Invited Presentation

Geographic Information Systems and Applied Economics: An Initial Discussion of Potential Applications and Contributions

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Geographic Information Systems (GIS) are becoming increasingly important to virtually all of the natural and social sciences. Applied economists will find that GIS can make valuable contributions to many of the problems with which they are concerned. Moreover, a great deal of the science behind GIS technology would benefit from the contributions of applied economists. This paper presents some initial suggestions for the ways in which GIS may be important to economics and the GIS related issues concerning which applied economists could provide useful insights.

Introduction

To those of us already caught by the rising tide of interest and activity concerning Geographic Information Systems (GIS) it may seem that there can be no academic or professional discipline as yet untouched by its waves. While a healthy skepticism toward such movements has kept many of us from being entirely swept away in its rip, there are no fewer than five professional associations in the United States whose annual meetings are almost entirely devoted to GIS, and it is becoming nearly impossible to attend a meeting of natural or social scientists where GIS is not among the topics of discussion. Statements such as "North America is currently experiencing a revolution in the linking of computer-based Geographical Information Systems (GIS) to planning issues" (Harris and Elmes) are neither uncommon nor seemingly inaccurate. Virtually every academic geography, planning, and natural resource management department has one or more GIS specialists. Nearly all national planning agencies, every state and province in the United States and Canada, and a substantial and growing percentage of counties and large and moderately sized cities have some GIS capability (Fischer & Nijkamp).

Perhaps more than a few of us have expected this wave of interest to crest and break, giving way to calmer reflection on what this technology is about and what long term role it can play in the disciplines in which we are schooled. It is the intent of this paper to consider what GIS technology may have to offer to applied economists and what contributions applied economists may be able to make concerning the many issues that surround the growing use of GIS. Perhaps then we will be in a better position to decide whether this rising tide of interest in GIS is a natural flow, caused by the attraction of technology and information, that will soon move into its ebb phase, or the beginning of a more permanent condition of high tide.

GIS

GIS has been defined in alternative ways; common ground includes the notion that a GIS is a collection of tools and methods for acquiring, storing, managing, transforming, analyzing, summarizing and displaying spatially referenced data for the purpose of understanding and contributing to the solution of real world problems (Burrough; Fischer and Nijkamp; Fernald). While the general expectation is that these tools and methods will be computerized, there remain even today elements of data collection, interpretation, and analysis that are

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visual and manual and yet form essential components a functional GIS.

The major elements of a GIS are often described as:

- a data base of spatially-referenced, natural and anthropogenic features and associated attributes that comprise both spatial and tabular data elements;
- computer software to allow for the input, storage, retrieval, manipulation, analysis, and output of both feature and attribute data;
- computer hardware and peripherals that work in conjunction with the software to enable all the listed software functions to occur;
- an appropriate set of standards, methods, procedures, user interfaces, quality controls, and the people who apply them; so that the GIS products can be objectively replicated, measured and evaluated.

With the growing demand for more and better geographic information and technology, advances within these four elements of a GIS are occurring at a rapid pace. In the area of data collection, for example, there have been significant improvements, and corresponding cost reductions, in the last two or three years in the sophistication of Global Positioning Systems (GPS) (a satellite-based radio-wave, point-location technology) and the recent maturation of digital ortho photography (a digitally-produced, planametrically-accurate, photographically derived image base map). These two technologies alone may well reduce the time and cost required for base map compilation to one quarter or one tenth of what it was just a decade ago.

At the same time, continuing reductions in the cost of computer processing capacity and data storage and retrieval devices enables the collection, storage, and processing of much larger data sets. Hence, because today's systems can effectively use data with much greater detail and at higher resolutions, the tendency exists to build data bases that are far more content-rich than before. Resources that are saved due to increased efficiency of technology are applied to capturing much richer data.

Many early studies have shown that the most significant costs (70% on average) associated with the development of a GIS are in the area of data base creation. Improved efficiencies in data capture can lead to significant cost reductions. Such cost reductions can place GIS capabilities within the reach of organizations with relatively fewer resources.

