last two decades there has been a dramatic growth in the use of Geographic Information Systems (GIS). The market research firm Daratec (2001) estimates that total user spending on GIS hardware and software reached $7 billion in the year 2000, with projected growth of 12% in coming years. This growth has been stimulated at least in part by the widespread proliferation of personal computers and advances in the capabilities of GIS software packages. While early uses of GIS tended to focus on resource management problems (Goodchild, 1993a), the technology has expanded into a variety of fields, including anthropology, resource economics, wildlife ecology, oceanography, among others (e.g. Allen et al, 1990; Dale and McLaughlin, 1988; Wright, 1996; Morain, 1998; Maguire et al, 1991; Gilliland and Baxter-Potter, 1987).

At the same time, the study of GIS as a specific field of inquiry is now prevalent in the university setting. GIS courses are becoming more common at both the graduate and undergraduate level, with an estimated 200 programs offering certificates in GIS and 50,000 students in American universities receiving at least one course in GIS each year (Phoenix, 2000). Faculty positions as well as departments are being established for academicians with the skills necessary to conduct research in GIS theory and techniques. The National Center for Geographic Information and Analysis (NCGIA), which is funded by the National Science Foundation, has supported several research initiatives on spatially based information systems (NCGIA, 1989, 1997). Numerous conferences are held every year on GIS topics and issues each year, as well as conferences where GIS topics occupies one or more sessions. While the number of journals specifically devoted to studies of GIS remains relatively small, a number of journals regularly have articles that feature the use of GIS technologies (e.g. Landscape Ecology, International Journal of Remote Sensing, Journal of Forestry, Journal of Wildlife Management, and Conservation Biology). However, some researchers have raised questions as to whether GIS is more property defined as a separate discipline or simply a tool of other disciplines (Wright et al, 1997a; Graf, 1999).

This chapter discusses the history of the debate over the relative merit of Geographic Information Science between GIS users and social geographers. Metrics for measuring the GIS field are presented and applied to articles published in four leading journals during the period of 1996 to 2001. The overall findings are evaluated and discussed.

GIS: Systems versus Science

For almost two decades after its inception in the early 1970s, the development of Geographic Information Systems generated little critical notice in scholarly journals. Dobson (1983) presented an enthusiastic summary of the benefits of automating cartographic processes in the Professional Geographer. His call for a "comprehensive set of geographic analysis tools" (p. 142) was largely unnoticed by those outside of the small community of GIS practitioners, despite the larger audience of geographers who subscribed to this journal. Most articles related to GIS tended to focus on specific applications of the technology, rather than any theoretical or philosophical discussions.

This situation changed in the late 1980s and early 1990s, when a series of critiques of GIS appeared in academic journals such as Political Geography Quarterly, Environment and Planning A, and Progress in Human Geography. In an editorial for the Association of American Geographers newsletter, Association President Terry Jordan (1988) defined GIS as “mere techniques” and declared that the field of Geography’s intellectual foundation was threatened by "the rush to GIS and similar easily justified but non-intellectual expertise." In a highly referenced editorial, Peter Taylor (1990) stated that the field of GIS was impoverished because it was reduced to facts (information) rather than theories or abstractions (knowledge). He concluded that GIS would leave geography “intellectually sterile – high-tech trivial pursuit” (page 212).

The roots of these criticisms lay in the rise and fall of the ‘quantitative revolution” in the field of geography decades earlier. During the 1960s, researchers such as Burton (1963) and Haggett and Chorley (1967) promoted the use of mathematical and statistical methods to explain geographic phenomena as well as the use of the scientific method and hypothesis testing techniques. Work generated during this period included the initial development of statistical techniques for analyzing spatial data, probability mapping and the increased use of remotely sensed imagery. However, by the mid-1970s there was growing criticism that the positivist approach to geography was too deterministic to account for human behavior (Harvey, 1973). Geographers began to look for social science theories as the primary theoretical construct, under the rubric of "humanism" (Barnes, 2001). This background explains Taylor's definition of a GIS as the "positivist's revenge" (1990, p. 212), as he viewed GIS as a return to the use of computers and models in geography.

The response by GIS practitioners tended to fall into one of two camps. Some advocates launched vigorous defenses of the technology and field. For example, Openshaw (1991) retorted to Taylor's article that "without information how can there be knowledge" (p. 621). He described critics of GIS "technical cripples in geography" (p. 624) who were more concerned with their own relevancy within the field due to the increased popularity of GIS than any philosophical dispute.

Others adopted a more moderate approach in their attempts to justify the intellectual credentials of GIS. Michael Goodchild, who would become the primary spokesperson for this group, argued that there were certain research questions that were unique to the field of GIS. In a keynote address (1990a), he established two conditions for the establishment of GIS as a field of inquiry: 1) that the domain contained a legitimate set of scientific questions, and 2) that spatial data were unique. Unlike Openshaw, who enthusiastically promoted the idea that GIS and some developments in geography could be used to support a variety of intellectual disciplines, Goodchild attempted to ground GIS firmly within the field of geography and felt it would require people trained in "geographical phenomena" (1991, p. 336) in order to be effective. He treaded gently around the issues related to quantitative geography, offering only the possibility that there might still be some value to positivism in the field (1991).

Openshaw's antagonistic tone inspired a more heated response from GIS critics. Taylor and Mark Overton (1991) took Openshaw to task for his claim that it was possible to have geography that was free of an underlying philosophy, as well as his belligerent tone towards those geographers who did not use GIS. Smith (1992) discussed the use of GIS to support military efforts in the Gulf War, thereby raised the ethical implications of the use of GIS. Lake (1993) defined GIS as fundamentally positivist because it is unable to account for the subjective differences between those individuals being digitally represented. He compared this approach to the prevalent post-positivist approach in geography, where actors took precedent over theories (i.e. Marxism, feminism). He concluded by criticizing GIS practitioners for not engaging in more self-examination as to the epistemological and ethical issues surrounding the technology's use.

While Openshaw responded to these critiques with another spirited article (1992) in which he stated that most of the critics of GIS seemed to be unaware of its real capacities, Goodchild began an effort to stake out a claim that GIS was a separate field of inquiry. He coined the term "Geographic Information Science", which he defined as the "generic issues that surround the use of GIS technology, impede its successful implementation, or emerge from an understanding of its potential capabilities", and offered two conditions for recognizing science in GIS: 1) that the domain contained a legitimate set of scientific questions; and 2) that spatial data were unique (Goodchild, 1992). Claiming that both conditions had been satisfied, he then listed some of the disciplines that might have a role in contributing to the advancement of GIScience: geography, cartography, remote sensing, statistics, economics, psychology, computer science and mathematics. He noted that the increasing number of articles related to the use and applications of GIS being published in peer-reviewed journals, as compared to conference proceedings and gray literature, should assist in establishing the field's legitimacy.

For the tenth anniversary of Dobson's "automated geography", the editor of the Professional Geographer requested articles from both proponents and critics of GIS. Dobson (1993) asked if GIS had spawned a scientific revolution by allowing for the creation of hypotheses and theories that can only be tested using this technology. John Pickles weighed in that GIS was "purely a formal set of tools" (Pickles, 1993, p. 452) and that automated geography had failed to perform any sort of auto-critique. For his contribution, Goodchild (1993b) again focused on defining the topics that could be explored in GIScience and skirted the issue of the methodologies used for this research. By establishing a moderate stance, he could continue to encourage further dialog with human geographers.

This dialog began to happen soon after the publication of the Dobson articles in a series of venues. In November of 1993, a conference was held at Friday Harbor, Washington where the primary players in the debate were invited to discuss their respective points of view (Sheppard, 1995). One outgrowth of this meeting was "Initiative 19: The social implications of how people, space, and environment are represented in GIS", a National

Center for Geographic Information and Analysis project funded by the National Science Foundation. The topic of the initiative was "the growing influence and social implications of GIS development and use", with the leaders and core planning group being comprised of the principle researchers at the Friday Harbor conference. In 1995, John Pickles' influential "Ground Truth: The Social Implications of GIS" contained not only criticisms of GIS from human geographers but also included articles by Goodchild and GIS proponent Howard Veregin.

In recent years, there have been few published conflicts between human geographers and GIS practitioners, to the point where Schuurman (2000) felt justified in reviewing the debate as a historic event. The most prominent event within the last five years was a dialog between Wright, Goodchild and Proctor (1997a and 1997b) and Pickles (1997) into whether GIS was a tool, tool-maker, or science, based loosely on electronic postings on the GIS-L listserver. While the primary points ran along previously established lines, in their first article Wright et al. (1997a) make two interesting observations on the relationship of science and GIS. First, the authors state that "whether GIS is a geographical science in and of itself depends on both the rigor with which the tool is employed and the scope of the tool's functionality given the nature of the substantive problem". The implication is a more rigorous approach would be more scientific. The authors also caution that "'doing GIS' is not necessarily the same as "doing science;" the latter depends on the methods deployed on the substantive problem, i.e., are they scientific?" The next section of this chapter will explore what is meant by a rigorous and scientific approach and whether research in GIS has met this standard.

The Nature of Scientific Research

In his classic text "The Logic of Scientific Discovery", Popper (1959) states that epistemology can be examined either as a problem of ordinary or common sense knowledge or as a problem of scientific knowledge. While ordinary knowledge gained through personal observation or beliefs may be the first step towards understanding, only scientific knowledge allows for real growth in understanding. Scientific knowledge comes from the deductive method, whereby a falsifiable theory or hypothesis is put forth and empirically tested. Over time, confirmed theories may continue to withstand testing (although they can never be fully verified), be rejected due to more severe testing, or be superceded by a well-corroborated theory that is more universal in that it incorporates the original theory.

In the initial stages of the development of a field, research is oriented towards "hypothesis generation" rather than "hypothesis testing" research (Nyerges et al, 2002; Hartwick and Barki, 1994). These preliminary studies tend to be observational and descriptive in nature, relying on loose associations for its conclusions. As a field matures, practitioners will begin to develop tentative hypotheses that explain the results of previous research. In order to determine if a hypothesis is reliable, experiments must be conducted that test the inferences of the theory. If the data from testing continue to support the hypothesis or at least not refute it, others may use it with increasing confidence. Over time, members of a field will draw upon hypotheses that have not been disproved to develop theories that provide a broad-based explanation and/or prediction as to behavior in the real world (Bonoma, 1985).

The development of a field will require different methodological approaches, depending on the areas being explored. For example, some questions may be best answered through the use of a survey while others may be more suited for a site-specific case study. As the decision to use one research approach over another involves trade-offs, a well-developed scientific field will use multiple data-gathering techniques in order to gain a comprehensive picture of the objects at hand (Yin, 1994; McGrath, 1995). A reliance on tested research designs that are grounded in theory is necessary to avoid adopting inadequate or erroneous conclusions (Fisher, 1998).

PURPOSE AND OBJECTIVES

The remainder of this chapter will assess the overall maturity of research in the GIS field. For the purposes of this research, two metrics will be employed to measure the condition of maturity:

1) Multiple Methodologies: At the outset of a field's development, studies will utilize a limited repertoire of research approaches. As the depth of inquiry and number of practitioners increases, there will be a corresponding growth in the use of different research methods (Farhoomand, 1987)

2) Emphasis on Empirical Testing: As an existing body of knowledge becomes well-developed, researchers will move towards methods that have a high degree of data integrity (e.g. laboratory experiments, models, field tests) to increase confidence in the results (Jacquez, 1998; Onsrud et al., 1992).

The choice of these two criteria is not meant to suggest that there are not other measurements available. Other suggested criteria include the existence of a well-accepted dependent variant (Pinto and Onsrud, 1997; DeLone and McLean, 1992), the existence of a cumulative tradition within the field (Keen, 1980) and the views of those performing research (Teng and Galletta, 1990). However, the two criteria chosen are relatively easy to measure and at a minimum should serve as a starting point for a larger discussion about the maturity of the field.

Therefore, maturity of a field will be defined as the breadth of its research methods and the degree of empirical research used by its researchers. Two hypotheses will be tested:

H1: There was not a statistically significant increase in the breadth of research methodologies employed by GIS practitioners during 1996 to 2001.

H2: There was not a statistically significant increase in the number of experimental studies undertaken by GIS practitioners from 1996 to 2001.

METHODOLOGY

Four hundred and seventy eight (478) articles published in four journals over a six-year period (1996-2001) were examined in order to assess the maturity of the field. The four journals included in this study were the International Journal of Geographic Information Systems (IJGIS), Urban and Regional Information Systems Association Journal (URISA), Cartography and Geographic Information Science (CGIS) and Transactions in

GIS (Transactions). These journals were chosen based on their specific focus on research related to concepts, techniques, and applications related to GIS.

Only research articles from IJGIS, Transactions and CGIS were reviewed in this study. This selection criterion removed editorials, technical reviews, book reviews and other articles that were not intended to be viewed as scientific research. For URISA, only refereed articles that had GIS-related topics (e.g. use, technology, or theory) were included in the analysis.

Each article in the survey was classified using a modified version of the research taxonomy first proposed by Vogel and Wetherbe (1984). The categories are:

Laboratory	laboratory study of GIS-organizational problems with an experimental design and high degree of control
Field Test	examination of one or more organizations with experimental design and controls
Survey	examination of one or more organizations with an experimental design but no controls
Case Study	examination of single or multiple organizations with no experimental design or control
Engineering	deals with application of mathematics, science or statistics; includes theorem proofs and descriptions of techniques and methodologies
Opinion	subjective article based on opinion rather than observation

The first three categories (Laboratory, Field Test, Survey) are considered to be empirical research methods due to their use of experimental designs and/or controls (Farhoomand, 1987; Cheon et al, 1993).

In the majority of instances, the research presented in a journal article could be classified into one of the above categories. There were cases, however, where more than one research methodology was presented. In order to arrive at the most conservative estimates of the discipline's maturity, each article was classified under the most rigorous methodology applicable (with "Opinion" as the least through to "Laboratory" as the greatest). For example, if the first part of an article described a particular technique while the second part applied it in a specific setting, it would be classified as a "Case Study" methodology (rather than "Engineering").

As with previous uses, the application of this structure to the articles validated the taxonomy. It was found to be an effective and comprehensive means of classifying research articles. To ensure the reliability of the procedure, a random selection of thirty-eight articles (8% of the total) were reviewed by a research colleague who was given instructions about the classification system. A calculation of the Spearman Rank Correlation Coefficient found a positive correlation between the two evaluations at a $p = .01$.

RESULTS

Table 1-1 tabulates the breakdown of articles reviewed by research type during the six-year investigation period. The preponderance of articles examined during the study period fell into the Case Study (36%) and Engineering (26%) categories. A Pearson Chi-square test found that the proportion of articles did differ significantly across the years ($p = 0.02$). However, the sparse number of articles in the Field Test and Survey in some years (frequency less than 5) make the significance test suspect. In order to account for the sparse cells, another test was conducted by grouping the articles published from 1996-1998 in one category and the articles from 1999-2001 in another. Again, the Pearson Chi-square test indicated that the proportions differed significantly across the two time periods ($p = 0.046$).

Table 1-1: Tabulation of Articles in Surveyed Journals by Research Type

	1996	1997	1998	1999	2000	2001	**TOTAL**
Laboratory Experiment	5	7	7	5	16	14	54
Field Test	8	3	2	1	3	2	19
Survey	7	2	4	3	5	3	24
Case Study	27	27	21	25	37	35	172
Engineering	29	22	18	26	16	15	126
Opinion	8	11	17	14	23	10	83
TOTAL	84	72	69	74	100	79	478

To determine where these differences were occurring, each research method was compared against the others to see if there was any significant difference in proportions. For example, the number of Laboratory articles over the six-year study period (5, 7, 7, 5, 16, 14, respectively) were compared against the number of other articles (79, 65, 62, 69, 84, 65). Both the Pearson chi-square and Cochran's test of linear trend were applied, at a significance of $p = 0.05$. The results are presented in Table 1-2.

Table 1-2: Test for Change in Proportions for Individual Research Methods

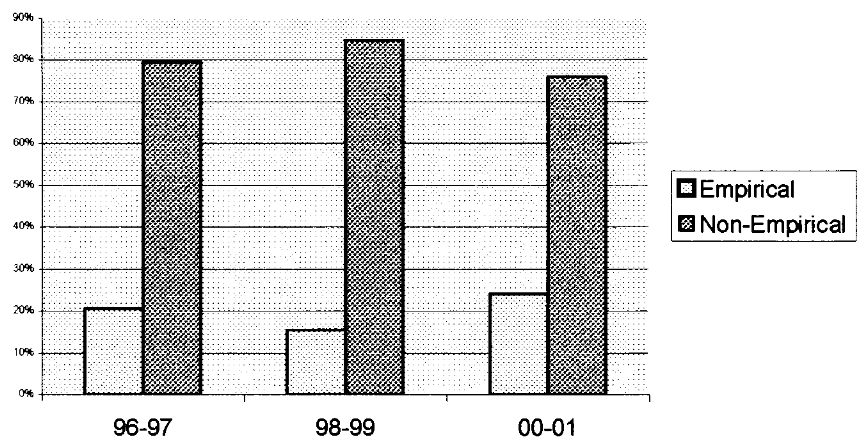
Method	Difference in Proportion?	Linear trend?
Laboratory Experiment	No (p= 0.086)	Yes (p = 0.009)
Field Test	No (p = 0.109)*	Yes (0.024)*
Survey	No (p = 0.673)*	No (p = 0.359)*
Case Study	No (p = 0.534)	No (p = 0.162)
Engineering	Yes (p = 0.014)	Yes (0.004)
Opinion	No (p = 0.078)	No (p = 0.267)

* Because more than one-fifth of the fitted cells had a sparse frequency (<5), the significance values are suspect.

For the Pearson's chi-square test, only one method (engineering) showed a significantly different change in its proportion relative to the other tests over the study period. This finding indicates that the relative proportions for the other approaches remained constant during the study period. Three methods (Laboratory Experiment, Field Test, and Engineering) did show a linear trend, with the proportion of Laboratory Experiment articles increasing as the proportion of Field Test and Engineering articles decreased. However, the small number of articles classified as Field Test makes any calculations of significance suspect.

Figure 1-1 presents the number of empirical versus other articles that appeared in the journals during the six years of the study period, divided into three periods for ease of visualization. A Pearson Chi-square test showed that the proportion of empirical versus non-empirical articles did not change significantly during the study period ($p = 0.318$). Similarly, Cochran's test for linear trend found that there was no evidence that there was a trend towards increasing or decreasing the number of empirical articles over the study period ($p = 0.646$).

Figure 1-1: Number of Empirical Against Non-Empirical Articles



DISCUSSION

The results of this analysis offer mixed results as to the maturity of the GIS discipline. There was a significant change in the breadth of research methodologies employed during the study period. This shift appears to be primarily due to a decline in the proportion of engineering articles, although a less restrictive p value would have shown a significant rise in the proportion of Laboratory Experiments and decrease in Opinion articles. There was also a significant trend towards an increase in Laboratory Experiments while both Field Testing and Engineering articles showed a decrease.

However, the changes in the range of research methodologies employed did not necessarily lead to an increase in the use of empirical studies. On average, only 20% of the articles published in a given year fell into one of the three hypothesis testing research designs. The predominance of Case Study and Engineering research overshadowed any advances in the empirical approaches to GIScience. Although the growth in Laboratory Experiment articles suggests that this situation may change, it may be some time before there is equity in the employment of empirical versus non-empirical research designs by researchers.

Even as the use of empirical research rises, however, it will be important to analyze research topics as well as research designs. Of the thirty-eight (38) Laboratory Experiments reported, more than one third (37%) were found in Cartography and Geographic Information Systems. Many of these studies focused on cartographic issues, such as map projections, line generalizations, and map design, as Leitner and Buttenfield (2000, pg 3) note that there is a "long-standing tradition of empirical research in map design as a paradigm for eliciting and formalizing cartographic knowledge". Therefore, at least some portion of the articles classified as Laboratory Experiments were designed to explore paradigms developed before the inception of GIS. As this study included all articles that could be considered even tangentially connected to GIS technology, there is an argument that it over-reports the number of articles that could be considered part of a unique GIS discipline, rather than an exploration of previously established research themes.

There is also anecdotal evidence that some portion of the empirical research being conducted is focused on refining the application of techniques rather than on issues of GIS implementation. There was a significant decrease in the use of Engineering articles at the same time as a demonstrated trend of an increasing proportion of Laboratory articles. Several of the Laboratory articles reviewed began by presenting a particular technique and then testing its accuracy or efficiency, often against other approaches (e.g. Power et. al., 2001; Park et. al, 2001; Ratcliffe, 2001). While it is not possible with this study to determine if researchers are explicitly shifting from Engineering to Laboratory research designs, there does appear to be at least a loose correlation that could be more fully explored in future studies.

