GEOGRAPHIC INFORMATION SYSTEMS AND WATER RESOURCES

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Geographic information systems (GIS) are a relatively new tool for most people working in water resources studies. While such systems have been around for a number of years, they have generally been accessible only on mainframe computers or work stations. With the development of GIS software that will run on personal computers, they have become a tool of considerable value in water resources studies.

There are several basic approaches to representing spatial data in geographic information systems. Raster and vector approaches are the most common, but there are also tessellation, or polygonal mesh approaches, such as quadtree (used in SPANS, a product of TYDAC Technologies) and triangulated irregular networks (used in PEMSO, a program developed by a consulting firm and now used by Ohio EPA). At its simplest, a raster system describes a two-dimensional space in terms of a grid of rows and columns. A vector system describes the space in terms of points (which could be gaging stations), lines (which could be rivers or roads), and polygons (which could be watersheds, aquifers, marshes, or lakes). Some GIS software allows the user to work with both. The software packages I am using most often at Miami U., primarily for the analysis necessary to prepare a drought atlas of the United States, are:

- IDRISI, a raster package with vector capability, developed by Ron Eastman in the Clark University Department of Geography and introduced in 1987; it has nearly 100 program modules.

- IMAP, a raster package used with IDRISI, developed by Cyrus Young and William Renwick in the Miami University Department of Geography. It displays three maps simultaneously, together with a tabular summary of any one of them.

- ATLAS*GIS, a vector package marketed by Strategic Mapping, Inc., and a companion package, ATLAS*PRO, which primarily deals with mapping functions.

These packages use the DOS operating system. IMAP runs under WINDOWS 3.0. IDRISI, a widely used raster package, is able to use equipment with meager capabilities. It is possible to use an 8088 machine with minimal memory, albeit slowly. We are using it on 80386 (with coprocessor) and 80486-based machines with VGA color displays and 8-12 MB of extended memory.

What are they good for?

Analysis in water resources studies takes many forms. One kind of analysis utilizes spatial displays, such as a map that has a) the locations of raingages or b) the annual precipitation for a network of raingages or, in the national drought atlas, c) the ratio of the annual precipitation exceeded, on the average, in 90% of the years to the median precipitation. One might want to obtain annual precipitation over a watershed from the raingage network. One might then want to see how these precipitation measures vary with elevation, or how sediment yield varies with precipitation, soil type, vegetative cover, etc. There is nothing inherently complex about any of these displays, but a GIS program enables one to construct a small number of data bases and combine them rapidly in a multitude of combinations to answer the kinds of questions a hydrologist might raise. Moreover, one can do this in a matter of seconds, once the basic files are constructed. (Those who have been burned in the past by the potential implications of the part of the last sentence which says "once the basic files are constructed" shouldn't panic. The developers of

GIS software have usually taken pains to make this step as painless as possible, though it may not be a trivial exercise.)

Data are normally entered either by digitizing a paper map or aerial photo with a digitizing tablet or a scanner; by entering the geographical coordinates of points that define points, lines, and polygons; by translating spatial data from other programs; and by using spreadsheet or database programs with attributes of points, lines, or polygons, such as precipitation, vegetation type, land use, elevation, etc.

The power of a GIS system comes from being able to do such things as:

- Overlay one map over another. In several steps, many maps can be combined in this way.

- Add, subtract, multiply or divide a map by a constant,

- Add, subtract, multiply, and divide one map by another map.

One can also obtain many other pieces of information useful in water resources planning. In IDRISI, for example, in addition to all the characteristics mentioned above, areas, perimeters, and compactness ratios of polygons can be obtained. Watershed boundaries above any point can be obtained. Thiessen polygons can be constructed. Percentages of land in different uses or with different soil types can be readily obtained. LANDSAT and SPOT images can be processed. Slope gradient and aspect images can be calculated and displayed. In such applications as an initial wetland screening, where several criteria must be met, overlays of soil type, vegetation, and presence of water can speed up the process materially. With aerial photos taken at different times, with varying degrees of wetness, complex calculations of the differences in flooded area can be made in a matter of seconds.