Because public agencies continue to be the major purchasers of GIS information and components ($8 to $10 billion annually in the United States), government organizations are the most significant source of resources committed to the development of standards, methods, and quality assurance procedures (for both data and products). The federal government, in close association with the academic community through such programs as the NSF funded National Center for Geographic Information and Analysis (NCGIA) has recently focussed much of its resources on the development of national spatial data transfer and metadata (documentation) standards, as well as the creation of a National Spatial Data Infrastructure (NSDI) program.

GIS software belongs to a family of spatial data software that includes Computer Aided Design (CAD) software, Automated Mapping/Facilities Management (AM/FM) software, and Thematic Mapping software. It is differentiated from them by three functional capabilities: its ability to recognize relative direction and location (topology); the close coupling of graphic (feature) elements with intelligent data base attributes; the ability to process polygons (areas defined by points and lines) through a broad array of boolean operations.

Many commercially available GIS software products are on the market today. At the high end are those software systems that are fully featured and require substantial commitments of staff and computer time. Such systems cannot be installed or applied on a casual basis; they are not especially user friendly and require significant organizational resources. Some GIS software systems are designed with a particular set of applications in mind, such as those specific to transportation planning or land records management. When a product can be found that optimizes performance around a set of functions that closely match organizational needs, it is generally a more efficient product. On the other end are an increasing number of lower end packages that offer many fewer software features and may even lack some of the full range of topology, data base functions, and polygon processing capabilities. Some even have proprietary data formats or lack data input capabilities which can only be resolved by experienced programmers. Selecting the best GIS software for a particular mix of functional needs and organizational resources can be a difficult and time-consuming task.

Uses of GIS

The proceedings of various academic and professional meetings are filled with examples of the ways in which GIS technology is being applied. Yet, many of these papers are much the same and fail to provide any critical assessment of the nature and value of the contribution that the GIS made to the actual problem at hand. Very few papers generally have surveyed the applications of GIS in any broadly applicable fashion and even those have been found to contain some significant omissions or to be lacking in objectivity. The more important areas to which GIS is currently being applied include natural resource and land use planning, environmental assessment, protection, and management, infrastructure management (roads and utilities), transportation planning, public health, social services delivery, economic development, property and land records management, facility siting, and marketing.

The natural resource planning agencies have clearly led the way in the United States in the development of GIS programs at both the federal and state levels. This is in contrast to the European and Australian experience with GIS in which cadastral (land records) systems played the dominant role. Natural resource agencies have tended to focus their GIS capabilities toward building inventories of natural features (wetlands, surface and ground water resources, habitat types, soils, and vegetation) and the uses that we make of them (pollution discharges, land use, population distribution, water supplies). The primary motivation has been the prevention or mitigation of conflicting uses and the understanding of causes of environmental degradation. These broad inventories of the natural and built environment have allowed agencies to conduct some relatively simple analyses such as development suitability, facility siting, risk assessment, and habitat designation.

Planning agencies at all levels of government in the United States are generally viewed as being among the primary beneficiaries of GIS (Harris and Elmes). Planning agencies most often deal with land, its uses, and the local decisions and regulations that govern them. Much of what planning agencies do involves granting and keeping track of permissions to use land in a specific manner. Secondarily, planning agencies often participate in decisions about where to place things that provide for common needs such as roads, schools, hospitals, fire stations, and waste disposal sites. Sometimes these agencies make plans of a more comprehensive nature and they must try to optimize the use of finite resources, build community resources that match local preferences, generate alternative scenarios, or model the outcomes of possible decisions. Several papers (Harris; Fischer and Nijkamp) have shown that planning agencies have been quite successful in using GIS to conduct the more basic and routine tasks for which they are responsible, but are considerably less successful in applying GIS to more complex tasks such as generating alternative plans and projecting outcomes.

Within the past several years we have witnessed the release of some small scale yet nationally consistent GIS data bases (TIGER, for example) and the value-added private sector products that they have enabled. These products have spurred development of some social service applications of GIS that would not otherwise have been possible. Social service agencies equipped only with the address of a client can now plot the location of the nearest needed facility or the optimum site for a new service provider. Public health specialists can more easily locate cases of special interest and more readily discern patterns of interest. Even the daily migrations of the homeless in search of food and shelter are more readily apparent to the GIS-capable.