Given this apparent movement from Engineering to Laboratory testing, it was therefore surprising to note the low proportion of Field Test articles (4%) given that Case Studies accounted for 36% of all articles. Clearly there are advantages to studying GIS use, as compared to techniques, in an applied setting as it allows for an exploration of complex issues of organization and culture. While the Case Study is the most easily applied design for conducting applied research, at least one methodology for conducting scientifically rigorous case study research has been suggested (Ostrud et al., 1992). However, only one of the Case Studies examined in this study (Sieber, 2000) employed this approach. Further research is necessary to determine if there are barriers to implementing this or other theory-based case study research methods or if this absence represents a reluctance on the part of GIS practitioners.

It is instructive to compare the GIS field with that of the Management Information Systems (MIS) in response to criticism as to the discipline's scientific maturity. The idea of MIS's emerged out of research at Harvard in the early 1970s, where senior managers at Westinghouse Electric Company were studied and a system was developed to support their monthly scheduling for production levels (Lucey, 1989). As with GIS, MIS technology was initially viewed as a tool for more mature disciplines (management science, economics, and psychology, particularly human behavior). MIS emerged as an independent field of study at the start of the 1980s, with its own journals, societies, and a limited number of departments on university campuses.

At around this time, members of the field began a self-examination as to the current state of MIS research. At the first annual International Conference on Information Systems (ICIS) in 1980, Keen (1980) suggested that research at the time was naïve and based on untested assertions and surveys. Numerous studies followed on a variety of topics, including profiles of journal and universities (Vogel and Wetherbe, 1984; Lending and Wetherbe, 1992), research topics (Culnan, 1986, 1987), research methodologies (Farhoomand, 1987; Stolen, 1993; Hamilton and Ives, 1982, 1983; Cheon et al, 1993; Alvavi and Carlson, 1992) and practitioners' views of the field (Teng and Galletta, 1990). While some of these MIS articles have been literature reviews or subjective in nature (e.g. Benbasat and Nault, 1990; Mason et al, 1997), the greater part of the articles reviewed in the course of this study relied on hypothesis-testing methodologies.

In contrast, the preponderance of articles on the scientific nature of GIS identified in the course of this study were opinion pieces. Only two articles, both by Wellar and Wilson (1993, 1994), attempted to quantify the role of the scientific method in GIS research through the use of surveys to researchers and a literature review (they found no significant use of "hypothesis-testing" methodologies). It is likely that the causal difference is the nature of the disciplines from which the two scientific interests sprang. While MIS drew upon fields with long traditions of utilizing the scientific method, most early GIS practitioners arose from geography departments during a time where the dominant paradigms were those associated with human geography. In this environment, it was necessary to thread a course of advancing GIS as a separate science (GIScience) while not rejecting the viewpoints of departments whose faculty would decide issues such as tenure and funding (Schuurman, 2000).

Differences in the backgrounds of the MIS and GIS scientific communities may also have influenced the degree of self-examination. Kuhn (1970, p. 177) defines a scientific community as "practitioners of a scientific specialty who have undergone similar educations and professional initiations." While MIS scientists may have very diverse backgrounds, they usually have at least some training in one or more well-established discipline (e.g. management science, economics, computer science). In contrast, the GIS community has no established curriculum or communication channels.

It has been suggested in the GIS literature that the nature of GIS technology and data is not conducive to the scientific method. Berry (1998) notes that the current data rich environment allows for GIS researchers to "mine" the data to derive hypotheses, as compared to the standard scientific approach of setting the hypothesis before collecting data. Goodchild has stated that "GIS has re-established the importance of intuition and simplicity of exploration over those very hard-core confirmatory hypothesis testing techniques" (Schuurman, 1999). It certainly is true that the increasing availability of spatially-explicit data will allow researchers to develop hypotheses in a more ad-hoc manner, rather than rely on set research designs for the collection of data. However, the validity of these assumptions will still need to be rigorously tested if GIS is ever to move from the specific to the general, from the descriptive to the explanatory.

There are three primary criticisms that could be levied against this research presented here. First, the choice of four journals out of the potential pool of available sources could speak to a sample bias. While the choice of journals was in part influenced by availability and ease of access, the publications chosen are considered by the author to be bellwether journals and representative of the state of GIS research. Second, the fact that articles may employ more than one research strategy opens the possibility of misclassification. This concern was recognized at the outset of the study, prompting the decision rule that, when there was a doubt over the proper classification of an article, the most rigorous method would be applied. As was described earlier, a separate check by another party supported the contention that there was adherence to this rule.

The third potential difficulty is that the small number of Field Test and Survey articles recorded suggests that the sample size in terms of the number of journals reviewed was inadequate. However, a cursory review of other potential journals indicates that it may not even be possible to fill these sparse cells or at a minimum would require the addition of at least eight or more journals to the study. Because these journals would need to be specifically chosen to close the gap there would be a stronger argument for sample bias, particularly as the scope of journals allowed in the sample would need to be considerably expanded.

CONCLUSIONS

There is currently a shift in how GIS is viewed in academic circles as to its scientific merit. After ten years of publishing under the name "International Journal of Geographical Information Systems" the editors changed the journals name to "International Journal of Geographic Information Science" in 1997. This is particularly significant as IJGIS was the first academic journal still in publication to be based solely on the publication of articles on the theory and application of GIS. In 1999, the Cartography and Geographic Information Society performed a similar word change in the name of its "Cartography and Geographic Information Systems" journal to "Cartography and Geographic Information Science." At the time, Editor Robert Cromley stated that the change in name was "necessary to be current with trends in the discipline." This year also sees the hosting of the Second International Conference on Geographic Information Science and a movement to have the National Science Foundation formally recognize GIScience as a coherent research field.

Yet despite these name changes and research venues, the results of this study offer mixed results as to the overall maturity of the GIS field. While researchers have moved beyond the Case Study and into a greater range or research designs, there was significant change in the use of empirical methods of research. The field as a whole has not achieved the maturity demonstrated by the MIS field at a similar point in its development cycle (Cheon et al, 1993).

As most journals have a backlog of articles due to publishing schedules and review times, there are discernable trends as to how research strategies might change over time. Laboratory studies may be beginning to take precedence over engineering papers, although it is unclear if the issues being examined are central to the GIScience research topics. Case studies will continue to be an important tool for understanding GIS use but there is little evidence that researchers are moving from "hypothesis generating" to “hypothesis testing” approaches. At the snapshot in time that this study encompassed, there was no evidence that the GIS scientific community is moving towards a more rigorous approach to scientific inquiry.

This research presents another challenge to GIS researchers to move towards the utilization of more traditional scientifically rigorous methods. As early as 1992, Onsrud et al. called for GIS practitioners to “develop a body of research that builds upon a falsifiable hypothesis and test them through rigorous methods” (pg. 33). Jacquez (1998) has advocated the development and use of appropriate research designs for GIS work and the use of different datasets to test hypothesis. In a keynote address at the first GIScience conference in 2000, ten years after Michael Goodchild made his first speech defending the scientific merits of GIS in research endeavors, Berry (2000) called upon those in the field to overcome what he termed the "fundamental schizophrenia" between quantitative approaches and social theory in order to move towards the goal of Computational Geography. The findings of this study indicate that GIS research requires a greater degree of maturity before it can be considered an independent field of inquiry.

CHAPTER 2: DEVELOPMENT OF A SPATIAL DECISION SUPPORT SYSTEM FOR CONSERVATION PLANNING

INTRODUCTION

Throughout the world, human use of the landscape has increasingly altered the structure and function of natural ecosystems. Population growth, technological changes, and socio-economic structures have led to the conversion of vast areas of land for settlement, agriculture and forestry (Turner et al., 1990; Swanson, 1995). With an estimated 39% to 50% of the Earth's land surface transformed, all ecosystems are either dominated directly by human induced change or influenced by it (Vitousek et al, 1997).

Anthropogenic modifications of the landscape have been a major cause in the decline of biological diversity (Soulé, 1991; May et al, 1995). Biodiversity is commonly measured in terms of the number of species present in an ecosystem, but genetic and habitat diversity across the landscape have also been recognized as important values. The major proximate causes of species extinction are habitat loss and degradation (Flather, 1994; Ehrlich, 1988; Wilcove et al, 1998; Fahrig, 2001). The relationship between habitat removal, fragmentation, and isolation to declines in certain species has been demonstrated in a number of studies (e.g. Andren, 1994; Saunders et al, 1991; Dale et al, 1994; Wilson, 1992; Koopowitz et al, 1994). Some biologists have suggested that habitat destruction may be creating an "extinction debt", where extinctions occur some time after the initial habitat insult (Tilman et al, 1994).

There is also increasing evidence that human development is impacting public health, particularly with regard to quality of drinking water. Incidences of cryptosporidiosis have been documented in a variety of recreational water settings in the United States since 1988, including a lake, community and hotel pools, a large recreational water park, a wave pool, and a water slide (Anonymous, 1997). The 1993 outbreak of the disease in Milwaukee, which resulted in 400,000 people becoming ill and 40 deaths, brought national attention to the need to safeguard reservoirs and groundwater supplies (Appleton, 1993).

Land conservation or preservation is frequently cited as the most effective means of limiting the detrimental effect of these anthropogenic forces (Newmark, 1995; Crowell, 1991; Dicks and Christianson, 1991). Programs which rely solely on land use regulations have often failed to produce the desired results because of the organizational and political difficulties associated with imposing and enforcing restrictions over a broad range of human activities (Willmer, 1992). Instead, conservation biologists have suggested the implementation of parks, reserves, wilderness areas, and land trusts to offer permanent protection of natural resources of concern (Flather et al, 1997).

In the United States, public support for land conservation in general has been demonstrated in a number of venues. In 2001, voters in state and local ballot initiatives approved $905 million in funding for parks and open spaces (LandVote 2001, 2001). Federal initiatives such as the Clean Water Act, the Farmland Protection Program, and the Land and Water Conservation Program contain mandates and funding to support land acquisition. Recent federal legislation provided tax incentives for landowners to adopt conservation easements, which are in essence the sale of development rights in perpetuity (Hutchinson, 2000).

Despite this apparent mandate and some success stories, there continues to be concern over rapid habitat loss in this country. The number of endangered or threatened species listed as part of the Endangered Species Act continues to rise. Critics note that federal agencies such as the U.S. Fish and Wildlife Service (now the National Biological Service) lack the resources necessary to identify, much less protect, critical lands for threatened and endangered species (Wilcove et al, 1996). The Service itself has acknowledged that some species have gone extinct before they could be protected under the Endangered Species Act (Federal Register, 1997). There are also grounds to believe that the federal government's approach to private landowners is economically inefficient and engenders distrust (Polasky and Doremus, 1998; Shogren et al, 1999).

Land trusts organizations are increasing being looked upon as a vehicle for achieving habitat protection. The term "land trust" has been applied to a variety of situations, but for the purpose of this discussion its working definition will be: "a private nonprofit organization established to protect resources permanently for the public benefit through the purchase or acceptance of land and/or conservation easements". The majority of land trusts focus on natural and scenic concerns, although some are oriented towards historic and recreational goals. Land trusts vary in scale (from local to regional to national) and size (in terms of staff and area of interest). According to the National Land Trust Census, there are an estimated 1,300 local and regional land trusts currently in existence and these groups have protected more than 6.2 million acres of open space (Land Trust Alliance, 2001). The private nature of the groups allows them to overcome bureaucratic hurtles that often hinder governmental agencies and they are often able to establish a better rapport with local landowners than representatives of regulatory bodies.

However, it has been suggested that these groups of largely untrained private citizens often lack the technical tools necessary to meet their mission given limited resources (Huse, 1995; Kellogg, 1999). Particularly when faced with land acquisition issues, these groups are often faced with complex decisions involving multiple and often conflicting objectives with few staff or computation resources. This chapter discusses the development of an operational Spatial Decision Support System designed to allow conservation groups to explore the decision space of potential land acquisitions. The SDSS will be implemented in a land trust environment and theories related to user acceptance of GIS technology will be applied for testing.

Nature of the Land Conservation Problem

Land by its very nature can be available for a variety of uses, which could include agriculture, forestry, urban and industrial, and recreational. Conservationists are therefore interested in identifying those lands managed for best use would be to be managed so as to preserve an important component or components (Natural Research Council, 1993). This process generally involves identifying the relevant attributes of a subsection of the landscape (usually a parcel) and performing a comparative evaluation against other potential units of land. While land trusts may seek to protect different attributes of a parcel (e.g. social, historical or visual value) in this evaluation process, this research will focus on those criteria related to biological and/or physical resources.

Since the founding of the modern conservation biology movement in the 1970s (Balmford et al, 1998), there has been considerable research directed towards developing the theoretical underpinnings for this comparison process. Simberloff (1991) reviewed those most commonly associated with land conservation, including the dynamic equilibrium theory of island biology postulated by MacArthur and Wilson (1963), the relationship of species diversity and population to area (Soulé, 1987; Veech, 2000), and the influence of habitat fragmentation and isolation (Turner et al, 2001). Simberloff concludes that these theories "are valid, but, like all metaphors, imprecise" (1991, p. 53).

Perhaps the most common means of providing in situ protection of biological resources has been the establishment of reserves or reserve networks (Noss et al, 1996a). The United States national park system is an example of a reserve network, although the rationale for establishing these parks has historically gone beyond biological concerns. Margules and Usher (1981) identified nineteen criteria that had been used to prioritize the siting of reserves, with diversity, naturalness, and rarity of species and habitats being the most popular. Of particular concern are "hotspots", a term coined by Myers (1988) to describe localities with exceptional concentrations of species with high level of endemism and that were threatened by human activities. The effect of different reserve designs, in terms of such variables as size, shape, and connectedness, have been studied extensively (i.e. Pickett and Thompson, 1978; Butcher et al, 1981; Soulé et al., 1988; Temple and Cary, 1988; Lindenmayer and Nix, 1993; Andrén, 1994; Vickery et al, 1994; Wiens, 1994; Cumming, 2002). Land trust holdings, whether as direct acquisitions or as conservation easements, constitute either a special form of reserve or, depending on the degree of forethought put into acquisitions, part of a reserve network.

One criticism levied against land conservation programs is that they tend to be opportunistic in nature, relying on market availability or crisis management over planning to allocate resources to the most threatened or valuable lands (Pressey et al, 1993; Reid and Murphy, 1995; Groves, 1992; Soulé and Sanjayan, 1998). In response, advances in computational technology have allowed for the creation of mathematical programming techniques for selecting systematically areas for inclusion in a reserve (ie. Belbin, 1993; Lomolino, 1994; Csuti et al, 1997; Pressey et al, 1996). These algorithms rely on the development of criteria to represent the attributes of the area under study and subsequent application of mathematical formulas to determine optimal or efficient solutions.

However, the utility of these selection techniques has been challenged primarily on two fronts. First, most of these models tend to consider one criterion at a time whereas the stakeholders may wish to balance multiple objectives (Church et al., 1996; Kiester et al., 1996). This situation is particularly prevalent when scarce resources require that trade-offs occur between anthropogenic (i.e. economic) and environmental concerns, although biodiversity goals may also come into conflict (e.g. as McGarigal and Marks (1995) note, increases in edges often involve decreases in compactness although these two indicators are commonly used to measure biodiversity). Second, the derivation of a conservation value implicitly involves the application of goals and values, which may not be shared with or transparent to the stakeholders involved (Norton, 1994; Vane-Wright et al, 1991). The values of the stakeholders must be explicitly stated *a priori* and incorporated into whatever mathematical function is used if the results are to be meaningful in a particular management or political setting. Two alternative approaches to identifying priority conservation lands have been to integrate Multi-Criteria Evaluation techniques into GIS packages or to create a Spatial Decision Support System (Jankowski, 1995).

Integration of Multi-Criteria Decision Making and GIS

While the term Multi-Criteria Evaluation (MCE) is widely used in the literature (Eastman et al., 1995; Heywood et al, 1994), other terms such as Multi-Objective Decision Making or Multi-Criteria Decision Making are often used interchangeably. All of these techniques assist the decision maker in choosing an optimum solution from a range of alternatives by evaluating multiple measures of quality, whether called criteria, attributes or objectives (Rosenthal, 1985). Reviews of the range of MCE techniques available may be found in Cohon and Marks (1975), Voogd (1983), Steuer (1986), Romero and Rehman (1987), Stewart and Honert (1998), and Triantaphyllou (2001).

Cohen (1978) suggests two categories of MCE techniques: those that focus on generating non-inferior solutions (e.g. linear programming) and those that incorporate user preferences. In the second case, the decision maker is required to develop a weight for each object of interest. Options are then evaluated based on the weighting of their objectives, with the best option having the highest value. There are a number of these weighting methods currently available and the preference for one against another should be determined by the nature of the task faced by the decision maker (Tecle, 1992).

MCE has been used extensively in water resource planning (e.g. Gershon et al, 1982; Davis et al, 1991; Ridgley and Rijsberman, 1992; Insua and Salewicz, 1995; Makowski et al, 1996). However, there has been little quantitative work devoted to developing MCE techniques to facilitate land acquisition. Almost all of the related research has focused on facility siting or planning applications, where the problem centers on the allocation of existing resources rather than the acquisition of new ones (Wright et al., 1983; Liang and Wang, 1991; Hokkanen and Salminen, 1997; Melachrinoudis, 2000). The literature suggests two reasons for the lack of studies on this issue. First, the land acquisition problem is inherently spatial in nature while most MCE techniques utilize tabular data sets (Dokmeci et al., 1993; Alvarez, 2002). Second, MCE techniques are generally designed for a small set of alternatives so that the massive datasets required for watershed level analysis would make the analysis computationally intense (Eastman et al., 1995). This contention is supported by the fact that the relatively few studies that have used MCE alone to assist with land acquisition (e.g. Diamond and Wright, 1988; Wright et al., 1983) have allowed only a limited number of feasible sites.

Geographic Information Systems (GIS) allow for the spatial referencing of tabular data, so that geographically explicit data can be manipulated, analyzed, and displayed (Parker, 1988; Fedra, 1993). Interactive analysis of spatial databases can show complex relationships among various environmental and/or anthropogenic elements (Goodchild, 1993a; Bishop et al, 1990). Because a significant amount of GIS research centers on locational analysis, the integration of the choice functionalities of MCE with GIS was a natural research direction and over the last decade, there has been significant progress on this front (Jankowski et al, 2001a). Several prototypes have been developed (e.g. Carver, 1991, Walsh, 1993; Lotov et al., 1997; Zeng and Zhou, 2001) and case studies have been reported for site selection, real estate, and natural resources (Christianson, 1989; Southwest Florida Water Management District, 1990; Davidson et al., 1994, Charpratheep et al, 1997; Jankowski and Ewart, 1996; Wyatt, 1997; Strager et al., 1997, Long, 1998). One commercial GIS software package, IDRISI, includes MCE modules (Eastman, 2001) and developers have created extensions for ESRI's ArcView program such as Spatial Group Choice, which evolved into GeoChoice (Jankowski et al., 1997).

While a GIS does provide a powerful set of tools, a number of researchers have argued that current GIS technology does not provide sufficient decision support tools (Crossland, 1992; Kyem, 2000). The majority of GIS projects require the presence of a GIS technician to serve as the interface between the technology and stakeholder or decision maker (Heywood et al., 1994). However, this approach requires that the decision-maker is able to define the problem and fully articulate the objectives or the analysts may produce results that are ultimately unsatisfactory.

Spatial Decision Support Systems

Spatial Decision Support Systems (SDSS) are a natural outgrowth of efforts to integrate Multi-Criteria Evaluation (MCE), and Geographic Information Systems (GIS) in order to overcome the limitations of each system (Cooke, 1992; Densham, 1991; Crossland et al., 1995). SDSS are designed for specific ill-structured spatial problems. The technology tends to consist of a data management core, usually a GIS, supplemented by analytical modules and accessed by a custom interface (Walsh, 1993; Fedra and Feoli, 1998). SDSS tend to support a decision research process, rather than a narrowly defined decision making process (Jankowski, 1995). The roots of the SDSS concept lie in the research associated with modern Decision Support Systems, a term coined by P.G. W. Keen (Freyenfeld, 1984).

While there is general agreement that SDSS support spatial decision making, there is disagreement in the literature over the exact definition of the term. Some authors have defined SDSS as modified GIS packages (Honea, 1991; Keller and Strapp, 1993; Negahban et al, 1993). Others have argued that models or DSS that have the ability to display their analysis results graphically should also be termed SDSS (Reisinger and Davis, 1987; Arnold and Orlob, 1989). This definition of a SDSS describes a "loose" coupling of the GIS with the DSS or model: there is a linkage between the components that allows for the transference of data, but they do not operate as a single system (Zhu and Healey, 1992).