GIS is an intuitively valuable tool to so many because of some of the simple functions it is capable of. Too much information is often available relative to any decision and the relevance and applicability of that information can often be unclear. GIS offers the promise of organizing and sorting through a very messy world of information, generalizing that information in some suitable fashion, combining it with other information, and producing a graphic output of understandable simplicity. Therein also lies one of the most significant dangers to the consumers of GIS products. If before we had to contend with the evils of lies, damn lies, and statistics, we must now contend with the evils of lies, damn lies, statistics, and GIS. False assumptions about the quality and integrity of data, inappropriate operations and transformations, and lack of fundamental appreciation for what constitutes good science can lead to results that are both meaningless and a profound waste of resources.

The Relevance of GIS to Applied Economics

"GIS has become a sine qua non for geographic analysis and research in government, business, and academia." (Dobson). If, as Dobson and other writers suggest, the strength of GIS innovation and diffusion is that science and society are at the early stages of technological, scientific, and intellectual revolution as profound as those initiated by the printing press or the computer, can its broad and effective use by applied economists be long delayed?

Applied economists, like many other natural and social scientists, must often use data that are inherently spatial in nature. They use these data to derive meaningful information and then must apply that information to the type of problem solving in which they typically engage. We shall consider the kinds of problems to which GIS technology currently lends itself, the analytical functions of which GIS is capable, and the need to extend the capabilities of GIS beyond their current limits.

We might also reflect on several issues that have emerged in Massachusetts over the past few years to which both GIS and applied economics might have made significant contributions:

1. How can the effects of agricultural chemicals on drinking water supplies be minimized?
2. How can natural resource damages under the federal Superfund statute be assessed and how might we estimate the economic losses associated with those damages?
3. How shall we locate sites with physical and demographic characteristics that might make them suitable locations for hazardous waste treatment facilities?
4. What are the expected benefits of the cleanup of Boston Harbor and Massachusetts Bay and who should bear the costs?
5. How can a no-net-loss policy for wetlands be constructed and what role should large-scale mapping of wetlands play in that effort?
6. What will be the economic impacts of applying land use controls to protect drinking water from the effects of non-point source pollution?

All of these examples have certain features in common. They all involve spatial elements, they involve both geographic and demographic representations, and they are concerned with the values that we place on resources and their use. While both GIS and economics can contribute to each problem separately, together the contribution could be far greater.

Applied economists trade in many of the same issues as their colleagues in the physical sciences, yet from a rather different point of view. They are not concerned solely with the locations, qualities, and quantities of resources, but also with how they are used and valued; not only with the impacts of rules, regulations, and modifications of the physical landscape, but also the costs or benefits they will generate.

The analytical capabilities of GIS allow for the discovery of important spatial relationships among physical features and among socioeconomic characteristics as well. Among the many analytical functions of GIS are those concerned with data base query (for both locational and attribute values), measurement (classification, distance, area, volume), generation and analysis of surfaces, networks, and buffers, connectivity (proximity, contiguity, spread), nearness, and co-occurrence (overlay). More than 64 such analytical functions have been identified (Goodchild and Brusgard) and most are available within the more fully featured GIS software programs available today. Aronoff (1989) as well as others have used relatively simple classification schemes under which to organize these many functions.

Most geographic data are representations of physical features and most models built using GIS technology are concerned with the representation of physical space. But virtually all of the analytical functions of GIS can be applied to attribute data as well, thus allowing for the development of models that represent spatially arranged, socioeconomic phenomena. Couclelis (1991) suggests that these predominant absolute (physical) views of geographic space present significant limitations and that what is needed is the ability to construct models that treat geographic space as relational. Applied economists will find greater utility in the relative or conceptual models that represent the value that society places on physical resources and their characteristics.

Potential Contributions by Applied Economists

Applied economists could make contributions to both the science and technology of GIS in at least two primary areas. The first of these is in the application of GIS to those problems with which applied economists generally concern themselves. At the start this will involve learning the mechanics of GIS technology and discovering to what extent the current capabilities of GIS software can be applied to problems of an economic nature. The second involves active reflection and understanding of the broader conceptual issues, including valuation, generated by the growing use of GIS within our society.

A great deal of the discussion among the GIS research community, however defined, is concerned with the extent to which current GIS technology is capable of addressing the needs of socioeconomic geography and regional science (Couclelis). While numerous writers have supported this general notion that current GIS technology does not yet do justice to the needs of researchers and decision makers whose primary concerns are with socioeconomic issues, at least one view is that "If, today, GIS is not valued for its analytical strength, the weakness results, not from lack of GIS capability, but from a lack of will or vision among users." (Dobson). Dobson continues in this same paper to assert that "as early as the 1970s . . . many pertinent physical and cultural features were simulated through GIS linked with econometric models, location-allocation models, environmental assessment models, and spatial databases. . . ." We are therefore inclined to agree with the position that considerably less has been accomplished with GIS in the area of socioeconomic studies than might have been possible. It is the appropriate role of applied economists to extend the applications of GIS into the "relative" space of the social scientists through the use of existing economic models and the development of new ones based on the use of GIS technology.

We will suggest a few of the broader conceptual issues generated by the use of GIS which might interest economists. At least two research initiatives within the program of the NCGIA would have benefitted by further involvement of applied economists; Initiative #4, *Understanding the Uses and Assessing the Value of Geographic Information,* and Initiative #9, *Sharing Geographic Information.* From the first of these two initiatives have emerged some early attempts to apply benefit-cost analysis to GIS projects (Dickinson and Calkins). Those initial attempts demonstrated the difficulties associated with measuring the non-market benefits of GIS programs, but did little to resolve the theoretical issues of what could be considered benefits and how to measure them. The French economist Didier (1990) has made a significant contribution to this issue of assessing the value of geographic information and asserts that all benefits of geographic information are non-market benefits and must be measured accordingly. A U.S. Geological Survey economist (Gillespie) was among the first to settle on the use of two categories of benefits, efficiency and effectiveness benefits, that now appear to have earned general acceptance among those who concern themselves with this issue. Taupier (1992) summarized the available literature on the application of benefit-cost analysis to GIS and examined the various categories of benefits proposed by various writers. Smith and Tomlinson (1992) were first to offer measures of willingness-to-pay (WTP) as appropriate to the measurement of the benefits of GIS programs.

In spite of this progress, much remains to be done in the application of benefit-cost methods to GIS programs. Given the substantial investments in public resources now being made in the development of GIS capabilities, decision makers need strong reassurances that these investments will lead to valuable results. While it is often possible to understand the specific products and outputs of GIS programs, it can be more difficult to place value on those outputs and to determine how to include both internal and external benefits in the analysis. Often, the positive results of GIS programs are expressed as better decisions, reduction of risk, and avoidance of future damages. Close examination of these expected positive results shows that many are indeed quantifiable by experienced benefit-cost analysts. Continued improvements in methods for assessing the value of GIS programs would be welcome.

NCGIA Initiative #9 fostered further discussion of the value of geographic information, this time in the context of how institutions should behave relative to providing access to geographic information. Several participants asserted that marginal cost pricing of public sector geographic information has legal precedence (Onsrud) and that it is the most efficient policy in maximizing social benefits (Taupier). This issue of public access to geographic information is still generating considerable interest, since many government entities are still wrestling with issues of how or if they should generate revenue from the sale or licensing of spatial data. It is a policy issue that has been difficult to settle for many government agencies in the United States due to a broader confusion about the role of government under shifting political and economic philosophies.

Issues having to do with the value of geographic information extend far beyond this concern for providing public access and designing efficient pricing policies. Agencies are constantly dealing with issues of the appropriate scale, detail, or resolution of spatial data sets. We now possess the technical sophistication to produce spatial data that are infinitely accurate and infinitely expensive. While agencies should only be prepared to pay for those data from which they can generate positive net benefits, no practical guidance has been offered as to how agencies should evaluate the appropriate level of detail and expenditure. In some cases natural resource scientists and regulatory officials encourage the development of data at very high resolution even when it is unclear how that level of detail will be used. In many other cases data are collected that are unfit for many specific applications because they lack sufficient detail.

Even federal programs designed to build nationally consistent data bases often lack clear economic justification. The national Digital Ortho Photography program managed by the U.S. Geological Survey has determined that this image base map will be comprised of one meter resolution images regardless of whether that coverage is of a densely developed or topographically complex area or is of a generally uniform landscape about which little detail is needed. The result is that federal funds are potentially over-spent in smaller states that are more densely settled. Such a situation is unnecessary given modern technology and data base tools that are capable of seamlessly joining a mosaic of areas sampled at different densities and then generalizing unnecessary detail to present an image of consistent resolution across a wide area.