For the purposes of this discussion, SDSS will be considered the spatial analogue to DSS and a set of characteristics will be used to describe and loosely define these systems. DSS are generally aimed at contributing the modeling, evaluation and judgment tools necessary for decision-making, particularly for problems related to business management (Fick and Sprauge, 1980; Finlay, 1994; Mennecke, 1997). Geoffrion (1983) offers six distinguishing characteristics that may be found in a given DSS:

1) DSS address unstructured or ill-structured problems;
2) DSS have user-friendly interfaces;
3) DSS combine analytical models and data in a flexible manner;
4) DSS allow the solution to develop by creating a series of alternative solutions and allowing the user to explore those solutions which seem most feasible;
5) DSS are oriented towards the user and as such support a variety of decision-making styles; and
6) DSS are interactive and allow an iterative problem solving approach.

In addition to the characteristics of a DSS presented in Geoffrion (1983), the following criteria from Densham (1991) will be added:

1) SDSS provide mechanisms for the input of spatial data;
2) SDSS allow for the representation of the complex spatial relations and structures that are common in spatial data;
3) SDSS include spatial and geographical analysis techniques; and

4) SDSS provide output in a variety of spatial forms, including visual displays, maps, and other more specialized types.

These additional capabilities allow the SDSS to integrate both spatial and non-spatial databases into a variety of analytical and spatial models.

Research on the development of SDSS has been ongoing through the last decade, encouraged in part by an initiative of the National Center for Geographic Information and Analysis (Densham and Goodchild, 1990,1994). Early articles focused on the theoretical issues related to the development and implementation of the systems (Armstrong and Densham, 1990; Djokic, 1993; Dibble and Densham, 1993; Confer, 1994; Kilgore et al, 1994; Jankowski, 1995; Couclelis and Monmonnier, 1995). More recent research has centered on the development of prototype SDSS platforms (Srinivasan and Engel, 1994; MacDonald, 1996; Carver et al., 1996; Feick and Hall, 1997; Malczewski et al, 1997; Rousseau et al, 1997; de Silva and Eglese, 2000; Frank et al., 2000) and the field has matured enough that books and conferences on the topic are being produced (e.g. Malczewski, 1999; Thill, 1999). Some of these SDSS have offered tools for determining optimal land use and land suitability (Sharifi, 1993; Jun, 2000; Bojorquez et al, 2001).

Case Study Research Methodology

While research related to the SDSS technology are still in the initial stages, considerable research over the past two decades has been directed to studying the factors that may affect the adoption and implementation of Geographic Information Systems and information systems in general (e.g., Croswell, 1991; Cerullo, 1980; Robey and Sahay, 1996). As described in the previous chapter, the majority of these GIS research studies have focused on the generation rather than the testing of hypotheses.

This apparent gap in the literature is most likely due to the perceived necessity of conducting this research in an applied setting, which lends itself to the case study research design. The case study method is considered to be richest way of exploring the organizational, socioeconomic, and political context. Lee (1989), however, identifies four primary criticisms of the case study: inability to control observations; inability to control deductions; results cannot be replicated; and results cannot be generalized. These factors contribute to at least a perceived lack of scientific rigor inherent in the method, as the focus of the research is on describing phenomena rather than testing theories (Budic and Godschalk, 1996).

As part of the National Center for Geographic Information and Analysis' Initiative 4 on the Use and Value of Geographic Information, Onsrud et al. (1992) drew upon the work of Lee (1989) and Yin (1989) to advance a methodology that preserved the flexibility of the case study method while addressing these statistical concerns. A theory or theories is selected and the conditions that are likely to exist if the theory is true are then determined. After completing the information gathering process at the case study location(s), a qualitative analysis known as "pattern matching" between the theoretical and the observed outcomes. For example, previous studies in the literature have suggested that the successful implementation of GIS will rely on the presence of a "champion" within the organization. If several cases of a particular business sector demonstrated that their organizations fully integrated the technology without such an advocate, this finding would appear to falsify this hypothesis. If, however, each case did have such a proponent, then the theory is said to not yet be falsified or corroborated. This process is consistent with the recommendations of Baroudi and Orlikowski (1989) on how to address the statistical shortcomings of the case study method.

While the methodology suggested by Onsrud et al. offers a means for conducting case study research in a scientifically rigorous manner, it has not been widely tested for GIS-related technology. In this chapter, the development of an SDSS to support land conservation activities is presented. The SDSS was then customized to meet the needs of a land trust organization located in Maine, USA and evaluated utilizing this modified case study research design. This study represents the first attempt to apply this methodology for research involving an SDSS or the adoption of a new GIS technology.

PURPOSE AND OBJECTIVES

The research objectives of this chapter are as follows:

1. Development of Prototype Spatial Decision Support System (SDSS): A prototype SDSS will be created that provides the tools for land trust organizations to explore the decision space of potential land acquisitions. The SDSS will be developed following the information needs identified in a formal Information Requirements Analysis with three organizations that focus on land acquisition activities.

2. Implementation and Testing of SDSS: The SDSS will be utilized by one of the three organizations participating in the development stage. The Case Study Research method will be used to test theories related to user acceptance of GIS technology using the SDSS.

Each of these objectives will be explored in separate sections within the chapter, for ease of reading.

DEVELOPMENT OF SPATIAL DECISION SUPPORT SYSTEM

Study Site Locations

Three sites were chosen for the Information Requirements Analysis (IRA) interview process. The selection of these organizations was based on: a) their active interest in acquiring (as compared to simply holding) land for natural resource conservation; b) the size of their watershed area of interest; and c) their willingness to participate in this study. Although the selection of these sites does not represent a random sampling of possible sites, the use of additional sources (described in the methods section) reduced the possibility of bias affecting the results.

New York City Department of Environmental Protection

The New York City (NYC) water supply system is the largest in the world, providing water daily for over nine million residents and visitors through a network of reservoirs spread across almost 2000 square miles (5180 square kilometers) in the Catskills Mountain Region (Department of Environmental Protection, 1990). During the time that the IRA was conducted, the City was implementing an ambitious watershed protection program that included the acquisition of approximately 80,000 acres (323.7 square kilometers) of watershed land. To meet this goal, the City was increasing professional environmental and GIS staff, as well as acquiring hardware, software, and spatial databases. The author worked closely with Department of Environmental Protection (DEP) staff in the development of a method for coupling GIS technology with multi-objective decision-making algorithms, a precursor of this research (Murphy, 1994).

Ducktrap Coalition

The Ducktrap Coalition, based in Mid-Coast Maine, USA, is a working partnership of local business interests and community organizations. The primary objective of the Coalition is the conservation of open space within the Ducktrap River watershed, which is encompasses an area of approximately 36 square miles (92.3 square kilometers), through the use of land acquisition and conservation easements. At the time of this study, the Coalition relied on one staff person to perform all of its GIS mapping and analysis.

Sheepscot Valley Conservation Association (SVCA)

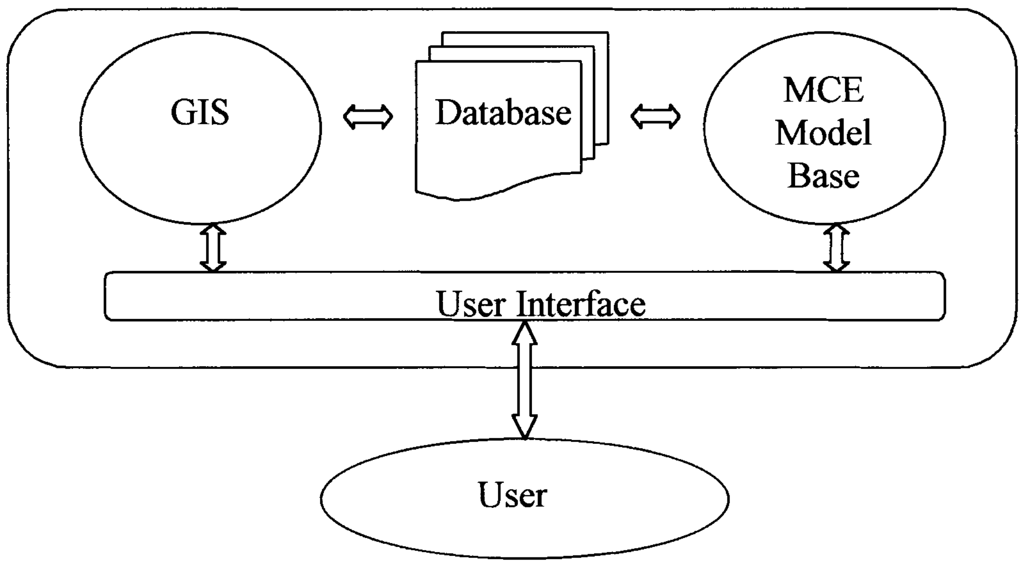
The SVCA is a membership-based organization located in Maine, USA that relies on private donors and granting agencies for funding. Located in the Mid-coast counties of Lincoln, Kennebec and Waldo in the state of Maine, USA, the Sheepscot river watershed is approximately 58 miles (93 square kilometers) long with a drainage area of almost 230 square miles (595.7 square kilometers). In addition to its other conservation goals, the SVCA is actively engaged in acquiring land and conservation easements for the protection of the Atlantic salmon. At the time of the IRA, the organization relied on volunteers to manage its GIS functionalities.

Methods

The IRA was conducted following the protocols outlined in Teng and Sethi (1990). Interviews were held with three members of the New York City DEP, one staff person with the Ducktrap Coalition, and one staff person and two volunteers with the Sheepscot Valley Conservation Association to determine the goals and decision process of the organization (Munroe and Davis, 1977; Lederer, 1981). A semi-structured interview process was followed in conducting the IRA, to ensure that certain questions were uniformly asked at each site while still allowing for participant feedback (Lederer, 1981). The resulting "information needs inventory" was compared with the existing literature to ensure no gaps were present (e.g. Natural Research Council, 1993; Endicott, 1993; Noss, 1996b). The inventory was also reviewed by six participants in the 1998 Annual Conference of the Land Trust Alliance.

Based on the specifications outlined in the IRA, the design of the prototype Spatial Decision Support System incorporated four components: 1) a database with spatial and non-spatial attributes; 2) a MCE model base; 3) a user interface and 4) a GIS. (see Figure 2-1). The ArcView package (ESRI, 1999) served as the GIS, primarily because its programming language, Avenue, allowed for customization of the interface. In addition, these programming capabilities allowed for the realization of the model algorithms and their connection with the other components. The result was a shell approach, where components of the system are interfaced to create a seamless environment (Djokic, 1993).

Figure 2-1: Architecture of SDSS Design



The unit of analysis for the system was the parcel, as this is the scale at which land trusts operate. For each parcel, all of the necessary factor and constraint values needed to be assigned. Factors are criteria that enhance or subtract from the suitability of an option, while constraints limit the selection of an option (Eastman et al, 1995). As an example, a parcel that is adjacent to a stream may be more desirable for conservation purposes than one that is not. "Proximity to water" is therefore a factor. If the user only wishes to consider parcels that contain wetlands, then wetlands become a constraint.

Based on feedback from the IRA participants, eight criteria were employed as factors for this prototype development phase: three natural features (presence of wetlands, distance to stream, and slope) as well as an overall weight for these features ("Water Quality") and three anthropogenic features (property value, acreage, and proximity to other conserved lands) with another overall weight ("Management"). Two constraints, size of parcel and slope, were also incorporated. This limited number of factors was based in part on research that showed that it was more cognitively difficult for decision makers to assign weights that reflected actual preferences when there are a high number of criteria (Kirkwood, 1997).

Using a spatial coverage developed as part of previous work in the Catskills Mountain region (Murphy et al., 1995), values for the six factors and two constraints were assigned to each parcel within the watershed. Certain anthropogenic features of the parcel, such as its market price and acreage, were readily coded as factors as there was one value for the entire watershed. For natural features, whose extent does not necessarily fall within legal boundaries, assigning a factor value was more problematic. To avoid introducing bias, it was decided that the highest value for a natural feature present would be assigned to the whole parcel. As a result, a parcel with steep slopes or a wetland had that factor value assigned to the whole parcel even if the area occupied by these features was small relative to the size of the remainder of the parcel.

In designing the model base, the IRA participants were presented with six potential MCE methods for weighting alternatives. While two of the choices were eliminated due to their perceived complexity, there was no consensus on the optimum method from the remaining choices. Therefore, the model base of the SDSS incorporated these four (4) models:

Simple Selection: The decision maker (DM) can identify parcels or regions within the watershed that contain certain features or meet certain rules. The decision rule evaluates each alternative, Ai, by the following formula:

If A_i so that $\Sigma_j\ x_{ij} >= c_j$, then Ai is true

where x_{ij} is the score of the *i*th alternative with respect to the factor value for the *j*th criterion and c_j is a user-selected value.

For example, the user may request that only those parcels that are greater than 200 acres and have a wetland occupying them are highlighted. This is similar to ArcView's query function, except that the potential selection criteria are predefined. As a preference-eliciting tool, this module operates under a binary standard: either the factor or constraint is or is not important to the DM.

Ratio Estimation Method: The Ratio Estimation Method is an additive value function also referred to as the Swing method. It is represented as:

$$A_i = \Sigma_j\ w_j v(x)_{ij}$$

where the score for alternative Ai is the sum of the values of x_{ij} (the score of the *i*th alternative with respect to the *j*th criterion) multiplied by a weight (w_j). The sum of the weights has been normalized to one while the component values of $v(x)_{ij}$ have been scaled to a range [1,100] using a value function.

Under this method, the DM assigns a hundred points to the most important attribute and then gives fewer points to the other attributes. These points should denote the importance of this criterion relative to the most important attribute. The attribute weights are elicited by normalizing the sum of the points to one (see von Winterfeldt and Edwards, 1986).

<u>Weighted Linear Combination</u>: This approach is one of the best-known models for decision making in a GIS environment. It is mathematically represented in the same manner as the Ratio Estimation Method. However, the DM assigns weight values based on a range of 1 to 100, with no prerequisite that one criterion be assigned 100. Higher scores indicate that the user prefers that criterion over others. The optimum choice is decided by identifying the maximum Ai and the relative preference for one alternative against another can be determined in a similar manner.

<u>Pairwise Comparison</u>: Also known as the Analytical Hierarchy Process, the DM enters values ranging from one to nine in a matrix that reflects relative preference for one factor over another. The matrix's eigenvalues are used to derive the weights, which are then applied to the factor values. One of the advantages of this technique is that the matrix structure can measure the degree of inconsistency present in the pairwise judgments, and

thereby help ensure that only justifiable rankings are used as the basis for planning (see Saaty, 1980).

Each of the four methods were encoded using ArcView's Avenue programming language so that information could be drawn from the sample spatial database with parcel data. For the three methods involving weights, it was necessary to normalize the factor values. A linear scaling operation was performed to transform factors to a uniform [1,100] scale. For example, a property with a wetland would have a value of 100 while smallest property would have a value of 1. This normalization process was necessary to allow for comparison of factors that may utilize different scales (e.g. the price of a parcel against its proximity to a stream).

As discussed earlier, the use of the ArcView programming language allowed for customization of the user's working environment. A number of the tools and menu bars offered in the standard view window were hidden or removed to limit the users' options. These constraints were considered necessary by the focus groups as land trusts tend to have volunteers and staff whose technical expertise and willingness to learn new technologies is limited (Sieber, 2000).

Results

The prototype SDSS opens in the same manner as other ArcView Projects. The view window is initiated in the project space, with all of the standard ArcView tools (e.g.

zoom, pan, identify). In the Menu bar is an SDSS option, whereby the user selects which of the four methods he/she wishes to employ. For each method, the user enters a numerical value weight for each attribute by either using a slide bar (Figure 2-2) or inserting the number manually (Figure 2-3). The user may also constrain the decision space by the size and/or average slope values for the parcel. Both of these examples use a spatial coverage of a watershed in the Catskill Mountain region for illustrative purposes.

After entering the desired values for each criterion, the user clicks on a button to initiate the module's calculation process. With the Simple Selection method, a query is performed so that all of the parcels that meet the stated constraints are colored in. Only the outline of the remaining parcels is displayed, so that the user may have a sense of where the important parcels lie relative to other properties.

For the algorithmic-based methods, the entered values are processed to produce a weight value for each factor. These weights were subsequently multiplied by the corresponding normalized attribute value to derive a value rating for that factor. For example, parcels with wetlands were assigned an attribute value of 100 while those without received a zero value. If the user assigned a value of 43 for the wetland factor in the Weighted Linear Combination approach, the total score for that attribute would be 4300 for all parcels that had wetlands.

Figure 2-2: Interface for Weighted Linear Combination MCE Method

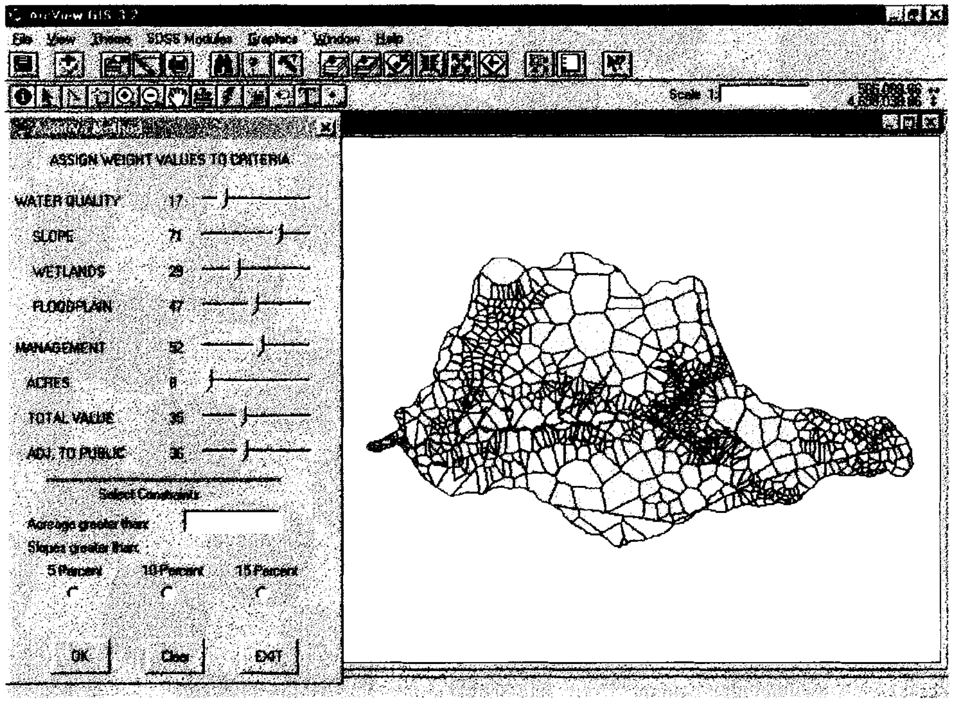
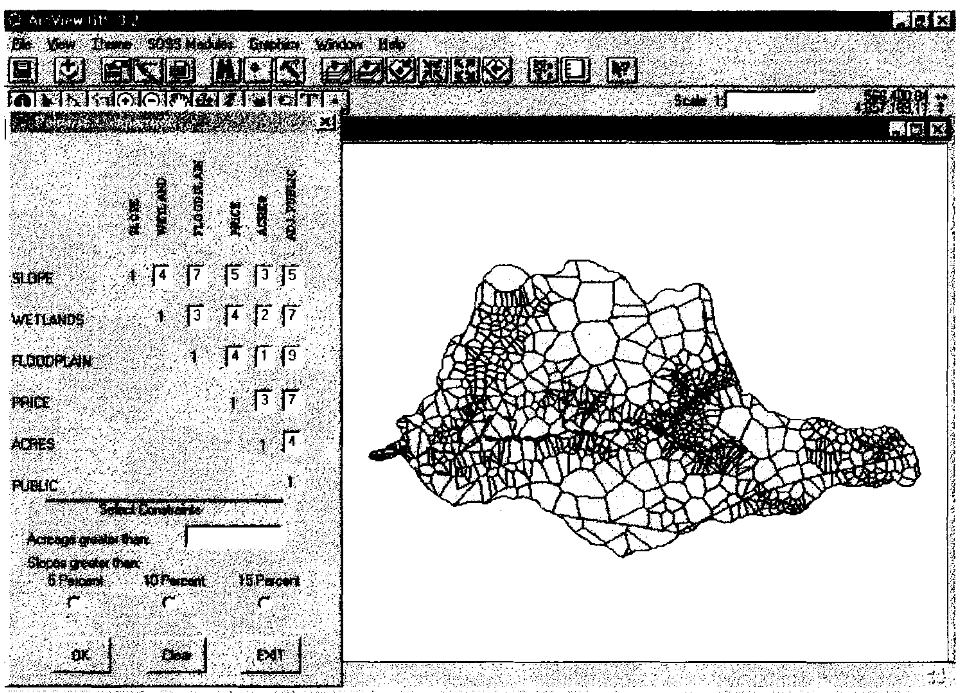


Figure 2-3: Interface for Pairwise Comparison MCE Method



The scores for all attributes were summed for each parcel for a ranking score. Because of the highly divergent values that could be produced using the three weighting methods, the ranking scores were normalized to a value of 1-100 to allow for an easier comparison of the alternatives. Each property within the view window was then populated with its final normalized rating value, producing a chloropleth map where highly desirable properties were displayed in green and the least desirable in red.