We suspect that as readers reflect upon these and other ideas contained elsewhere in this paper that other potential GIS issues to which economists could make valuable contributions will occur.

Examples of GIS Applications

We believe that it is useful to present some cases in which decision makers might well have benefitted from the addition of economic analysis to the GIS analysis conducted on their behalf. In doing so, we indicate how the analysis might have been extended to provide more useful decision-making aids.

Underground Storage Tanks

In Massachusetts, like many other densely populated areas, there are significant problems with contamination of drinking water supplies by volatile organic compounds (VOCs). It is a widely held belief that the major source of VOC contaminants is leaking underground storage tanks. Indeed, at one time, the U.S. EPA suggested that leaking underground storage tanks could be the number one threat to environmental quality and drinking water supplies in the United States. There are believed to be over 50,000 underground storage tanks in the state, the majority of which hold petrochemicals. It was once estimated that as many as 10% of those tanks could have leaks. The Massachusetts Department of Environmental Protection (MDEP) decided to develop a program, using GIS technology, to remove those underground tanks that appeared to present the greatest risk of contamination because of the age and material of the tanks and its proximity to drinking water supplies.

Estimates of the cost of the damages caused by leaking underground storage tanks were never developed even though such costs might be rather easily calculated based on the removal and disposal of contaminated soils and the remediation or replacement of contaminated water supplies. Costs associated with the effects on human and ecological health must also be included where they exist.

Records on the locations of underground storage tanks were in rather poor condition. Permits are issued by local fire departments and a record of each permit is filed with the state Department of Public Safety. In addition to the lack of standard information on the permit forms, however, locational information was found to be substantially unreliable.

The MDEP decided to pilot a program in 28 municipalities within standard-metropolitan-statistical-areas for which complete address ranges were available through the U.S. Bureau of the Census TIGER files and for which records on the locations of underground storage tanks appeared to be reasonably complete. The GIS application depended upon existing data to show the location of drinking water supplies, groundwater aquifers, and either delineated or interim (half mile buffers) zones of contribution to the water supplies. The GIS used a function commonly known as address matching in which approximate locations of specific properties with known street numbers are interpolated from a data base containing street segments and address ranges. Tests later showed that locations derived from address matching in this application were accurate within 200 feet.

Each underground storage tank was given a unique numerical identifier that tied it to both a street address and location and a complete record showing age, ownership, materials, and content. Tanks were then prioritized for testing, examination, and removal based on proximity to zones of contribution to water supplies, age, and material.

In discussion about the benefits of this GIS application it was proposed that the value of the reduction in risk of contamination with VOCs should be based upon the avoidance of costs that would be incurred to remove and dispose of contaminated soils and remediate or replace drinking water supplies. The benefits associated with reduced risks of impacts to human and ecological health were acknowledged but regarded as too difficult to measure.

Although the pilot program was regarded successful, the MDEP chose not to proceed with full implementation. The decision was based upon concerns about the poor overall quality of records on underground storage tanks and the cost of obtaining complete address ranges for all Massachusetts municipalities.

The decision against full implementation was a bad economic decision. The cost of complete address ranges would have been only $10,000 and an investment of $100,000 would have allowed for nearly complete reconstruction of underground storage tanks records. The costs avoided by the prevention of even one significant case of VOC contamination would have exceeded all programmatic expenses.

Watershed Protection

The Boston metropolitan area depends upon drinking water supplies from 90 miles west of the city. In order to create this water supply system the state had to disincorporate and flood four rural communities in the 1930s. Even though the area remains fairly rural, new standards contained in the recent amendments to the federal Clean Water Drinking Act would eventually require the construction of an expensive filtration system. The state chose to institute a set of land use restrictions within the 28 towns that made up the watersheds to this drinking water supply system. The state legislature passed the law containing those restrictions even though it was clear that some filtration would still be necessary due to the fact that the water supplies pass through two holding reservoirs with even more significant water quality problems. The restrictions were concerned primarily with protection against non-point source pollution.