Figures 2-4 and 2-5 present examples of iterations using the Additive Overlay method. In both cases, the user has selected a series of weights for the eight criteria and no constraints. In the first example (Figure 2-4), those properties located nearest to the waterways are generally ranked highest, due to the high values assigned to properties within the floodway and the Water Quality criteria. However, the user in second example has emphasized the importance of the cost and size of a parcel. As a result, priority is given to less expensive and larger parcels (see Figure 2-5). The user could begin to compare these maps to determine properties that seemed to meet multiple objectives best.

The prototype was beta-tested by three professionals in the conservation field, including one of the New York City DEP staff members who participated in the IRA process. The final product was compared against the IRA inventory requirements to ensure completeness.

Figure 2-4: Example One of Parcel Rankings using Additive Overlay Method

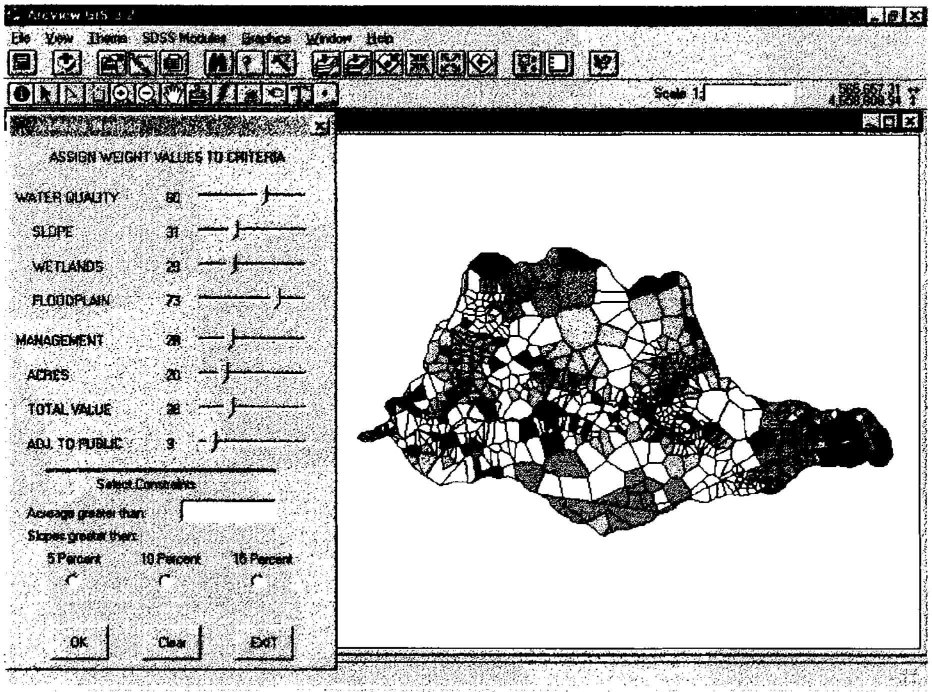
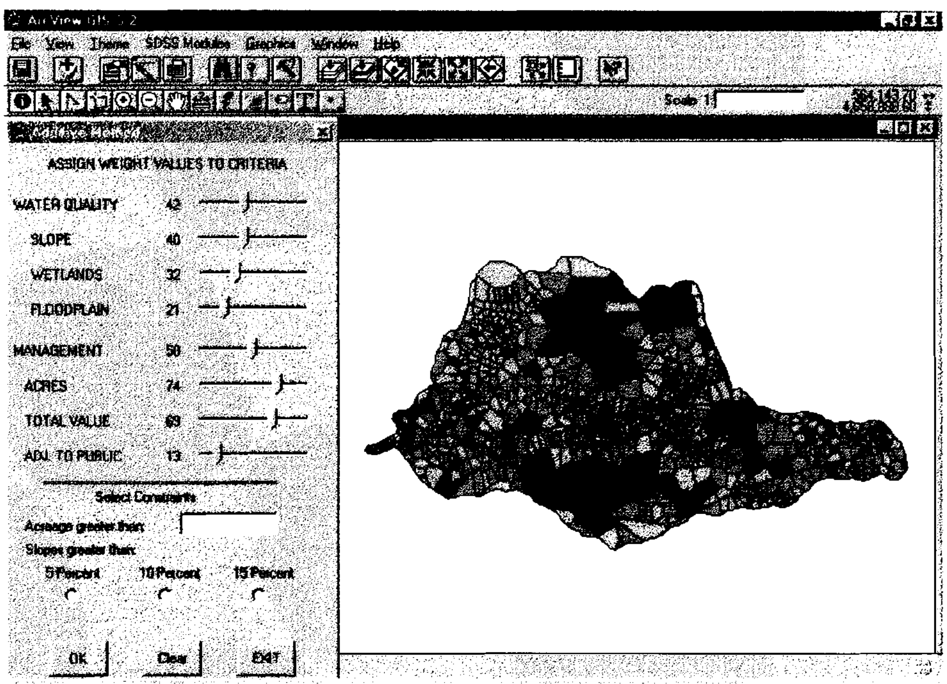


Figure 2-5: Example Two of Parcel Rankings using Additive Overlay Method



Discussion

The prototype SDSS met each of the specifications laid out in the Information Requirements Analysis inventory. It fulfilled its basic requirement of allowing users to research the decision space in a directed manner, as compared to the open nature of a standard GIS platform. The beta-testers also felt that the user interface directed this exploration in an intuitive and user-friendly manner.

The selection of the particular spatial dataset utilized in the prototype presented an advanced insight into the functionality of the SDSS. In general, the beta testers felt that the most valuable lands for conservation would be larger parcels located adjacent to waterways. However, the configuration of parcels in the watershed was such that the parcels located nearest to waterways tended to be smaller in size than those located in the upland areas. Sensitivity analysis found that the weighting for other factors, such as steepness of slope and the presence of wetlands, exerted a more profound influence on the final rankings than expected. The New York City DEP staff member commented that, while the final rankings tended to be different than he would have anticipated given his knowledge of the region, the results represented a logical outcome given the spatial conjunction of natural and human features on the landscape (J.Wolfe Tone, New York DEC, pers. Communication, 1998). These results, in his opinion, presented a defensible public policy approach to the prioritization of parcels within this region.

In initial versions of the prototype, the production of a final rankings map required several minutes to perform. Anticipating that users could grow frustrated with this time lag, modifications to the database and the model base were implemented. The final calculation and display process was sufficiently quick that the user could have a better sense of how even slight modifications of the numerical values entered for each attribute could affect the priority of parcels. The net effect is that users could perform a qualitative sensitivity analysis on the results.

All three of the beta-testers noted that the significance of the rankings in terms of public policy would be dependent on the system's ability to elicit appropriate weight values. This raised two issues of concern in terms of the program's use. First, there was a question as to, in the case of conflict, which user's values could legitimately be used to determine priorities. The subjective nature of combination scoring systems (Turpie, 1995) means that the choice of actors is critical. However, it was also suggested that each organization would have a process for making decisions in place and these procedures could be applied to this issue.

The second issue focused on the uncertainties associated with ensuring that a particular weighting scheme has elicited accurate user values, which has been well explored in the literature (e.g. Wainer, 1976; Schoemaker and Waid, 1982; Borcherding et al., 1991, Pressey et al, 1997). The general consensus appears to be that it is misleading to interpret a weight as an overall measure of the importance of an attribute, but rather it should be viewed as an indicator of relative importance. When viewed in this context, the goal of the SDSS shifts from presenting a "correct" ranking to understanding the relative advantages of one alternative against another (Malczewski, 2000). The beta-testers agreed that the system did allow for this type of analysis and therefore could be an appropriate technology for a land trust organization faced with selecting from a larger set of alternatives.

IMPLEMENTATION AND TESTING OF SDSS

Based on the results of the review of the prototype Spatial Decision Support System (SDSS), it was deemed appropriate to move to the second objective of this research. In this phase, the SDSS was to be implemented within a land trust organization. Competing theories regarding user acceptance of GIS technologies were evaluated using the Case Study Research Method.

Site Selection

The selection of a case study area is central to ensuring that the results of the research provide sufficient understanding as to the phenomena under consideration (Williamson and Fourie, 1998). The Sheepscot Valley Conservation Association (SVCA) was chosen as the test case for the SDSS for personnel and programmatic reasons (see Figure 2-6 for location map).

Figure 2-6: Location of Sheepscot River Watershed in Maine, USA

Routine staffing changes at the New York City Department of Environmental Protection and the Ducktrap Coalition resulted in none of the original participants in the Information Requirements Analysis being available for this testing phase. Two of the three SVCA respondents in the IRA were available and open to participating in this stage of the project. At this point, individuals had moved from volunteer to a part-time status so it was suggested that they might have a broader prospective as to the utility of the system (although this theory could not be quantifiably proven).

The more compelling factor in the selection process was that the SVCA had demonstrated a pressing need for tools to support the identification of suitable lands for acquisition within a relatively short deadline. In November of 1999, the U.S. Fish and Wildlife Service and the National Marine Fisheries concluded that the Atlantic salmon populations were dangerously depleted and the agencies jointly proposed listing the salmon as an endangered species under the Endangered Species Act. The proposed rule cited an increasing number of demonstrated and potential threats to critical salmon habitat as a result of human activities, including nutrient inputs, sedimentation, water temperature alterations, and streambank vegetation removal (Federal Register, 1999). The State of Maine formally opposed this ruling and offered the Maine Salmon Conservation Plan as the best protection for the salmon (Maine Atlantic Salmon Task Force, 1997).

Among its other provisions, the Plan established Watershed Councils in each of the seven rivers of concern and set aggressive goals for the amount of critical salmon habitat that must be protected through conservation easements or acquisition within each watershed by these Councils. Watersheds that did not demonstrate significant progress in meeting this mandate by December of 2001 were subject to expanded enforcement of existing state legislation and the imposition of new regulations. As a member of the Sheepscot River Watershed Council, the SVCA was concerned that the size of the region and the small number of staff available would make it difficult to meet the land acquisition goals within the allotted time period. The staff members were therefore very interested in exploring how the SDSS could support this activity.

Methods

The SDSS was modified to address the specific needs of the SVCA. The work of Kleinschmidt Associates (1999) and Murphy (1995) were used to determine the appropriate factors and constraints, along with management objectives identified by the SVCA. Spatial coverages of environmental and anthropogenic features in the watershed were the Maine Image Analysis Laboratory (land use), the Maine Office of GIS (soils, slopes, waterways, wetlands), and the U.S. Fish and Wildlife Service (fisheries habitat classifications, fishery population data). A coverage of parcel boundaries and Grand List information within the watershed was provided by the SVCA.

The Case Study methodology employed was first advanced by Onsrud et al. (1992), based on previous research by Lee (1989) and Yin (1989). The theories selected for testing were first used by Murphy and Wright (1998) in a demonstration study of the methodology. Drawing upon work completed both in the Management Information System and Geographic Information System fields, four theories related to the implementation of GIS were chosen:

User Competence Theory: If a user lacks sufficient training in the specific GIS system or experience with computer systems, resistance to the expanded use of a GIS will be great. (Igbaria and Nachman, 1990; Baroudi and Orlikowski, 1988)

Relative Advantage Theory: If the user does not perceive that the GIS will be significantly useful in accomplishing tasks relative to the current method, the intended user will not utilize the technology. (Leonard-Barton, 1987; Rivard, 1987)

Managerial Support Theory: The lack of managerial support or a 'champion' for the GIS will cause staff to resist using the system. (Leonard-Barton, 1987; Budic and Godschalk, 1994)

External Support Theory: If users receive insufficient support from outside sources (including the vendor), then users will become frustrated with the technology as a whole. (Croswell, 1991; Brown, 1996)

It should be noted that the case study methodology does not specifically require that more than one theory be tested for a single case. However, each additional theory under consideration increases the overall power of the study. As each theory was considered robust enough to be a plausible explanation for the phenomena under consideration, they were all included as part of the research.

Prior to initiating contact with the study participants, a set of predicted outcomes if each theory was correct was outlined (Table 2-1). Data as to actual conditions were collected through a survey with structured and open-ended questions and interviews with the participants. A qualitative analysis of this information was performed to determine which predicted outcomes, if any, appeared to be confirmed.

There were two hypotheses being tested during this research:

- Research at the case location will not falsify any of the four theories;
- None of the theories will prove to be a better explanation of the user's acceptance of the SDSS than the other three.

Table 2-1: Predicted Outcomes of Acceptance Theories for SDSS

Theory	Predicted Outcome
User Competence Theory	• Providing a SDSS to an organization that has personnel who frequently use GIS should increase user acceptance. • Providing a SDSS to an organization that has personnel who have received training in GIS should increase user acceptance. • Providing a SDSS to an organization that has personnel who frequently use computers should increase user acceptance. • Providing a SDSS to an organization that has personnel who have received training in computers should increase user acceptance.
Relative Advantage Theory	• Providing a SDSS that is perceived to support organizational decision- making should increase user acceptance. • Providing a SDSS that is perceived to improve job performance should increase user acceptance. • Providing a SDSS that is perceived to offer tools that are an improvement over the current means of completing tasks should improve user acceptance.
Managerial Support Theory	• The presence of a "champion" promoting the SDSS should improve user acceptance of the SDSS. • Strong overall managerial support for the SDSS should improve user acceptance of the SDSS. • Strong organizational support for the new technologies should improve user acceptance of the SDSS.
External Support Theory	• Providing adequate training in the use of the SDSS should improve user acceptance of the implementation of the SDSS. • Providing adequate technical support for the SDSS should improve user acceptance of the implementation of the SDSS. • Providing adequate training materials should improve user acceptance of the SDSS.

Results

The SDSS was installed at the headquarters of the Sheepscot Valley Conservation Association, along with the pertinent data. The study participants were allowed a two month testing period, during which time they were encouraged to record comments and request additional information as necessary. The two respondents reported that they had experimented with the technology and had demonstrated it to three board members as well as a state official who was partially responsible for implementing the Maine Salmon Conservation Plan.

Upon completion of the testing phase, the two members of the SVCA testing group were asked to evaluate the software. The small size of the watershed (seventy-five parcels) meant that the participants had a good sense of relative merit of parcels within the watershed in terms of acquisition values. In reviewing the results of testing, they noted that no valuable parcels were ranked low or undesirable parcels overrated. There was also consensus that those parcels that consistently fell in the top ten percent of the rankings warranted further scrutiny, based on available spatial data and/or user knowledge of the region. There were insufficient resources in this study to perform an analysis in the field as to whether those parcels that scored highly would be the suitable options to meet the SVCA's conservation goals.

When asked to rate their overall satisfaction, the two participants felt that their organization was moderately satisfied (4 out of 5) with the SDSS. These individuals were then asked to complete the survey, where the respondent rated their agreement or disagreement to a statement on a scale of one to five. Each statement was based on a predicted outcome for a particular acceptance theory. The respondents also answered preset questions that were also related to the predicted outcomes.

Results from the surveys and interviews were synthesized into a single observed outcome, as show in Table 2-2. This table also includes an evaluation of the degree of support that the outcome shows for a particular theory. For example, the third outcome of the Relative Advantage category shows that the users felt that the SDSS produced a moderate improvement in their ability to complete tasks. As their overall evaluation for the software was moderately satisfied, there appears to be correlation between their level of satisfaction and their perception of the utility of the system. In contrast, both participants use GIS regularly and have used computers for years. As it would be expected under the User Competence theory that this background would produce a high level of satisfaction, pattern matching shows only weak support for this theory.

The User Competence Theory demonstrates a weak pattern match with the expected outcomes. Both of the SCVA participants were highly trained in GIS technology, so their support of the SDSS technology was more moderate than would be expected. This finding suggests that 1) the users needed to be specifically trained in SDSS for there to be a commiserate high ranking of the software; 2) the users' GIS training contributed by raising the rating to a higher level of satisfaction than would have been noted by a novice user group; or 3) other factors contributed significantly to the overall rating. Follow-up conversations with the participants indicated that the SDSS software was sufficiently

Table 2-2: Pattern Matching of Four Acceptance Theories for SDSS

Theory	Predicted Outcomes if theory is true	Observed Outcome	Evidence of Support or Falsification of Theory
User Competence	1. Organization that has personnel who frequently use GIS should accept.	1. On average, participants use GIS several times per week.	Weak Support
	2. Organization that has personnel who have received training in GIS should accept.	2. Participants have taken a GIS course and used various ArcView educational materials.	Weak Support
	3. Organization that has personnel who frequently use computers should accept.	3. Both participants have used computers for several years.	Weak Support
	4. Organization that has personnel who have received training in computers should accept.	4. The participants strongly agreed that they had received adequate training in the use of computers.	Weak Support
Relative Advantage	1. SDSS that is perceived to support organizational decision- making should be accepted.	1. The participants moderately agreed that the SDSS could support decision-making.	Support
	2. SDSS that is perceived to improve job performance should be accepted.	2. Not Applicable	Neutral
	3. SDSS that is perceived to offer tools that are an improvement over the current means of completing tasks should be accepted.	3. The SDSS appeared to be a moderate improvement over the current means of completing tasks.	Support
Managerial Support	1. Presence of a "champion" promoting the SDSS should lead to acceptance.	1. The SCVA did not have a champion for the SDSS or GIS.	Falsify
	2. Strong overall managerial support for the SDSS should lead to acceptance.	2. The SCVA board did not show strong support for the SDSS, although supported GIS in general.	Weak support

	3. Strong organizational support for the new technologies should lead to acceptance.	3. The SCVA board strongly supports new technologies.	Weak support
External Support	1. Adequate training in the use of the SDSS should lead to acceptance. 2. Adequate technical support for the SDSS should lead to acceptance. 3. Adequate training materials should lead to acceptance of SDSS.	1. The participants felt that the training provided was insufficient. 2. The participants did not use technical support, so they could not comment. 3. The participants felt that the training materials were inadequate.	Falsify Neutral Falsify

similar to the standard ArcView package that they felt they had received adequate training in its use. This information would appear to discount the first alternative, but the other two possibilities remain untested.

The Relative Advantage Theory appears to be supported or at least not falsified by the study's outcomes. The respondents' moderate level of satisfaction with the SDSS was commensurate with their evaluation as to the degree of support the software offers for accomplishing their required tasks. The second predicted outcome was removed from consideration because, while the participants were working part time for SVCA, their paid duties did not involve land acquisition. However, they were involved in these activities on a volunteer basis so they could reasonably respond to the other outcomes.

The findings demonstrate support for some but not all parts of the Managerial Support Theory. The SVCA board strongly supports the use of GIS and new technologies, suggesting that the technology should have received a higher ranking. However, the SCVA did not have a single champion for either the SDSS or GIS so the expected outcome would be a lower rating than actually given. While the theory is not strictly falsified, it appears that its inclusion of the necessity of both organizational support and a single champion created a logical inconsistency. Further refinement will be required to create a more robust theoretical construct.

Finally, the pattern matches appear to falsify the importance of the External Support Theory in terms of user acceptance of the technology. The participants in the study felt that the training and associated materials were inadequate, yet they still registered moderate support for the SDSS. They did not use any technical support, so they could not comment on the potential benefits of this aspect of the project.

Discussion

At the outset of this study, two hypotheses were presented for testing. The first hypothesis stated that "research at the case location will not falsify any of the four theories". An analysis of the result shows that, while one theory was supported and two others were weakly supported, the External Support Theory appears to be falsified. The predicted outcomes from this theory did not occur in the case study setting and therefore no pattern matching occurred. Therefore, this hypothesis is rejected.

The second hypothesis was stated that none of the theories would prove to be a better explanation of the user's acceptance of the SDSS than the other three. The Relative Advantage Theory was the only one of the four theories where each of the pattern matching couplets was not either weak or non-existent. Therefore, this theory does appear to have better explanatory power than the other three and the hypothesis is also rejected. This finding is consistent with the work of Nedovic-Budic and Godschalk (1996), who found that the perceived relative advantage was the major determinant of a local government official's decision to adopt GIS.

Before accepting the results of this study, however, an evaluation of the overall experimental design is required. Lee (1989) stated that a case study could be considered scientifically valid if it met four requirements: 1) controlled observations; 2) controlled deductions; 3) allowances for replication; and 4) allowances for generalization. By establishing the conditions of supporting or falsifying the hypotheses at the outset and following a protocol for extracting the necessary information, this study meets the first two criteria. The same methodology could be employed in other locations, so the study passes the replicability test.

A potential problem with this method deals with ability to generalize in situations involving complex human interactions. The difficulty is in ascertaining how much the findings from a case study can be said to pertain to this one particular place and how much can be generalized. However, in this case, the subject case is not a particular organization but rather one of a broad class (i.e. land trust organizations). Therefore, a sufficient number of similar studies in a range of circumstances could be implemented so the research design allows for generalizability even if this study does not achieve it (Campbell, 1975).

The case study method also requires an analysis of the overall scientific rigor employed. Onsrud et al (1992) suggest several means for quantifying this process, including a measurement of representation of the degrees of freedom present (Table 2-3). This approach does not produce a single numerical value for degrees of freedom as is found in traditional statistical analysis, as values within a row cannot be added. However, these values may be compared to similar tables in other studies in order to give a sense of the reliability of one study against another.

Table 2-3: Degrees of Freedom for Four Acceptance Theories Applied to SDSS

Theory	Number of Predictions	Number of Organizational Settings	Number of Rival Theories Against Which Tested
User Competence	4	1	3
Relative Advantage	3	1	3
Managerial Support	3	1	3
External Support	3	1	3

One factor that was not anticipated at the outset was the potential impact of a cost/benefit analysis on the degree of user acceptance of the software. In interviews following the testing period, the participants felt that the software package could be a significant aid to the programmatic goals of the organization. However, this endorsement appears to at least be partially hinged on the fact that the software and data would be available at no cost (the SVCA had received their ArcView software package through a grant from ESRI's Conservation Program). Given that there was no mention of cost at the outset of the project, this issue could not be adequately explored in this study. But it does raise the question of whether or not an SDSS that is built upon a relatively expensive GIS software package is an "appropriate technology" (Yapa, 1991) for smaller organization such as the SVCA, even if the users were satisfied with the functionalities and usefulness of the package.

During the interviews conducted after the testing period, the SVCA evaluators were asked to assess the degree of confidence they assigned to the results. There appeared to be agreement that the SDSS provided a "coarse" filter of potential parcels from the population within the watershed. However, an on-site visit would be necessary to ensure that the parcel did meet the programmatic goals of the state of Maine's salmon protection program.

There are two criticisms that could be brought to bear on this study, both related to the sample pool. The first difficulty is its reliance on a single case study setting for its conclusions. Yin (1994) states that a single case study is appropriate if it presents a critical test of an existing theory, is an extreme or unique event, or serves a revelatory purpose. In this situation, this investigation served a revelatory purpose as the author is unaware of any other study of this sort from an extensive literature review. In effect, this study became a pilot study upon which future research could be based. A larger number of case studies will need to be employed in the future if the results are to be considered generalized to the larger population.

Similarly, the similarities of the two participants in the study make it difficult to evaluate the accuracy of the pattern matching exercise. For example, pattern matching for the User Competence theory indicated weak support for the all of the outcomes. Both of the participants had a high level of technological competence but were only moderately satisfied. However, it could be postulated that their skill set allowed them to overcome difficulties that less GIS competent individuals would have not. This finding suggests that the sample pool should contain not only organizations but also individuals who differ in their backgrounds. It may be advisable to add an additional column to the column suggested by Onsrud et al. (1992), as shown in Table 2-3, to include a metric for the number of individuals interviewed as well.

CONCLUSION

Increasingly the burden of meeting our public conservation goals has fallen upon the shoulders of organizations made up of largely untrained private citizens. These groups are often faced with complex decisions involving multiple and often conflicting objectives with few staff or computation resources. While the dedication and energy of these conservation organizations is laudable, it is becoming increasingly clear that there is a need to provide these individuals with user-friendly tools for exploring the decision space of the problems they face.

The recent development of Spatial Decision Support Systems (SDSS) holds the promise of facilitating these activities. SDSS are essentially a variation of Geographic Information Systems (GIS) that allow the decision maker to interact directly with the available spatial data (Densham, 1991). An operational SDSS was designed in this study to identify and rank suitable land parcels for protection given multiple criteria and user values in a spatial setting.

As shown in the previous chapter, the dominant research strategy adopted so far for exploring critical implementation factors in GIS has been the use of case studies. This approach is considered the appropriate means of exploring information systems such as GIS (Benbasat et al, 1987), but suffers from a lack of scientific rigor. Onsrud et al (1992) suggested a methodology for case study research that could be easily implemented with proper preparation at the outset and which meets the requirements of the scientific method. The SDSS was implemented in a land trust setting and four theories of user acceptance of technology were tested using a case study research methodology. The research found that one theory, the Relative Advantage theory, provided a better explanation of the phenomena under investigation.

An analysis of the research design found that the study met the requirements of the scientific methodology while achieving a reasonable level of rigor, suggesting that this approach should be more widely adopted. However, there are only a few demonstrated applications of this methodology in the literature (see Nedovic-Budic and Godschalk, 1996; Nedovic-Budic and Pinto, 2000; Sieber, 2000) and each of these studies examined the use of GIS platforms that had been in place for several years rather than new technology. This finding suggests that more efforts should be made to popularize this methodology within the GIS academic community, through education efforts and/or the setting of higher standards by research venues such as journals and conferences.

This research represents the only investigation of an SDSS in a natural setting using a "hypothesis testing" case study methodology known to the author. The apparent success of the technology suggests that it should be tested by a wider audience in order to determine how well it performs in other settings. However, the case study methodology requires significant time resources in terms of customizing the SDSS with appropriate data and conducting field interviews. In the next chapter, a methodology will be advanced for evaluating the software in an applied setting while still maintaining a scientifically rigorous research design.

CHAPTER 3: EMPIRICAL INVESTIGATION INTO USER SATISFACTION WITH A SPATIAL DECISION SUPPORT SYSTEM

INTRODUCTION

The protection of the natural environment is a growing concern across the globe and within the United States. As our understanding of the complex interaction of natural processes with economic and cultural forces grows, the process of determining appropriate uses of land becomes increasingly problematic. Land planners are often faced with the seemingly contradictory goals of promoting both a sustainable environment and a robust economy (vanLier, 1998). At the same time, there is an increasing emphasis on including the opinions of stakeholders and the public at large in the decision making process (U.S. Environmental Protection Agency, 1995; Born and Sonzogni, 1995; Richman, 1997).

Technologies such as Spatial Decision Support Systems, which generally integrate Geographic Information Systems with Multi-Criteria Evaluation, are promising tools for resolving these conflicts. These systems bring three components of traditional land use planning – information, models, and visualization – into a single architecture (Klosterman, 1999). The expectation is that the ability to view relevant information and compare alternative scenarios will lead to better decision-making (Shiffer, 1995).

However, despite this potential, most of the research has focused on the development of these tools rather than on exploration of the factors affecting their use (Klosterman, 1998;

Jankowski and Nyerges, 2001b). SDSS platforms have been employed in a number of settings but the analysis of their overall success has been qualitative and anecdotal in nature (e.g. Heywood et al., 1995; Jankowski and Ewart, 1996, Carver et al, 1996; Feick amd Hall, 1999; Vacik and Lexer, 2001; Zhang and Day, 2002). The issue is important as a lack of knowledge concerning the relative importance of different factors affecting the implementation of a GIS may result in an inefficient allocation of resources. Delays in the successful implementation of a GIS may also decrease managerial and staff support.

In Chapter 2, the development and implementation of an operational Spatial Decision Support System to support land acquisition activities was discussed. In this next stage of research, the SDSS was distributed to a set of land trust organizations for testing. A survey instrument designed to measure the overall satisfaction with the SDSS was distributed to these groups and an analysis conducted as to factors that most contributed to user acceptance of the technology. To the author's knowledge this study represented the first experimental research on spatial decision support technology where the testing group worked in their own organizational environment, rather than a laboratory setting.

Spatial Technologies in Planning Activities

From the mid 1960s to the 1980s, the use of spatial technologies was hindered by hardware, software, and data constraints. Computers had a limited capacity to store large datasets and display graphics, software capabilities were narrow in focus, and data were expensive to develop (Coppock and Rhind, 1991). The relative newness of the technology also confounded implementation efforts, frequently resulting in large expenditures with little return (Innes and Simpson, 1993). The long planning horizons and failure rates created a reluctance among managers to embrace the technology (Aronoff, 1989).

The evolution of the computer industry during the late 1980s and early 1990s from large expensive centralized systems to affordable smaller units promoted a similar transformation in GIS-related technologies. Spatial technologies began to be developed that applied to a wide range of situations as computers began to handle more complex modeling and display functions (Croswell, 1994). The software packages that became available increasingly used Graphic User Interfaces rather than command lines, thereby reducing or eliminating the need for extensive user training (Cartwright, 1995). There was also a concurrent increase in the number of free or low cost spatial datasets being made available to the public (Henderson, 1995). Governmental agencies began to direct significant financial resources towards the creation of spatial datasets (Joerin et al., 2001). More efficient data storage media such as floppy disks and CD-ROMs were available and the Internet became seen as an effective distribution method (e.g the Federal Geographic Data Committee Clearinghouse at http://www.fgdc.gov /clearinghouse/clearinghouse.html). The increasing "user-friendly" nature of GIS coupled with decreasing associated costs resulted in a wider use of the technology (Daratec, 2001).

As the capacity of spatial technologies to support analysis and decision making activities advances, there has been increased concern over who has access to this information (Sheppard, 1993; Obermeyer, 1998; Talen, 1999). Lack of access to models and tools is thought to inhibit full public participation in the planning process (Aitken and Michel, 1995; Harris and Weiner, 1998). In addition, the inability of the public to interact with the available data in a meaningful way may lead to poor decisions (Elwood and Leitner, 1998; Craig, 1996). This had led to charges that the use of GIS technology has an elitist overtone, as most platforms require a degree of technological sophistication that may not be present in local or community groups (see Pickles, 1995). The research related to making spatial tools available and accessible to all stakeholders has fallen under the rubric of "Public Participation GIS" (Schroeder, 1997).

Spatial Decision Support Systems (SDSS) hold the potential to allow for an interactive and comprehensive analysis of available data at a scale that is commensurate with that of the user's decision space. These systems generally link the ability of a GIS to store, manipulate, and display spatially explicit datasets with mathematical and cartographic models. By allowing the user to interact directly with the datasets, the technology avoids the "Hidden GIS Technocracy" discussed by Obermeyer (1995) whereby organizations must rely on experts to interpret the results of geographical analysis and modeling.

In recent years there have been deployments of these systems in a number of environments, including the World Wide Web (e.g. Jankowski et al, 1997; ESLARP, 1996; GeoMed, 1996). Yet these projects have not explicitly defined the degree to which certain factors contributed to or inhibited acceptance of these technologies.

Understanding these dynamics is particularly critical with grassroots groups, as institutional barriers may exist to accepting this technology. These may include organizational attitudes towards technology, available financial resources, and technical competence of staff and volunteers (Sieber, 2000). As GIS becomes a more viable and attractive technology for these organizations, it becomes increasingly important to provide guidance on how these systems should be implemented to avoid frustrations that could impede acceptance.

Measurements of Success

In order to begin to determine the influence of different factors on the success of a spatial technology, it is necessary to establish a measurable metric for success (DeLone and McLean, 1992; Pinto and Onsrud, 1997). While the principle aim of implementing a Geographic Information System is to improve the efficiency and effectiveness of an organization, past studies have concluded that it is extremely difficult to measure the improved efficiency that an information system brings to an organization (Myers et al., 1997).

The selection of an appropriate measurement of Information System success is a long standing concern, one that has been consistently reported as one of the top issues of Information Technology (IT) executives (Ball and Harris, 1982; Hildebrand, 1998) A review of the literature suggests several potential measurements of success. These include Performance Measures, Information Quality, System Use and Goal Attainment (Weill and Olson, 1989; Ahituv, 1980; DeLone and McLean, 1992; Anderson, 1996).

One commonly accepted surrogate for effectiveness is 'user satisfaction', or the extent to which a user believes a system meets their information needs (Goodhue, 1995). Nolan and Steward (1974) first proposed user satisfaction as a surrogate for the effectiveness of an information system. Their rationale was that an effective system would increase worker satisfaction and therefore worker productivity. Since this initial article, numerous authors have advocated its use (e.g. Igabarian and Nachman, 1990; Yaverbaum and Nosek, 1992; Miller and Doyle, 1987). Cerullo (1980) concluded that user attitude or user satisfaction is the single most important factor in the successful implementation of new information systems technology.

Some authors (e.g. Melone, 1990; Udo, 1992) have questioned the assumption that user satisfaction has been demonstrably linked to the effectiveness of an information system based on the lack of empirical research. However, Iivari and Ervasti (1994) and Gatian (1994) both performed an analysis of this relationship. In a field study of 21 public sector organizations, Iivari and Ervasti (1994) concluded that user satisfaction may be a reliable indicator of the ability of a system to be implemented and its overall effectiveness. Gatian (1994) found that user satisfaction could be linked to user behavior with the information system.

Given the increased emphasis on user satisfaction as a surrogate for effectiveness, it is not surprising that various instruments for measuring attitude have been proposed (Doll and Torkzadeh, 1988; Jenkins and Ricketts, 1985; Moore and Benbasat, 1991). The Ives, Olson, and Baroudi (1983) user satisfaction survey, a shortened version of work by Bailey and Pearson (1983), is one of most widely used and tested instruments currently available (Doll et al., 1995). The instrument asks users to evaluate 13 scales using a Lickett scale for two adjective pairs (items) per scale. For example, "Degree of training" would be rated on seven-point scale for the adjective pairs "complete / incomplete" and "high / low" (with a 4 being no opinion).

Although the Ives, Olson and Baroudi survey and its derivatives have been widely used, there are theoretical and implementation issues involved with their use. Hufnagel and Conca (1994) and Nisbett and Wilson (1977) offer cautionary information on the potential for user bias and errors in responding to survey questions. Galletta and Lederer (1989) detail some of the difficulties associated with scale unit surveys, including scale units, item heterogeneity, and instrument reliability.

METHODOLOGY

With the significant rise in the use of Geographic Information System (GIS) technologies over the last two decades, there has been a corresponding increase in literature devoted to identifying the factors that may affect the adoption and implementation of a GIS within an organization (Campbell and Masser, 1995; Nedovic-Budic, 1998).

In the previous chapter, four theories related to the user acceptance of GIS-related technology were examined using the Case Study Research methodology. This research design required that the validity of certain predicted outcomes be compared to the actual outcomes observed. The imprecise nature of pattern matching required the utilization of essentially qualitative measures. In addition, the single case study placed restrictions on the use of metrics that required comparisons to have value. For example, it is not possible to determine if the number of staff people within a single organization influences user satisfaction without having another point to compare against.

In this chapter, a modified survey research design is utilized to evaluate the factors that affect user satisfaction with the SDSS. This methodology will allow for the software to be investigated in an applied setting without the significant resources required to conduct field interviews. A fifth theoretical grouping, "System Performance", will be added to the four theories used in the second chapter. The Geographic Information Systems and Information Science literature suggests several specific factors that can be applied to each of these theories (see Croswell, 1991; Cerullo, 1980; Onsrud and Pinto 1993; Budic, 1994a; Robey and Sahay, 1996; Huxhold, 1991).

Table 3-1 presents the criteria of concern for this study. These factors were chosen based on their prominence in a review of the literature as well as their applicability to this particular research design. For example, some criteria considered important in other studies, such as access to communication channels and organizational diffusion mechanism, were rejected because the short-term nature of this study prevented an

Table 3-1: Primary Factors Affecting SDSS Success

Class	Relates to:	Factors
User Competence	Personal characteristics of individual using GIS	• Familiarity with GIS • Familiarity with computers • Length of SDSS Use • Cognitive Style • Previous training
Relative Advantage	Types of decisions being addressed by GIS	• Perceived benefits of SDSS • Perceived benefits of GIS • Perceived benefits of computers • Complexity of decisions
Managerial Support	Institutional structures of organization using GIS	• Managerial support for GIS • Managerial support for computers • Budget • Staffing of organization
External Support	Existing support structures outside of organization using GIS	• Quality of training provided
System Performance	Technological functionalities of GIS	• Accuracy • Response Time • Cost • Ease of adoption

adequate analysis of these conditions. In addition, factors related to the existence of an infrastructure that supported the software (such as user groups, talking to previous users, and educational opportunities) were also not possible given that the specific SDSS under consideration represents a new technology.

It was also necessary to employ surrogates for different factors. For the Relative Advantage theory, the total acreage of concern to the land trust served as the "complexity of decisions" value. Similarly, the "ease of use" factor under the System Performance category was represented by whether or not the organization had a GIS platform. The utilization of these surrogate values was considered necessary to ensure standardization across groups.

The research plan for this study followed the following stages:

Identification of Sample Land Trusts

The unit of analysis for this study was non-profit, local and regional land trusts with a conservation or environmental focus within the United States. Potential study locations were identified using the 1998 membership directory of the Land Trust Alliance, the largest umbrella organization for nongovernmental (NGO)/non-profit land acquisition agencies. Although there were 1,213 non-profit, local and regional land trusts entries in the directory, only 434 were included in the sampling frame. The other entries were not considered because a) their area of interest was less than 10 acres in size; b) they were primarily concerned with historic preservation; or c) there were duplicate entries for groups that covered more than one state.

The potential pool was stratified into three classes according to acreage (10-100 acres, 100-500 acres, greater than 500). These intervals were chosen based on natural breaks in the acreage values in the pool, so the end result was roughly even classes. A random selection of fifty (50) organizations was taken from each class, for an initial sample pool of 150. In addition, all forty-six (46) land trust organizations in the state of Maine were selected to facilitate the onsite trainings that were under consideration at the time. It was later decided that this training option would not be pursued because it would not be possible to standardize this training sufficiently, but these groups had already been sent letters of invitation to participate in the study. In all, the final sample pool included 196 members out of a possible 434 (45%).

In December of 1999, the members of the initial sample pool were sent a letter of introduction and a consent form (see Appendix A for samples of documents). Each letter of introduction was sent on letterhead and personalized to increase legitimacy and resultant response rates (Bailey, 1987). The consent form collected background characteristics of the group and its willingness to participate. Land trusts were asked to return the consent form within two months in order to participate in the study. A pre-stamped standard letter envelope was included in anticipation of increasing return rates (Rea and Parker, 1992).

Development of Questionnaire

For the first part of the questionnaire, a user satisfaction survey based on a modified version of the one presented by Ives, Olson, and Baroudi (1993) was developed. Raymond (1987) found that this instrument was particularly reliable and valid for measuring user satisfaction in small organizations. Ten scales or topic areas were chosen and two questions developed for each (for a total of twenty questions in the instrument). For each question, users were asked to provide a score ranging from 1 (unsatisfied) to 5 (satisfied). The scale was reduced from the normal 1-7 based on feedback gathered from four reviewers. An overall satisfaction rating was derived by calculating the mean of the scores for the 20 questions.

The second part of the questionnaire elicited information relative to the success factors of interest as shown in Table 1. These criteria would serve as the independent variables later in the study), in order to test different theories of GIS adoption and implementation. Each section of the second part of the questionnaire addressed different factors under investigation. While Sections 1 to 4 were developed independently, Section 5 was a simple version of the standard Myers-Briggs Type Indicator survey (Myers-Briggs, 1962). Section 6 allowed the participant to provide unstructured feedback. This section could not be quantitatively evaluated, but did allow the participants to share information on the SDSS' utility that might not be captured through the questionnaire.

The majority of factors were based on either fixed characteristics of the land trust organization (e.g. staffing, familiarity with GIS) or its response to the SDSS (e.g. ease of use, perceived benefits). There were four other factors under consideration in this study that needed to be set. Background materials provided user groups with one of two values for the accuracy of the system (60% or 90%) and one of three values for its cost ($5.00, $100.00, or $500.00), depending on their placement in the research design (see below). Each user group also received one of two training manuals: 1) a detailed training manual that included a step-by-step tutorial with background material and a description of the mathematics involved in the program's calculations; or 2) a simple training manual that only provided the tutorial.

The final version of the questionnaire and training manual was presented to three individuals for review. These were the same individuals who beta-tested the SDSS in Chapter 2. After incorporating their remarks, another group of six provided comment. The final version of all materials was produced at the end of this second round.