The Massachusetts legislature, in the statute, required the use of GIS to analyze the percentage of land within the 28 towns that would be affected by the restrictions and eventually to identify each private parcel affected and provide data whereby the economic losses that could be attributed to the restrictions could be calculated and individual landowners compensated. The GIS application was generally successful in estimating the land area affected by the restrictions. The GIS functions used included the buffering of tributaries and reservoirs and an overlay analysis of current land uses.

Some problems were encountered when it became clear that the available data were at a scale of 1/100,000 with estimated accuracies of plus or minus 160 feet. At that scale it is possible to assess only general and not specific impacts. Neither the state legislature nor private property owners were content with such a general assessment of impacts and the legislature chose to fund the development of all necessary data at first at 1/25,000 scale and eventually at 1/5,000. At the largest of these scales it is quite feasible to show property boundaries, stream locations and buffers in sufficient detail to assess the impact of the restrictions on each parcel. With that information the responsible agency expects to be able to provide adequate compensation to land owners.

It is unfortunate that the early application of GIS to this issue did not include an estimate of the economic costs associated with the proposed land use restrictions. Data to support such an economic impact assessment were readily available. The estimated cost of those impacts could have been easily compared to the estimated costs of filtration without land use restrictions and hence provide guidance to the legislature as to which was the more efficient course of action. A second opportunity was lost when the legislature had to decide on the total funds to be appropriated to compensate land owners for their losses. Again, the addition of economic analysis would have guided policy makers toward an appropriate level of funding. It is unfortunate that at no point in the process was the GIS analysis taken beyond the creation of an inventory and the measurement of physical impacts.

Eastern Equine Encephalitis

The residents of southeastern Massachusetts must periodically deal with the outbreak of a deadly environmentally borne virus called eastern equine encephalitis. This virus is always present in certain species of birds known to nest in wetlands. The virus is spread among the bird population by mosquitoes that feed only on avian hosts. Yet, every seven years or so this virus spreads beyond the bird population and affects horses and humans, to whom it is generally fatal. The state Department of Public Health (DPH) constantly monitors mosquitos in southeastern Massachusetts for the presence of the virus and if it is detected and then results in several horse cases or a single human case they recommend the broad aerial application of general use pesticides (malathion) to reduce the mosquito population and the risk of transmission. While the DPH can measure the effects of the pesticide applications on the mosquito population it cannot assess its ability to reduce risk of transmission. Public reaction to warnings of eastern equine encephalitis risk generally demand action on the part of the DPH.

The use of malathion has many negative effects as well. Many other beneficial insects are killed as are certain species of fish should sufficient concentrations of malathion drift onto lakes and streams. The public is nearly as unwilling to accept these environmental damages from the application of pesticides as they are unwilling to accept the risk of exposure to encephalitis. In 1991, the DPH and the Office of Environmental Affairs became determined to seek a less damaging approach to the control of mosquitos that might carry the virus. The approach adopted carried all the elements of a geographically extensive application of integrated pest management techniques and it depended heavily on the use of GIS technology. A fairly large interdisciplinary group of scientists were assembled to compile everything that was known about the virus, its hosts, and its transmission vectors. It was decided that one of four species of mosquitos must be considered the primary vector for transmission of the virus from birds to humans. The life cycle and habitat requirements of that species were carefully examined and it was determined that this species of mosquito was susceptible to control using a biological agent known as Bti as long as the mosquito larvae could be treated within 7 to 10 days of hatching. It was also known that significant hatches of these mosquitos occurred only after a period of significant rainfall and that the adult mosquitos bred only in a rather limited type of wetland habitat.

The use of GIS technology was important in several respects. First, it allowed for analysis of the adequacy of the spatial sampling regime of mosquito populations and the subsequent display of sampling results. Secondly, when the virus was detected within the mosquito population, it allowed for analysis of the geographic distribution of the virus. Third, it allowed for the monitoring of conditions that could result in a significant hatch of mosquitos that could serve as vectors for the virus. The use of GIS also permitted the mapping of all suitable breeding habitats for the vector species. Finally, should all the necessary conditions occur for a potential outbreak, it allowed for intervention to be targeted to those specific areas where all conditions were present.