Mailing of Survey

In April of 2000, the eighty-one eligible organizations that had returned the consent form were sent a package of information that contained a letter of introduction, a training manual, and a copy of the SDSS on a floppy disk (which included sample data). Those organizations that did not currently have access to ArcView were sent a demonstration copy whose license was set to expire two months after installation.

The material sent to a land trust was based on the organization's position within the experimental design's Latin Square (see Figure 3-1). For example, an organization

Figure 3-1: Experimental Design

		C1	C2	C3
T1	A1			
	A2			
T2	A1			
	A2			

Where :

T1: User received simple training manual

T2: User received detailed training manual

A1: User is told SDSS results have 60% accuracy

A2: User is told SDSS results have 90% accuracy

C1: User is told SDSS is available for $5.00

C2: User is told SDSS is available for $100.00

C3: User is told SDSS is available for $500.00

placed in Cell T1:A2:C2 received a simple training manual and a background letter that stated the SDSS had an 60% accuracy and a cost of $100. Organizations were randomly placed into cells after being once again stratified by acreage.

In June of 2000, a second letter was sent to land trusts that had not returned their questionnaires. Where email addresses were available, emails were sent one month later to organizations that had not returned the requested materials. The letters reemphasized the importance of the study and offered to resend all of the relevant materials, including the ArcView demonstration disk.

Research Objectives

For the purposes of this study, there were two hypotheses being tested:

1. Research results will not falsify any of the five theories;
2. None of the theories will prove to be a better explanation of the user's acceptance of the SDSS than the other four.

For this research, the threshold P value for significance was set at 0.10. An alpha value of 0.05 would indicate highly significant results.

RESULTS

Out of 196 letters of invitation, eighty-one (41%) land trusts returned the consent form indicating their willingness to participate in the study. Slightly more than half of the consenting group did not have access to a GIS platform. Because the SDSS was built in a

PC environment, the ten respondents who had access only to a MacIntosh computer were removed from consideration after a confirmation phone call. Twenty-four (24) land trusts completed the survey, for a 30% return rate. Because of this low return rate, it was not possible to perform block-level analysis on the Latin-square design. Instead, statistics were limited to comparing results within rows and columns.

In order to compare the reliability of the user satisfaction instrument, the mean value for the nineteen questions related to user satisfaction was compared to the final question ("My overall satisfaction with our SDSS system is best described as:") using a Bonferroni t-test. There was no significant difference between the values ($p = 0.184$). The average of all questions was used as the User Satisfaction Rating for the remainder of this analysis. The overall average rating was 3.3, indicating mild satisfaction with the SDSS. This value was lower than that reported in Chapter 2, where the two participants from the Sheepscot Valley Watershed Association considered themselves to be moderately satisfied (4 out of 5) with the SDSS.

Questionnaire responses were entered into the Systat statistical software package (SPSS, 2000). Analysis consisted of univariate and bivariate statistical analysis. The results are presented in Table 3-2.

Table 3-2: Results of Analysis of Variance

Class	Factor	Analysis Results
User Competence	Length of System Use	F = 2.184 p = 0.10*
	Familiarity with Technology (GIS)	F = 3.213 p = 0.06*
	Familiarity with Technology (Computers)	F = 1.343 p = 0.29
	Previous Training	F = 4.575 p = 0.02**
Relative Advantage	Perceived Benefits of SDSS	F = 1.028 p = 0.49
	Perceived Benefits of GIS	F = 0.818 p = 0.61
	Perceived Benefits of Computers	F = 1.870 p = 0.16
	Complexity of Decisions	F = 0.743 p = 0.49
Managerial Support	Managerial Support (GIS)	F = 1.635 p = 0.20
	Managerial Support (Computers)	F = 2.323 p = 0.08*
	Budget	F = 1.107 p = 0.52
	Staffing of Organization	F = 0.683 p = 0.57
External Support	Training Provided	F = 0.031 p = 0.86
System Performance	Accuracy	F = 2.099 p = 0.16
	Response Time	F = 1.190 p = 0.35
	Cost	F = 0.999 p = 0.39
	Ease of Adoption	F = 6.714 p = 0.02**

* = Significant Result (alpha at 10%)

** = Highly Significant Result (alpha at 5%)

Based on the preset alpha values, User Satisfaction was significantly correlated with the following:

- Length of System Use (p = .10)
- Familiarity with GIS Technology (p = 0.06)
- Previous Training (p = 0.02)
- Ease of Adoption (p = 0.02)
- Managerial Support for Computers (p = 0.08)

To test the strength of the relationship between these variables and user satisfaction, regression analysis was run. Table 3-3 presents the results of a regression analysis using the dependent variable of User Satisfaction and the significant independent variables. The results indicate that both Previous Training (p = 0.054) and Length of System Use (p = 0.084) has a significant influence on user satisfaction, although not highly significant according to the standards established at the outset of the study.

Table 3-3: Results of Regression Analysis

	t-value	p value
Length of System Use	1.830	0.08*
Familiarity with GIS Technology	-0.294	0.77
Previous Training	2.064	0.05*
Ease of Adoption	0.109	0.92
Managerial Support for Computers	0.884	0.39

Participants' comments on the survey form were also evaluated for content. Twenty-one (21) out of twenty-four (24) land trusts provided feedback. Eleven (11) respondents spoke of the promise of the SDSS, although only four seemed to feel the system was complete in its current form. Three (3) individuals noted that data costs could be prohibitive for the system and one (1) person noted the difficulty in evaluating the SDSS' results using data from an unknown location. Three (3) posed questions as to the MCE techniques used and four (4) felt that the training manual was incomplete. All four of these individuals received the simple training document. Four (4) groups also stated that their land trust was too small for the software to add any efficiency to their operations.

The results provided the greatest confirmation of the User Competence theory, with significant values for three out of the four factors. Both the Managerial Support theory and System Performance theory had significant values for only one out of four criteria. This finding indicates weak support for these theories, which could potentially be strengthened with a refinement of the questions posed. None of the factors for either the Relative Advantage or System Performance theories were shown to have a significant correlation with user satisfaction, which would appear to falsify their importance in the acceptance of the SDSS technology.

DISCUSSION

A review of the literature found only three previous empirical studies devoted to the use of SDSS technology: Mennecke et al., 2000, Reitsma et al., 1996, and Jankowski and

Nygerges, 2001b. This investigation was unique in that the technology was tested in an applied setting, as the three other known studies utilized a laboratory setting. While the use of a laboratory design may have some advantages (including better control over subjects and increased participation rates), a field based design gives insights into how a spatial technology can best be successfully implemented and utilized in an organization's natural state (Mark, 2000).

At the outset of this research, two hypotheses were presented for testing. The first stated that none of the five research theories would be falsified. However, the chosen representative characteristics of both the Relative Advantage and External Support theories did not appear to have any effect on user satisfaction with the SDSS. The falsification of the External Support may be in some part due to the fact that both training manuals were designed to be as user-friendly as possible in order to avoid discouraging participation. A greater variation in the range of support provided would be necessary to ascertain when or if External Support becomes important.

The falsification of the Relative Advantage theory is more surprising, however, given its prominence in the literature (Nedovic Budic and Godschalk, 1996; Mennecke et al, 2000) and the findings of Chapter 2. One interpretation of the overall results and written comments is that, while the participants thought that the SDSS showed promised for assisting land trusts in general, they were not clear it would assist with the specific tasks they faced in their own work. This conclusion suggests that either the SDSS was not specifically tested by the individual directly involved in land acquisition or that participants could be satisfied with the SDSS in general but not as it specifically applied to their tasks within the organization. Further research would be necessary to explore the underlying reasons for this apparent discrepancy.

The second hypothesis was that none of the theories would prove to be a better explanation of the user's acceptance of the SDSS than the other four. As discussed above, the results do not support that contention. Instead, User Competence appeared to be the strongest theory, with three out of four potential factors being significant in terms of user satisfaction. In addition, two of the four theories failed to show any explanatory powers. Therefore, the two hypotheses presented for testing in this study are both rejected.

A statistical analysis found that five factors were significantly correlated with user satisfaction: 1) Length of System Use; 2) Familiarity with GIS Technology; 3) Previous Training; 4) Ease of Adoption; and 5) Managerial Support for Computers. Length of System Use and Previous Training will be discussed below. Previous research related to GIS technology by Budic and Godschalk (1994b) found that computer experience was a significant factor in a user's decision to accept the innovation. As the SDSS represents a specific type of GIS platform, it may be that previous experience with GIS serves a similar function in terms of decreasing barriers to acceptance.

Two of the significant factors, Familiarity with GIS Technology and Ease of Adoption, specifically required that the organization had a GIS within their organization. These organizations had already demonstrated an investment in the technology, which could transfer to the SDSS platform. However, it was surprising to see that Managerial Support for Computers was significant while Managerial Support for GIS was not. One explanation is that it is not necessary for a land trust's governing body to support GIS as long as the staff and volunteers with self-initiative are provided with adequate computing resources.

Regression analysis found only Length of System Use and Previous Training were significant. These results are similar to those of Onsrud and Pinto (1993), who employed a large-scale empirical survey methodology to identify quantitatively the critical traits for the GIS diffusion process. This study found that Access to Learning and Ease of Use were the two most critical factors in successful GIS adoption. They are also highly consistent with Carey (1988), who found that variables such as experience, education, and system use were highly correlated with the acceptance of new technologies. This suggests that individuals with the proper background and interest will achieve greater benefits with this SDSS (and most likely new technologies in general) than those who lack either of these characteristics.

Comparison with Case Study Research of Chapter 2

In the Case Study Research study presented in the previous chapter, the strongest explanatory hypothesis was the Relative Advantage theory, with weak support for the User Competence theory. In this investigation, User Competence has strong support while none of the factors related to the Relative Advantage theory were significant. The results for both the Managerial Support and External Support appear to be similar to those in the early study.

There are three likely explanations for this apparent reversal in the results for two of these theories. First, at the Case Study site all of the software and relevant datasets were installed directly. This deployment of the system may have alleviated some of the frustrations of other users, particularly those without a background in GIS. Second, in the interview stage of the Case Study research, both participants commented that the training materials provided were less than satisfactory. It may be that their background in GIS actually buoyed their overall rating for the system. Finally, the Case Study location had a specific set of goals to accomplish within a limited timeframe. The presence of a defined mission could have elevated the importance of evaluating the SDSS' benefits in the users' minds.

User Participation Information

In order to understand the barriers to the study, an analysis was made of the characteristics of groups that elected to move to different stages of the research design. There was a significant correlation ($p = 0.007$) between a group's decision to participate and the total acreage under its purview. The same correlation did not hold for the organization's budget ($p=0.410$) or whether it had full-time staff ($p=.302$). These findings are difficult to interpret, as generally speaking an increase in the size of an area of concern will result in the presence of full-time staff and a larger budget.

For those groups that did volunteer to participate, an analysis of the user responsiveness was also conducted, with the dependent variable being the user's decision to return the survey (i.e. "returned survey" and "did not return survey"). The following variables were found to have a significant effect:

- User had GIS ($p = 0.000$)
- Number of staff ($p = 0.019$)
- Budget of organization ($p = 0.081$)

Both the number of acres and volunteers were found to be insignificant ($p = 0.41$ and $p = 0.526$, respectively). This finding suggests that organizations with jurisdictions over larger areas of interests were more likely to volunteer for the study, but other factors influenced their decision to complete the evaluation process.

The presence of a GIS within an organization appeared to be the best indicator of a land trust's willingness to participate. There are a variety of potential reasons for this result. By having GIS on a computer, the user would not be required to go through the somewhat cumbersome step of installing the software. Staff familiarity with a GIS may have lowered the anticipated time necessary to test the SDSS, so that there would be less of a psychological barrier to participation. It is also possible that organizations with a GIS may be more open to advances in the technology and innovation as a whole.

Land Trusts with staffing and higher budgets also were more likely to participate. This finding is not surprising, given the time constraints placed on most volunteers. While their initial intent to participate may have been sincere, scarce resources often result in the abandonment of optional tasks (Sieber, 2000). This hypothesis is supported by the communications received from eight organizations that informed me that they would not be participating. Most cited time constraints due to new organizational or personal commitments. Future studies should investigate the potential of providing incentives for participation, particularly for smaller and volunteer land trust organizations. These incentives could include monetary inducements, publicity in local news venues, or entry into a lottery for assorted prizes.

Future Research Directions

The results suggest that not having access to GIS technology presented a barrier to participation. There are two options for overcoming this hurtle. First, the SDSS could be more tightly bundled with the shell GIS environment. For example, ESRI produces a package called MapObjects that allows a programmer to create all of the functionalities of the ArcView package as well as additional tools. This approach has the advantage of removing any of the functionalities that might complicate the potential user's trial experience.

Another option would be to develop an SDSS that was accessed through the World Wide Web (WWW). The Internet is already used for database warehouses and some public participation software packages (see Carver et al, 1996; Craig et al, 1998), but has been little progress in developing GIS-based decision support software in this environment (Ascough et al., 2002). The utilization of the Internet would also remove the need for access to a specific computer platform. The advantage to removing this requirement can be seen in this study, where 10 out of 81 willing participants (12%) had to be turned away.

While the use of the Internet application may offer the possibility for future studies to increase the number of participants, return rates may improve if more effort is made to customize the datasets used. Although only one of the evaluators who returned the survey commented on the difficulties in evaluating the ranking results for an unknown location, four individuals contacted by email to encourage their participation made mention of this issue. A nested experiment, where some groups received data for their region of interests while others did not, could be instrumental in determining how much this factor affects satisfaction as well as participation.

In reviewing the three laboratory-based empirical SDSS papers, one common feature is that these studies focused on evaluating how well the software supported decision-making related to a designated problem. Reitsma et al. (1996) presented a water resource issue while Jankowski and Nygerges (2001) and Mennecke et al., (1997) asked participants to complete site selection exercises. Although both of the training manuals detailed a series of steps designed to familiarize the user with the SDSS' capabilities, the users were not directed to complete a specific task or tasks. It is possible that the addition of a defined goal and endpoint may have engaged the user's interest and therefore increased participation. Standardization of the tasks to be completed would also help to promote a commonality of experience between the evaluators. However, as the purpose of the software is to explore a decision space, it will not be appropriate or useful to reduce the evaluation process to a series of small, precisely formulated tasks (Andrienko et al, 2002).

Finally, with an overall participation rate of 12%, this study suffers from the common problem of 'Nonresponse' (Groves & Couper, 1998). This missing data is important as the unknown characteristics and attitudes of non-respondents may cause inaccuracies in the study results. Although this study presents a limited analysis of non-respondents based on publicly available data and a limited survey for those who elected to participate, a more systematic attempt to determine the reasons for land trusts opting out of the study should be conducted. This information could detect the presence of a non-response bias that could be estimated and accounted for in presenting the final results.

CONCLUSION

In the past two decades, developments in spatial platforms such as Geographic Information Systems and Spatial Decision Support Systems have changed the ways in which planners and the public have acquired and use spatial data. Advances in computer storage and display capabilities have allowed these technologies to move from systems that could only be accessed by trained technicians to desktop units in the hands of the direct stakeholders and decision makers.

However, it is becoming increasingly clear that it is as important to understand how a GIS-based application is used as it is to develop the application (Nyerges et al, 2002). The expectation is that studies of this nature will allow for an easier integration of the technology into a real-world organizational setting, thereby promoting greater diffusion of the technology. It is particularly important to understand the barriers to user acceptance of the innovation in organizations that are resource poor, such as non-profits or other non-governmental organizations.

In this study, an operational SDSS was deployed in a field setting for testing by several land trust organizations. These organizations completed a survey designed to measure their overall satisfaction with the system as well as elicit information related to their overall attitude towards aspects of the SDSS and technology in general. The results were analyzed in order to produce a quantifiable assessment of the importance of certain factors on overall user satisfaction. The findings offer some insight into the issues that must be addressed in order to maximize user satisfaction, which presumably should translate into increased use by the land trust organizations.

This study represents the first empirical attempt to evaluate an operational SDSS in a field setting and one of the few for spatial technologies in general. By grounding the GIS research within the context of existing theories, there was a marked increase in the overall scientific rigor of the research compared to the majority of the existing applied GIS-related research. A motivating factor for this study is the belief that the movement from hypothesis generation to the hypothesis testing research designs is a necessary step to expand the depth and maturity of the overall discipline.

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APPENDICES

APPENDIX A: INITIAL LETTER TO PARTICIPANTS

UNIVERSITY OF MAINE

College of Natural Sciences, Forestry, and Agriculture

Department of Forest Management
5755 Nutting Hall
Orono, Maine 04469-5755

Dear ____________________

I am writing you today to invite you to participate in a research project related to land acquisition for natural resource protection. I obtained your name through the membership directory of the Land Trust Alliance organization.

My doctoral research focuses on the development of software systems to aid organizations such as yours in acquiring land in an efficient and effective manner. To this end, I have designed and programmed a Spatial Decision Support System (SDSS) that allows users to rank suitable parcels for acquisition given multiple criteria in a spatial setting. I would now like to have organizations such as yours test this software to determine its utility.

To participate in this study, please fill out and return the enclosed questionnaire in the pre-stamped envelope that I have provided. If you are randomly selected from the pool of interested organizations, you will be sent a copy of my SDSS to test over a one-month period. You will then receive a survey designed to determine your overall satisfaction with the system as well as elicit general information about your organization. This survey should take approximately one hour to complete and you may skip any question you do not wish to answer.

I hope that you will be able to help with this important research. This study represents a significant step towards realizing the promise of SDSS for natural resource protection and your contribution is vital. If you have any questions, please call me at 207-827-0513 or email me at Sean_Murphy@umit.maine.edu. Thank you for your help.

Sincerely,

Sean Murphy
Doctoral Candidate

APPENDIX B: INITIAL QUESTIONAIRE TO PARTICIPANTS

QUESTIONNAIRE

As part of a study on the use of Spatial Decision Support Systems, we are conducting a study of organizations such as yours that are interested in acquiring land for natural resource protection. The questionnaire is divided into two parts. The first part is a series of questions related to the general characteristics of your organization. The second part outlines a confidentiality agreement and obtains your written consent to be a part of this study as required by the University of Maine. Please feel free to expand on your answers on the reverse side.

Part One: General Characteristics of My Organization

1. My organization is currently concerned with protecting approximately________________ acres.
2. Our annual budget is approximately $__________________________.
3. We are/are not currently seeking to acquire land or establish easements on land within our jurisdiction.
4. We currently have __________ full-time staff and __________ volunteers directly involved with land acquisition or conservation easement activities.
5. I do/do not have access to a personal computer.

   If yes, this computer (circle one for each): is an IBM compatible / Mac,
   does/does not have a CD-ROM
   does/does not have a Zip Drive.

   If yes, how long have you used this computer for work-related activities? ___________ months/years
6. We do/do not currently possess or have access to a Geographic Information System.

   If yes, please name the system: Arc-Info Arc-View Map-Info

   Other:_____________________________

   How long have you used this GIS software? ______________ months/years

Part Two: Confidentiality and Informed Consent Information

As a subject in this study, I understand my name, the name of my organization, or any identifying references will not be published in any way without my explicit and written permission. Participation in this study is voluntary and I may refuse to answer a question or withdraw without penalty at any time. I assent that there is no more risk to participating in this study than that in everyday living. Completion of this questionnaire indicates my willingness to be a member of this research project under these conditions.

____ ______________

Name Date

Organization: ____

Mailing Address: ____

City, State, Zip Code: ____

APPENDIX C: SECOND LETTER TO PARTICIPANTS

UNIVERSITY OF MAINE

College of Natural Sciences, Forestry, and Agriculture

Department of Forest Management
5755 Nutting Hall
Orono, Maine

April 11, 2000

<Participant's Name>
<Organization>
<Street Address>
<City, State Zip Code>

Dear <Participant>
Let me begin by thanking you again for agreeing to be a participant in my doctoral research on the development of spatial tools to support land acquisition activities. Please find enclosed in this package the following items:

- The Spatial Decision Support System (SDSS) on a 3.5 floppy disk;
- An owner's handbook for the Spatial Decision Support System;
- A demonstration copy of the Arc-View GIS software on CD-ROM;
- A user satisfaction questionnaire; and
- A pre-stamped envelope for returning the questionnaire.

The handbook provides step-by-step instructions for installing and operating the SDSS. It can be run on either your hard drive or off the floppy disk. If you do not currently own the Arc-View software package, you will have an opportunity to inspect this Geographic Information System through software generously provided by ESRI. If you do currently own Arc-View, you will find that the SDSS operates as a normal Arc-View project.

As part of this study, I would like to ask that you evaluate the software for no more than a one-month period or until approximately the middle of May. If you are using the ArcView GIS demo version, you should be aware that the CD is designed to cease running after one month has elapsed so it is especially important you work within the planned study period. Pre-testing indicates it should require no more than 2 – 3 hours to explore the capabilities of the system. Once you feel you have adequately tested the software, please fill out the questionnaire and return it in the enclosed pre-stamped envelope. The survey should take approximately one hour to complete and you may skip any question you do not wish to answer.

As you proceed to test this software, you may have questions. Please do not hesitate to contact me by phone (207-827-0513) or email (Sean.Murphy@umit.maine.edu). Again, thank you for your help. Your cooperation is critical to providing decision-makers like yourself with the tools they need to effectively protect natural resources.

Sincerely

Sean Murphy
Doctoral Candidate

APPENDIX D: USER SATISFACTION QUESTIONNAIRE

QUESTIONAIRE

Now that you have tested the Spatial Decision Support System (SDSS), we are requesting that you fill out the following questionnaire to help us better understand your organization and your overall satisfaction with the system. While the results of this study will be published, all of your responses will be kept confidential and released in a generalized format. In cases where it may be useful to focus on your organization as a case study, a letter will be sent prior to publishing to obtain your permission and relevant sections will be sent to the your organization for review and approval. We ask that you answer each question as honestly as possible with the understanding that you may skip any question without penalty.

The survey is divided into two parts, with several sections in the second part. For each question, you should circle only one answer unless specifically requested to circle more. The entire survey should take no more than one hour to complete.

<u>**PART ONE**</u>

Please answer the following questions about the Spatial Decision Support System (SDSS) you have been using. There are no right or wrong answers. We are simply interested in your opinions on different aspects of the technology.

For the questions below, please circle the answer that best corresponds to your opinion. For example, if the question was:

What is the temperature outside today?
Very Cold 1 2 3 4 5 Very Hot

If you think it is very cold, you should circle 'one'.
If you think it is cold, you should circle 'two'.
If you have no opinion or are indifferent, you should circle 'three'.
If you think it is hot, you should circle 'four'.
If you think it is very hot, you should circle 'five'.

1. When I compare the SDSS to my initial expectations, I am:
   Disappointed 1 2 3 4 5 Pleased

2. The time required to produce information on the SDSS system is:
   Unsatisfactory 1 2 3 4 5 Satisfactory

3. I feel that I understand the results from the SDSS:
   Poorly 1 2 3 4 5 Very Well

4. I believe that the reports and maps produced by the SDSS are:
   Irrelevant to My Work 1 2 3 4 5 Relevant to My Work

5. The information produced by the SDSS is:
   Not Very Useful 1 2 3 4 5 Very Useful

6. I would describe the SDSS training our organization received as:
   Incomplete 1 2 3 4 5 Complete

7. The reliability of the maps and analysis produced by the SDSS is:
Unsatisfactory 1 2 3 4 5 Satisfactory

8. I think that accessing the SDSS program for use is:
Cumbersome 1 2 3 4 5 Simple

9. When I see the results of the SDSS, I am:
Not Very Interested 1 2 3 4 5 Very Interested

10. I would describe the SDSS training manual our organization received as:
Unsatisfactory 1 2 3 4 5 Satisfactory

11. When talking to other land trusts about this SDSS, I would:
Not Recommend It 1 2 3 4 5 Recommend It

12. The SDSS produces the information I need:
Slowly 1 2 3 4 5 Quickly

13. If the SDSS contained data for lands of interest to me, I think the program would be:
Not Very Useful 1 2 3 4 5 Very Useful

14. I would describe my skill level using the SDSS system as:
Novice 1 2 3 4 5 Proficient

15. The reports and maps from the SDSS contain the:
Wrong Type of Information 1 2 3 4 5 Right Type of Information

16. The analysis data produced by the SDSS system is:
Inconsistent 1 2 3 4 5 Consistent

17. The accuracy of the maps and spatial analysis produced by the SDSS is:
Inadequate for Our Needs 1 2 3 4 5 Adequate for Our Needs

18. The training I have received in using our SDSS system has been:
Insufficient 1 2 3 4 5 Sufficient

19. To become proficient at using the SDSS, I think it would require:
A Lot of Effort 1 2 3 4 5 Not Much Effort

20. My overall satisfaction with our SDSS system is best described as:
Very dissatisfied 1 2 3 4 5 Very Satisfied

PART TWO

For each of the questions below, circle the answer that corresponds to your opinion. Please note that with few exceptions, you should only circle one (1) answer for each question.

Section One

1. How often did you use the SDSS during the trial period?
   (1) One time
   (2) 2-4 times
   (3) 5-7 times
   (4) more than 7 times

2. On average, how much time did you spend using SDSS on those occasions that you use it?
   (1) Less than 1/2 hour
   (2) Less than one hour
   (3) 1-2 hours
   (4) 2-3 hours
   (5) More than 3 hours a session

3. What is the operating speed of the computer that you used to operate the SDSS?
   (1) 386
   (2) 486
   (3) Pentium I
   (4) Pentium II
   (5) Pentium III or higher
   (6) Don't know

Please circle the number that best corresponds to your opinion on the statements below. While it is difficult to make predictions based on a general piece of software, please make your best guess based on what you have seen of the SDSS at this point.

1= Strongly Disagree 3= Uncertain or no opinion 5= Strongly agree

1. I could envision how an SDSS similar to this one could be valuable for my organization.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

2. A SDSS similar to this one could greatly aid our decision-making processes.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

3. The SDSS output could be a valuable resource in our educational outreach activities.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

4. Using a SDSS such as this one could improve my job performance
   Strongly Disagree 1 2 3 4 5 Strongly Agree

5. Using a SDSS such as this one could increase my overall productivity.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

6. I think a SDSS such as this one could be a useful tool in completing my organizational tasks.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

Section Two
If you or your organization owns or has regular access to a Geographic Information System (GIS), please answer the following questions. Otherwise, please move on to Section Three.

What type of GIS system do you have access to? (circle all that apply)
Arc-Info   Arc-View   Map-Info   Other:________________________

1. How long have you personally used GIS technology?
   (1) Less than 6 months
   (2) Less than one year
   (3) 1-2 years
   (4) 2-4 years
   (5) More than 4 years

2. On average, how often do you use GIS for job-related work?
   (1) Less than once per month
   (2) Once per month
   (3) A few times a month
   (4) A few times per week
   (5) About once per day
   (6) Several times per day

3. On average, how much time do you spend using GIS on those occasions that you use it?
   (1) Less than 1/2 hour
   (2) Less than one hour
   (3) 1-2 hours
   (4) 2-3 hours
   (5) More than 3 hours

Please circle the number that best corresponds to your opinion on the statements below.
1= Strongly Disagree   3= Uncertain or no opinion   5= Strongly agree

7. Using our GIS improves my job performance
   Strongly Disagree   1 2 3 4 5   Strongly Agree

8. Using our GIS increases my overall productivity.
   Strongly Disagree   1 2 3 4 5   Strongly Agree

9. I find the GIS to be a useful tool in completing my organizational tasks.
   Strongly Disagree   1 2 3 4 5   Strongly Agree

10. Using the GIS enhances my overall effectiveness.
    Strongly Disagree   1 2 3 4 5   Strongly Agree

11. I find that using our GIS is a significant improvement over our previous ways of completing tasks.
    Strongly Disagree   1 2 3 4 5   Strongly Agree

12. My manager / Board supports and encourages the use of GIS in my work-related activities.
    Strongly Disagree   1 2 3 4 5   Strongly Agree

13. Our organization is aware of the benefits that can be achieved by a GIS.
Strongly Disagree 1 2 3 4 5 Strongly Agree

14. Our organization feels that the use of a GIS is critical towards achieving our organizational goals.
Strongly Disagree 1 2 3 4 5 Strongly Agree

15. Our GIS output has been valuable in the management of our lands.
Strongly Disagree 1 2 3 4 5 Strongly Agree

16. Our GIS output has been valuable in helping to protect our rivers and watershed.
Strongly Disagree 1 2 3 4 5 Strongly Agree

17. Our GIS output has been a valuable resource in our educational outreach activities.
Strongly Disagree 1 2 3 4 5 Strongly Agree

18. Our GIS is more useful than the SDSS we tested.
Strongly Disagree 1 2 3 4 5 Strongly Agree

19. What type of external training have you received in the use of a GIS (circle **all** that apply)?

- None
- User conference
- General training workshop (hands-on training)
- Software-specific workshop (hands-on training)
- Course(s) in related field (ie. Spatial analysis, remote sensing, computer programming)
- Course(s) focused on theory and application of GIS
- Undergraduate degree in GIS-related field or extensive use of GIS in completing degree requirements
- Graduate degree in GIS-related field or extensive use of GIS in completing degree requirements

20. Have you ever used vendor-supplied or other training materials?
Yes No

21. If yes, please circle all of the educational techniques that apply.
    - Instructional Video
    - Manuals or technical documentation
    - Web-based information
    - Tutorial provided by vendor
    - Tutorial provided by another external source
    - Tutorial provided by internal source

Section Three
If you or organization own or have regular access to a computer, please respond to the questions below. Otherwise please move on to Section Four.

1. How long have you personally used a computer?
   (1) Less than one year
   (2) 1-2 years
   (3) 2-4 years
   (4) More than 4 years

2. On average, how often do you use a computer for job-related work?
   (1) Once a month or less
   (2) A few times a month
   (3) A few times a week
   (4) About once a day
   (5) Several times a day

3. On average, how much time do you spend using a computer when you do use it?
   (1) Less than one hour
   (2) 1-2 hours
   (3) 2-3 hours
   (4) More than 3 hours

Please circle the number that best corresponds to your opinion on the statements below.

1. I am comfortable using computers for work-related tasks.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

2. My background gives me sufficient experience to use our computer(s).
   Strongly Disagree 1 2 3 4 5 Strongly Agree

3. I have received adequate training to use our computer(s).
   Strongly Disagree 1 2 3 4 5 Strongly Agree

4. Using our computer(s) increases my overall productivity.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

5. I find the computer to be a useful tool in completing my organizational tasks.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

6. My manager/Board supports and encourages the use of computers for my work activities.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

7. Our organization is aware of the benefits that can be achieved by computers.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

8. Our organization feels that the use of computers is critical towards achieving our organizational goals.
   Strongly Disagree 1 2 3 4 5 Strongly Agree

Section Four

This set of questions expands upon the information you submitted in your initial questionnaire. If you are not sure about the answer, please give your best estimate if at all possible.

1. My organization is currently interested in an area (watershed, etc.) of approximately ___ acres.
2. My organization currently has about ____ acres under protection (ownership, easements, etc.).
3. Our total annual budget is approximately $_____________________.
4. We expect to spend $_____________ annually to protect areas through ownership, easements, etc.

SECTION FIVE

For each question below, there are two columns with a set of activities or personal attitudes. While you may have characteristics in both columns, please circle the one that is the best fit with your personality. Please remember, you may chose to skip any question without penalty and your answers will be kept confidential.

1. For these sets of options, which are you more comfortable with? (circle one)

Column A	Column B
Like working in groups	Would prefer to work alone
Communicate with enthusiasm	Keep enthusiasm to myself
Meet people readily	Proceed cautiously when meeting people
Talk more than listen	Listen more than talk

2. Which set of learning styles best describes the way you take in information? (circle one)

Column A	Column B
Learn new things by observation.	Learn new things through general concepts.
Rely on past experiences.	Rely on hunches.
Tend to be specific and literal.	Tend to be general and figurative.
Value realism and common sense.	Value imagination and innovation.
Appreciate standard ways to solve problems.	Use new and different ways to solve problems and reach solutions.

3. Which column best describes the way you make decisions or address issues? (circle one)

Column A	Column B
Decide more with my head.	Decide more with my heart.
Chose truthfulness over tactfulness.	Chose tactfulness over truthfulness.
Notice ineffective reasoning.	Notice when people need support.
Deal with people firmly if needed.	Deal with people compassionately.
Note pros & cons of each option.	Note how each option affects people.

4. Which set is the best description of your approach to life? (circle one)

Column A	Column B
Prefer knowing what I'm getting into.	Like adapting to new situations.
Enjoy finishing things.	Enjoy starting things.
Feel better after making decision.	Prefer to keep my options open if possible.
Dislike surprises and sudden changes.	Enjoy adapting to last minute changes.
Like being settled and organized.	Like to be flexible and spontaneous.

<u>Section Six</u>

In the space below, please feel free to provide any comments you feel would help us better understand your level of satisfaction with the Spatial Decision Support System. Please feel free to discuss your opinions related to your current GIS or computer capacities. If you prefer, you may attach a separate sheet to this questionnaire for your comments. Thank you for your time and effort.

APPENDIX E: SPATIAL DECISION SUPPORT HANDBOOK

Handbook for

Land Acquisition Spatial Decision Support System

I. Welcome

Thank you again for agreeing to test this Spatial Decision Support System or SDSS. It is our hope that systems like this one will be the first step towards putting critical decisions back in the hands of decision-makers such as you. Your cooperation is the essential.

The information contained in this handbook is meant to serve as a guide for your exploration. Each section provides a description of what should be happening at that stage, followed by a step-by-step example. The Appendix section provides additional information this is not necessary for testing the software, but may help your understanding of the underlying processes.

Although this guide is designed to be a stand-alone document, you may encounter difficulties or have questions as you progress. While multiple users have tested this software, there is always a chance that an unexpected glitch may arise. Please feel free to contact me by phone (207-827-0513) or by email (Sean_Murphy@umit.maine.edu) if you have any problems or questions. My role during this process is to make your task as painless as possible and I'm happy to do whatever I can to help.

II. Why is it important to study Spatial Decision Support Systems?

New regulatory requirements and heightened public concern about the state of the environment have prompted many entities such as land trusts and public agencies to adopt programs to protect lands from developmental pressures. Land acquisition and conservation easements are frequently cited as the most effective means of conserving natural resources. In order to protect land effectively, decision-makers must be able to identify parcels for acquisition given multiple criteria and programmatic objectives.

Since the early 1980s, Geographic Information Systems have become a commonplace research tool for a variety of applications, including natural resource conservation. The ability of these systems to store, display and analyze spatially explicit data has added new dimensions to traditional problems facing researchers. However, while they have been very useful in providing new information, GIS applications have rarely provided direct support for decision-makers as most GIS packages are complicated and require that the user have special training.

Spatial Decision Support Systems (SDSS) are new technology that integrates the problem-solving tools of Multi-Criteria Evaluation (MCE) with the spatial abilities of a GIS. Decision-makers are allowed to explore the "decision space" of a problem or the set of results possible through different management choices. By allowing decision-makers to directly interact with the data available, it is hoped that the choices made will be more reflective of the real priorities of the individual or organization. <u>You have been chosen as one of a small group of individuals to test this software and so it is important that you return the enclosed questionnaire. Your participation today will increase our understanding of what needs to be done to make these systems a practical and effective tool for other natural resource advocates such as yourself.</u>

III. Additional Factors when Evaluating the Spatial Decision Support System

There are three areas of consideration that we ask that you consider when completing the final questionnaire:

1. Use of Generic Datasets

In previous research on SDSS software systems, the datasets used encompassed the region of specific concern to the test subjects. This study represents the first attempt to distribute a generic SDSS to many different users and it would be almost impossible to tailor the SDSS for each of the groups participating. Therefore, two generic watershed datasets are included for analysis in this package. While your lack of familiarity with the study areas will prevent you from directly confirming the results produced, you should be able to get a sense of the abilities of the SDSS. We ask that you consider this potential when evaluating the software.

2. Estimated Cost of Program

Because this SDSS was developed as part of a degree program, it is difficult to calculate the expenses involved in producing the software. In order to produce a reasonable valuation, a local consulting firm that specializes in spatial systems produced a cost-estimate. For the purposes of this study, please assume that your organization spent $100 for this software package when performing your evaluation of the system. If you do not currently own or have access to ArcView, please also assume that you obtained the ArcView system for free through a grant or donation.

3. Estimated Accuracy of Program

There are two primary sources of error in a SDSS: database error and decision rule error. Database error refers to measurement inaccuracies in the spatial layers used. For example, a slope measured at 5% may actually be 3% or 7%, depending on the uncertainty associated with the measurement technique used to collect the data. Decision rule errors are a product of how the criteria are combined and evaluated. This set includes errors in how information is acquired from the decision-maker.

Based on error assessments performed on this SDSS, this system has a 90% accuracy rating. This means that if a parcel is ranked 5^{th} out of 10, there is a only a 10% probability that it has been incorrectly classified. The accuracy of the system rises to 95% if you include the classes on either side of the ranking. In the above example, there is only a 5% chance that the parcel does not fall into the 4-6 range). Please bear this information in mind when performing your evaluation of the system.

IV. Installing the ArcView GIS Demo Software package

This SDSS is built upon the Arc-View software program, distributed by the ESRI Corporation. If you already have the ArcView GIS system installed on computer, you may move on to the next section. Those of you who do not have ArcView will be able to try this package out thanks to the generosity of ESRI's Higher Education Project. Simply place the disk provided in your CD-ROM and wait for the installation shield to pop up. If you would like to learn more about GIS and in particular ArcView, you should consider taking the WWW-based tour. If not, it is best to read the notes provided before installing the ArcView GIS Demo version on your computer. The length of the installation process will vary depending on the speed of your system.

V. Starting the Land Acquisition Program

In addition to the ArcView GIS Demo program you should find a 3.5 floppy disk with the materials sent to you. This disk contains the SDSS program as well as the datasets you will use. You may run the program off of your floppy drive or transfer all of the files on the disk to a new directory on your hard drive. The program will run much faster if the files are on the hard drive, but you must copy <u>all</u> of the files in order to avoid an error as you try to use the software.

There are two ways to initiate the SDSS program:

- Click on the Landacq icon (either on your disk or in the directory you copied it to)
- Open the ArcView program and chose the File Menu ->Open Project. Browse until you find the Landacq project. A project is a collection of spatial data sets, scripts for performing different options, and layout options.

<u>Note</u>: When you install ArcView, you may find that no icon appears on your desktop and there is no listing in the Start-> Programs menu. You may need to create your own shortcut. Click on your desktop with the right mouse button and select New- > Shortcut. Chose the browse option and in most cases you will go to: C:\esri\av_gis30\Arcview\bin32 (depending on where you installed the ArcView program. Click on the ArcView icon (a magnifying glass over a globe) to create the shortcut.

VI. Initial User requests

As you begin the program, you will be asked to select a Watershed View File. A view is a collection of spatial datasets or themes and there are two provided. The first, "Parcel Based Dataset", is a watershed where a number of data layers were available, including slope, distance to waterways and the existence of wetlands. It is organized by parcels within the watershed, so the size and value of each parcel is also available. The second view, "Region Based Dataset", contains three datasets that are commonly available for free from state agencies: slope, proximity to waterway, and presence of wetlands. Instead of parcels, the watershed is divided into grids of approximately the same size. For more discussion of the differences between the two views, please see Appendix A.

- To begin, chose the "Parcels Based Dataset".

You will then be asked to choose a theme to serve as your primary working file. A theme is a spatial dataset that may be displayed and queried. In each view there are two themes available. "Water" or "Hbwater" display the waterways within the watersheds and are provided primarily to help you get a sense of the watershed. The second option is either "Parcels" or "Region" (depending on which view you chose in the previous step.) Choose whichever of these is currently available as the primary theme.

- Click on the downward arrow and chose "Parcels".

A box will appear that asks you to assign environmental and economical criteria to fields in your working theme file. The criteria are:

Slope: change in elevation (higher numbers indicate a steep surface)
Wetland: presence of wetland as determined by National Wetland Inventory data
Floodplain: distance from waterway in yards
Price: total value of the parcel as determined by certified appraisers
Acres: size of property
Adj. To Public: indicates parcel is adjacent to a publicly owned piece of land (which may make it easier to manage the property)

In order to reduce your workload, the program has been preset so that the correct field name is assigned to each criterion automatically.

- Click on the OK button.

The project will now open up on your screen. The view you selected will be in the window, with the waterways lying on top of it. Depending on the size of your screen, you may find that it is not optimally placed or sized. It is perfectly fine to move the window by clicking on the top of the window and holding down as you move the mouse until it reaches your destination. You may also resize the project by moving mouse around the to outer edge of the project until you see a double-arrow symbol -- you may now hold down the mouse and move the window until it reaches the size for which you are looking.

WARNING: When you leave this program, you will be asked if you wish to save any changes that you have made to the Landacq project. In order to protect the program, please use the "File ->Save Project As" option so you do not permanently alter the original project.