The approach proved successful. Bti was applied following a hurricane that deposited several inches of rain in an area where the virus was known to be present. No use of malathion was warranted and the Bti application killed over 80 percent of the larval mosquitos present. The state considers the intervention to have been necessary and successful and the broad environmental impacts of previous control measures were avoided. Even the cost of control was less since the applications of the more expensive Bti were localized by the effective use of GIS.

Groundwater Protection

Studies of the effects of land uses on environmental media such as groundwater are prime candidates for the use of GIS technologies. One recent example is provided by the work of Iannazzi *et al* [1994], who sought to quantify the relationship between groundwater contamination by nitrates, sodium and volatile organic compounds (VOCs) and, among other factors, land uses in the buffer area surrounding municipal wells. Data on water quality tests for all municipal wells in Massachusetts were geographically referenced and land use layers were digitized for the entire state using the results of aerial photographs.

With well buffers defined as the area within one-half square mile of the wellhead, it was a straightforward procedure with GIS software to create a database in which each case is assigned a dependent variable value, the level of observed contaminant in a particular wellhead, and values of a set of explanatory variables including the percentage of the buffer area represented by the contaminant-contributing land uses and other site-specific factors. Armed with the sample of hundreds of observations, it was straightforward to estimate loading functions for nitrate and sodium contamination using least squares procedures, and VOC contamination likelihood using logistic regression.

With these loading functions made possible by GIS technology, one can approach environmental policy-making with greater sophistication than previously possible. We are made more aware that good policy for these problems needs good information as well as intelligent analysis. And that an overly simple framework may lead to a rather unpleasant form of surprise, and counter-productive results.

For example, the most common policy to protect groundwater in a wellhead protection area is to zone to restrict certain land uses thought to contribute to a particular form of contamination. Agricultural practices are known to contribute to nitrate contamination for example, and policy makers at state and local levels have proposed the restriction of intensive agricultural land uses in these protection areas. The surprise that may await is clear from the results of the estimated loading functions. If the restriction leads to a substitution of medium density residential land use for intensive agricultural production, for example, a contradictory result obtains. Nitrate contamination would rise rather than fall, because the nitrate loading coefficient for this land use is larger (roughly double) than that of agriculture. This much was shown by Harper, Goetz and Willis [1992].

But it is more complicated than that. When the policy framework is broadened to consider all contaminants simultaneously, the potential for surprise is magnified. Mansager and Willis [1994] describe cross-contaminant transfers and show that for the same policy scenario mentioned above, not only would the nitrate levels rise, but the sodium levels and the likelihood of VOC contamination would as well. It is a conundrum associated with environmental policy generally, and recognized early by Lave [1984], but it has not yet been fully understood or appreciated by policy-makers. And GIS technologies can be useful in helping to provide the information base needed to avoid these surprises.

Sparco and Mackenzie [1994] report a similar use of GIS at these very meetings. Their analysis involves estimation of a nitrate loading function for counties in Delaware. They use private rather than public wells as their unit of analysis. And they have well depth geographically referenced so that it is a simple matter to define the radius of the buffer area around the wellhead as a function of well depth. Indeed, as many alternative areal definitions of zones of contribution to wells as one would like can simply be evaluated using GIS technologies. This is indeed, a large advantage of that technology.

Conclusions

The tides of interest in GIS are not soon likely to subside. Rather, we need to redesign our harbors better to exploit a new, and rather permanent and bountiful, sea level. As this technology becomes more familiar, its use will broaden and deepen in applied economics. For first users, it will rather immediately enrichen the data available and enable, in some cases, questions to be explored empirically that would otherwise not have been possible. In others, it will allow applied economists to be more precise in their conclusions.

But just as GIS can be of substantial value to economic research, applied economists can be of considerable service to decision makers who use and manage these data bases. Economic value of information analyses should drive decisions about the appropriate scale, detail and resolution of spatial data. Surely, a single scale applied to a broad area with quite different levels of complexity can hardly be economically efficient.

And questions surrounding policies on public sector pricing of geographic information, and generation of revenue from the sale or licensing of spatial data, are clearly awaiting good economic input. How should institutions and agencies provide access to expensively acquired geographic information?

Clearly applied economists have much to gain in adopting GIS, and in turn they have much to offer in applying economic principles to the design, provision, and pricing of GIS data bases.

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