VII. Basic ArcView Functions

After you have responded to the initial user requests, the ArcView program should produce a screen that looks similar to Figure 1 below. The primary difference is that on the main menu at the top of the screen there is an option entitled Modules between the Theme and Graphic menus. In the Theme Window should be the Water and Parcels themes, each with a check next to them. If you click the right button down on either of these check marks, the theme should no longer be visible.

While the ArcView program has a number of features that could be useful to you in exploring spatial datasets, there are seven primary buttons that will be useful to you as you experiment with the SDSS.

Identify: Displays the attribute values of the active theme in a view. To make a theme active, click on it in the Theme window (it will appear raised).

Zoom In: Zooms in on a view. Click on a view and will zoom in by a factor of 2.0 on the center of that position or define a zoom area dragging a box with the mouse.

Zoom Out: Zooms out from position on view where you click with the mouse.

Pan: Allows you to move display. To pan, hold down mouse button anywhere over the view and drag in any direction. Release button to leave the display in desired position.

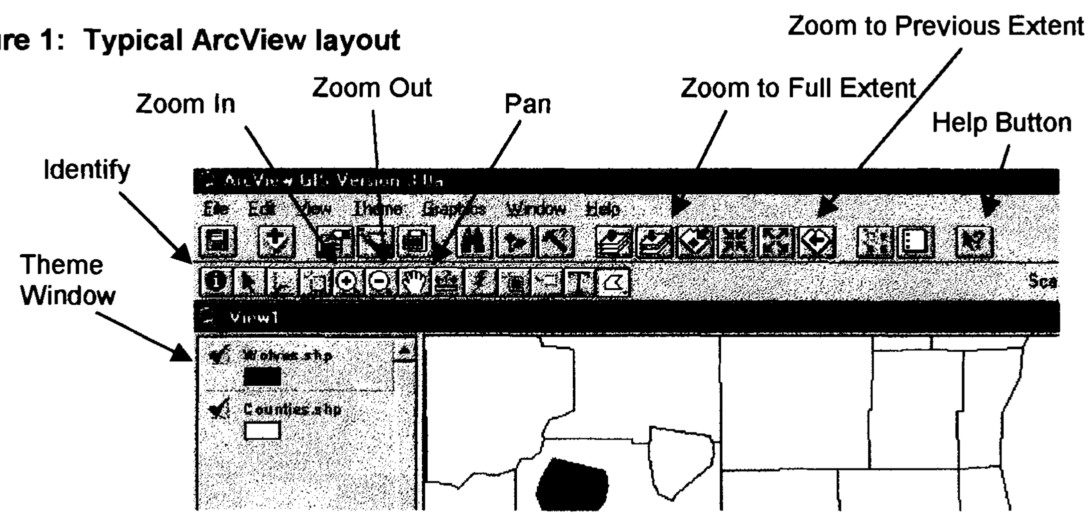
Zoom to Full Extent: Zooms to the full extent of all the themes in a view.

Zoom to Previous Extent: Goes back to previous position before your last zoom or pan.

Help Button: Lets you get help about any of ArcView's buttons, tools or menu choices. Click the Help button and then click any other button, tool or menu choice to learn more about it.

If you have any questions about any of the other tools provided, the Help menu will provide useful information. See Appendix B for some web sites with ArcView tutorials.

Figure 1: Typical ArcView layout



VIII. Modules

This SDSS has four modules that are designed to help the decision-maker rank the desirability of parcels or regions within a watershed based on the user's professed priorities. In each module you will be asked to express your preference for one criterion relative to other criteria. The methods employed will differ primarily in terms of their accuracy and degree of ease for the user. As you use each method, please keep track of how well you understand what is happening.

In most cases, decision-maker preferences can be expressed by weights. A weight is defined as a numeric value that indicates the relative importance of one criterion relative to others. The larger the relative weight, the more important the criterion is to the user. We use the concept of weights in our every day language when we make statements such as "I like chocolate half as much as vanilla" or "I'd pay four times as much to sit front row center then in the balcony".

For each module, a brief explanation of the theoretical underpinnings of the particular method being used is provided. This is followed by an example where sample numbers are provided. When you run each module, a dialog will appear on the left side of your project. After you enter your numeric values, the program will perform a series of calculations and produce a map indicating the relative preference for one region or parcel relative to others. Desirable areas are indicated by a green color, undesirable areas are red, and areas that do not meet the constraints you selected are assigned the color black.

A. Simple Selection

This module allows you to select parcels or regions within the watershed that contain certain features or meet certain rules. For example, you could identify those areas in the Parcels Based dataset that were larger than a certain size and have a wetland on them. Those of you who are familiar with ArcView will recognize that this module is simply a preset version of the Query function. In this module, each criterion is evaluated by an absolute standard: either it is or is not important for the decision-maker.

If you would like to explore the Query function more, make sure the Parcels or Region theme is selected (indicated by being slightly raised) or click on them to activate them. You may then chose the Query command from the Theme menu or click on the hammer icon.

Example:

- From the SDSS Modules Menu on the top bar, select Simple Selection Method.
- From the "Slopes Greater than Box", select 5 Percent and hit the OK button. Try the 10 Percent and 15 Percent options to get a sense of the topography of the watershed.
- Click on box to left of Wetlands options and hit OK button. Parcels with wetlands will be colored yellow. Note where these selected parcels are located.
- To confirm presence of wetland, select identity button and click on one of the selected parcels. In the identity box produced, the value for Wetl should be "100".
- Enter 50 in space for "Total Acres Greater than" option while leaving the Wetland box "on". Note that the number of parcels has decreased significantly. If you click the

Wetland box "off", you will see that there are not many parcels this size in the watershed.

- When finished, hit Exit button

B. Ratio Estimation Method

The Ratio Estimation Method requires users to express their preferences in a relatively simple manner. A score of 100 is assigned to the most important criterion in the eyes of the decision-maker. Smaller scores are given to the other criteria based on their value relative to other criteria. A series of calculations produce a normalized weight for each criterion (see Appendix C for a discussion of these rules).

Example:

- From SDSS Modules Menu, select Ratio Estimation Method
- Enter value of 100 in box to right of Slope and value of 10 in Floodplain box. Fill in remaining boxes with value of 50 and hit OK button. This configuration makes Slope and Floodplain the dominant criteria for determining the suitability of a parcel.
- A map will appear in screen with color range of green to red. To see what colors signify, move the Ratio Estimation Method dialog box to one side. In Theme Window you will see a legend that assigns the color green to parcels with a highest preference rating and reddish colors to the lowest.
- Enter value of 10 in Slope box and 90 in Floodplain box, leaving other values constant. Hit OK button and see if you can see differences in where undesirable properties are located. Recall where the high slopes were in the previous exercise.
- When finished, hit Exit button

C. Additive Overlay Method

The Additive Overlay Method, also referred to as the weighted linear combination or scoring method, is one of the best known methods of decision making in a GIS environment. The decision-maker assigns weights for each criteria based on her or his 'relative preference. Each pixel or vector of the corresponding data layer is then multiplied by this weight and these values are summed to produce an overall score. Higher scores indicate that the user should prefer those parcels or regions over others, assuming that the weights offered reflect the decision maker's real preferences. The concept of the Additive Overlay is further discussed in Appendix D.

Example:

- For this example, we will use the second dataset. From the SDSS Modules Menu, click on Reselect view. Choose the "Region Based dataset" for the Watershed View File and "Region" as the primary theme. Click OK when asked to assign fields.
- From SDSS Modules Menu, select Additive Overlay Method.
- Move the lever on one of the slider bars and the number to its left should change.
- Set the Slope slider on ~81 and Floodplain on ~18, with wetlands remaining at zero, and hit OK button. Notice where the least preferred areas (colored red) are located.
- Reverse the Slope and Floodplain values and hit the OK button. See if you can determine why there is a shift in the placement of the least desirable regions.

- In the Constraints section, click on the button limiting the selection process to slopes greater than 10%. Priority parcels are now near to the river that runs north to south.
- Click the clear button to set Slope and Floodplain to zero and deselect the slope constraint. Enter a value of 100 for Wetlands. Before you hit the OK button, see if you can predict the resulting map. Hit the OK button. Because a region either does or does not have a wetland, its value is either 0 or 100 (absence or presence of wetland).
- When finished, hit Exit button

D. Pairwise Comparison Method

Thomas Saaty developed this method during his development of the analytical hierarchy process (AHP). Values are entered in a matrix to reflect that user's preference for one criterion over another. One of the advantages of this technique is that you can utilize the matrix structure to test how consistent your comparison's are. While Appendix E gives a detailed explanation of the mathematics involved, it is easiest to understand this method through the use of an example.

Example:

- From Modules Menu, select Pairwise Comparison Module.

A 3x3 grid appears, with spaces for you to enter 3 numbers. The number "1" runs diagonally through the grid because these boxes compare the same criterion. There are only three boxes available because we can assume the comparison matrix is reciprocal: if you prefer Slope twice as much as wetlands (2), we can conclude that you prefer wetlands half as much as Slope (1/2).

In entering numbers in the grid, you should read it as "preference for row criteria over column criteria". For example, the value in the space in the upper far right corner of the matrix should express the value you place on slope over that of floodplains. In Saaty's preferred approach, the user assigns a value from one to nine to express the intensity of preference for one criterion over another (see Table 1 on the following page). To express a negative preference, enter a negative number or fraction. For example, if you prefer slope half as much as wetlands, you should enter a -2 or 0.5 in the top middle box.

- Enter a 4 in the first box on the top row, a 7 in the next box and a -5 (or .2) in the only box in the second row. Hit the OK button.

When you hit ok, the computer will give you the consistency rating for your values. In this case, a .5 is considerably higher than the recommended value of 0.10 or below. Why did this happen? With your first two rows, you established that you moderately preferred slopes over wetlands, but strongly preferred them over floodplains. Your order of preference is therefore, from highest to lowest priority, slopes -- wetlands -- floodplains. However, in your second row your negative number indicates that you moderately preferred floodplains to wetlands. This indicates inconsistency in your values.

- Enter a 4 in the first box on the top row, a 7 in the next box and a 5 in the last space on second row. Hit the OK button.

Your consistency is only slightly higher than the 0.10 threshold. For the purposes of this exercise, this is an acceptable number.

-
- Click on the OK button of the Consistency Rating dialog box. Note where the most desirable properties are to the west, where the slopes are highest. This should not be surprising, considering your strong preference for Slope over Floodplain.
- Enter the negative for all your previously entered values. Hit the OK button for this dialog box and for the Consistency Rating box. Note the shift in where the 'best' regions are located.
- When finished, hit Exit button.

Table One: Scale for Pairwise Comparison (Saaty, 1980)

Intensity	Definition
1	Equal Importance
2	Equal to Moderate Importance
3	Moderate Importance
4	Moderate to Strong Importance
5	Strong Importance
6	Strong to very strong importance
7	Very strong importance
8	Very to Extremely strong importance
9	Extreme importance

While it is relatively easy to see inconsistencies with a small number of criterion, it is obviously much more difficult with several boxes to fill. Try using the Pairwise Comparison method with the Parcels dataset to confirm this statement. You may notice that you produce much lower consistency ratings if you only use positive numbers in the matrix. However, this is obviously not always going to be possible in a real world scenario.

Appendix A: Description of GIS datasets

There are two datasets provided with this project. The parcel dataset has six criteria associated with it: slope, wetlands, floodplains, acres, price, and adjacent to public land. It is often difficult to acquire parcel and then spatially locate it within your area of interest. Even ten years ago very few communities had digital maps of their lots. But with advances in Geo-Positioning Systems (GPS) and the increasing use of GIS for regional planning, this type of data is now becoming more common.

The second data set (Region Based Dataset) has only three criteria: slope, wetlands, and floodplain. These layers represent the most common datasets that are available for free to interested users. For example, the state of Maine's Office of GIS now allows citizens to download this information for free off of its website. However, it is also relatively easy to create your own datasets to supplement this basic environmental information with information such as the location of historical sites, rare plant species, or other critical aspects of the landscape. All of these attributes were associated with a grid spread across the landscape to minimize the processing time for the SDSS and to allow all the data to fit on one disk.

You may ask which data type you should use while exploring the SDSS. In an ideal world, you would be able to experiment with both of them in order to get a sense of what kind of information you can gather from each. However, some of the modules provided in this SDSS may run slowly on your computer depending on the speed of your processing unit. In particular, the Pairwise Comparison Method and Additive Overlay Method do a number of calculations. In the interest of time, you may want to select the Region Based Dataset when you wish to experiment with these functions.

Appendix B: Selected list of ArcView Tutorial Sites on the Web

- http://sal.uamont.edu/sal/weih/introduction_to_arcview_tutorial.htm

[This web site slowly completes certain key tasks while you watch.]

- http://www.imlab.uiuc.edu/eslarp/gis/arcview/index.htm

[This site is a very basic tutorial on how to use ArcView.]

- http://www.library.wisc.edu/libraries/Steenbock/bipage/arcview/arcview.htm

[The University of Wisconsin has a very simple tutorial available.]

Appendix C: Ratio Estimation Method

There are four criteria in this example: A, B, C, D. The most important criterion is C in the eyes of the user, so it is assigned a value of 100. Other scores are given based on the perceived value of these criteria relative to C and the others. The original weight is calculated by dividing each Ratio Scale by the lowest score, in this case, 10. The total of Original Weight Values is summed. To normalize the weights, each Original Weight entity is divided by the summed total of all the Original Weight values. The sum of all the normalized weights is 1.

Table 2: Ratio Estimation Method

	Ratio Scale	Original Weight	Normalized Weight
A	10	1 (10/10)	.05 (1/22)
B	30	3 (30/10)	.14 (3/22)
C	100	10 (100/10)	.45 (10/22)
D	80	8 (80/10)	.36 (8/22)
		22	1.00

Appendix D: Additive Overlay Method

This approach is also referred to as the weighted linear combination method and is one of the most commonly used techniques for spatial decision making. The general equation is:

$$S = \sum w_i x_i$$

where S = suitability of alternative
w = weight assigned by the decision maker for criterion i
x = value of criterion I

The Additive Overlay module in the Spatial Decision Support System follows four steps:

- Identifies data layers to use in calculating suitability;
- Normalizes values in data layer;
- Multiplies data layer by normalized weight value
- Sums or subtracts values as appropriate to create suitability layer.

In the simple example below, three data layers are chosen: Slope, Wetlands, and Floodplain. Each layer is normalized using the formula:

((Cell Value – lowest value) / (highest value – lowest value)) * 100

For the upper right hand corner cell of Slope, the calculation is:

((3 – 1) / (3 – 1)) * 100 = 100

In this example the user chose three weights: 80 for Slope, 40 for Wetlands, and 20 for Floodplain. Using the normalization process discussed in the Ratio Estimation method, the weights for Slope, Wetlands, and Floodplain become 0.57, 0.29, and 0.14 respectively. The data layers are multiplied by these values in Step 3.

In the final step of this example, the layers are summed or subtracted. For both slope and wetlands, higher values are more preferred (it is better to have a wetland than not) so these values may be added. However, a property in general becomes less valuable as you move further from a stream or riverbank so the values are subtracted. In the final data layer, the cell with the highest suitability value is the one associated with medium slopes, reasonably close proximity to a waterway and the presence of a wetland.

Step 1

Slope

3	3	2
3	2	2
2	1	1

Wetlands

0	0	0
0	0	100
0	100	0

Floodplain

300	250	200
250	200	100
200	100	0

Step 2

Slope

100	100	66
100	66	66
66	33	33

Wetlands

0	0	0
0	0	100
0	100	0

Floodplain

100	83	66
83	66	33
66	33	1

Step 3

Slope (X .57)

57	57	38
57	38	38
38	19	19

Wetlands (X .29)

0	0	0
0	0	29
0	29	0

Floodplain (X .14)

14	12	9
12	9	5
9	5	1

Step 4

Suitability

43	45	29
45	29	62
29	43	18

Appendix E: Pairwise Comparison Method

In the pairwise comparison method, criteria are compared against each other in pairs to create a ratio matrix. Weights for each criterion are determined by normalizing the eigenvector associated with the maximum eigenvalue of the reciprocal ratio matrix.

Taking the example presented earlier, the resulting pairwise comparison matrix is:

Criterion	Slope	Wetland	Floodplain
Slope	1	4	7
Wetland	¼	1	5
Floodplain	1/7	1/5	1

To compute the criterion weights, the following steps should be taken (Table 3):

1. Sum the values in each column of the matrix;
2. Divide each element by its column total to normalize the matrix;
3. Compute the average of the elements in each row.

Table 3: Calculation of criterion weights

	Step One			Step Two			Weight	
	S	W	F	S	W	F		
Slope (s)	1	4	7	0.718	0.769	0.538	(0.718+0.769+0.538)/3 =	0.675
Wetland(w)	¼	1	5	0.179	0.192	0.385	(0.179+0.192+0.385)/3 =	0.252
Floodplain(f)	1/7	1/5	1	0.102	0.039	0.077	(0.102+0.039+0.077)/3 =	0.073
	1.393	5.2	13	1.00	1.00	1.00		1.000

The next step is to determine if the weights calculated are consistent given the values entered into the comparison matrix. The initial steps for this calculation are (Table 4):

1. multiply weight of first criterion (slope) by the first column of the pairwise comparison matrix, the second weight by the second column, and the third weight by the third column;
2. sum all of the resulting values by rows;
3. divide the result by the criterion's weight.

Table 4: Initial steps for determining consistency ratio.

Criterion	Step 1			Step 2	Step 3
Slope	0.675 * 1	0.252 * 4	0.073 * 7	= 2.194	2.194 / 0.675 = 3.250
Wetland	0.675 * ¼	0.252 * 1	0.073 * 5	= 0.782	0.782 / 0.252 = 3.119
Floodplain	0.675 * 1/7	0.252 * 1/5	0.073 * 1	= 0.220	0.220 / 0.073 = 3.014

To complete this calculation, we need two more numbers. First, lambda (λ) is the average of the three consistency vector values:

$$\lambda = (3.250 + 3.119 + 3.014) / 3 = 3.128$$

The Consistency Index is a normalized measure of the degree of inconsistency. It is measured through the following equation, where n is the number of criterion involved:

$$CI = \frac{\lambda - n}{n-1} = \frac{3.128 - 3}{3-1} = 0.064$$

To compute the Consistency Ratio, you must divide the Consistency Index by the Random Index (RI). The Random Index is based on the number of criterion being compared and is 0.58 for three criterion (1.24 for six).

$$CR = \frac{CI}{RI} = \frac{0.064}{0.58} = 0.110$$

Adapted from Jacek Malczewski, GIS and Multicriteria Decision Analysis

APPENDIX F: THIRD LETTER TO PARTICIPANTS

UNIVERSITY OF MAINE

College of Natural Sciences, Forestry, and Agriculture

Department of Forest Management
5755 Nutting Hall
Orono, Maine 04469-5755

June 2, 2000

<Participant's Name>
<Organization>
<Street Address>
<City, State Zip Code>

Dear <Participant>

Let me begin by once again expressing my gratitude for your willingness to examine the Spatial Decision Support System (SDSS) that I developed as part of my graduate research program. SDSS hold great promise for organizations such as yours and your participation in this study could yield exciting benefits.

I am writing today because as of this date I have not yet received the survey that was enclosed with the other SDSS materials I sent to you in April. If you have already completed the survey and it is simply in the mail, I appreciate your efforts and look forward to reading your comments. However, if you have not yet returned the survey I'd ask that you please consider trying to complete it within the next two weeks if at all possible. Due to the relatively high costs of producing and sending materials, the SDSS package could only be sent to a small number of land trust organizations. Your insights into the utility of this software are therefore critical to producing results that are significant and meaningful.

The summer months can understandably be very hectic, both professionally and personally, and I know from personal experience the difficulty in finding enough time. But in this case the couple of hours you spend now could have a real and lasting effect on tools available for preserving our environment in the future. If you have any questions or concerns, please feel free to contact me at 207-581-2831, the address above or at Sean_Murphy@umit.maine.edu. Thank you in advance for your assistance.

Sincerely,

Sean Murphy
Doctoral Candidate

BIOGRAPHY OF THE AUTHOR

Sean Murphy was born in Norwood, Massachusetts in July of 1966. He was raised in Montpelier, Vermont and graduated from Montpelier High School in 1984. He attended Dartmouth College and graduated in 1988 with a degree in History and Philosophy. After four years of working in the non-profit environmental sector, he matriculated at the Yale School of Forestry and Environmental Studies. After receiving a Masters in Environmental Management in 1994, he entered the Forest Management graduate program in the fall of 1994.

After receiving his degree, Sean will continue to work at the firm of Heindel and Noyes, an environmental consulting firm. Sean is a candidate for the Doctor of Philosophy degree in Forest Resources from The University of Maine in December, 2003.