It should be apparent from the above discussion that a GIS package enables preparation of large bodies of data, and may be used to directly perform many important analyses. Because these are the things that typically take so much time, GIS packages offer significant advantages to a water resources planner. There is an additional advantage of using GIS in water resources planning, and that is the ability to answer "what-if" questions that might be posed by members of a study team, including lay citizens, quickly and in a graphical form.

What are today's limitations of GIS?

Geographic information systems, as they exist in early 1992, are evolving rapidly to take advantage of new technology and user needs. My comments about limitations will soon be out-of-date, but do reflect some aspects of the philosophy underlying the development of the various software packages. The comments are grouped into comments about using the packages effectively and program output.

One characteristic of GIS packages has been that they are not always easy to learn. This has led to the rather common situation in which there is a "GIS person" who knows how to use the software, while other analysts must wait in line for access to this person. This situation implies that analysts spend a significant amount of time preparing a problem for the "GIS person". It makes using GIS less interactive than, say, spreadsheet and data base analysis. Some systems require months to learn well enough to undertake moderately difficult analysis.

Documentation and tutorials for virtually all of the GIS packages are still relatively primitive. It is common for producers of commercial systems to offer training courses of a week or more that cover at least the elementary stages of using the software. Universities are offering short courses, professional societies are offering one or two day introductions to GIS, and special conferences have been convened to help people learn how to use GIS and to explore what they can be used for. The packages I am using most, IDRISI, IMAP, and ATLAS*GIS, are easier than most to learn. With little or no external assistance, it is possible to follow the printed documentation and tutorials and acquire a working knowledge in a matter of a few days. With experienced assistance, this learning period can be even shorter. This means that many analysts could use GIS in nearly the same way they use spreadsheets and database programs, without requiring the skilled expertise of a specialist in the program.

A second limitation of current GIS packages is that they tend to be oriented toward graphics display rather than hard copy output. High quality analytical images on the screen cannot always be easily printed or plotted, nor can they be easily annotated. This limitation has been recognized, and improved output capability is being incorporated into program revisions. In my case, I am doing analysis in IDRISI, then translating output into ATLAS format for hard copy output to plotters.

A third limitation of some GIS packages is the inability to directly make changes in map projection. Although it is possible for small areas to ignore this issue, if the geographic area involved is quite large, and the accuracy requirements are relatively high, the projection of the data assumes considerable importance. While one can work with a map of the United States that assumes latitude and longitude are rectangular X-Y coordinates, the analysis suffers, and one usually will prefer a projection that looks more like the maps we are accustomed to seeing. Ancillary programs are available to make these changes in projection, and some programs will handle changes in projections internally. I have found it necessary to develop the projection in one program, then translate the data into another program for analysis, a more cumbersome procedure than would be desirable. There are, of course, some obvious tradeoffs to be made. A program that will do all these things is larger and more expensive, and is likely to be more demanding of hardware resources. It may also be more difficult to learn, though this is not a necessary consequence of added program capability.

Diffusion of GIS

If one thinks about GIS as an innovation diffusing through a profession, we are still in an early stage of diffusion. Using the Rogers and Shoemaker model of innovation diffusion, GIS systems are being used by people who are innovators and early adopters, who are willing to cope with the crudities of the systems in order to reap the advantages of the immense power they promise and, to a considerable extent, deliver. Emotional investment on the part of the innovators is nearly as high as it is for users of DOS, Macintosh, and UNIX-based workstation computers. Fierce arguments rage about which computer system and which kind of GIS package is "better". On the other hand, those who are not yet using them are skeptical about their value because of the perceived deficiencies of existing software.

Rogers and Shoemaker suggest analyzing the diffusion of an innovation in terms of the attributes of the innovation. Such things as relative advantage, compatibility, complexity, trialability, and observability are considered relevant to the pace of diffusion.

GIS systems promise substantial relative advantage over manual methods by being able to perform complex spatial analyses with great simplicity. On the whole, compatibility doesn't present significant handicaps, either, because scientists and engineers have become users of computer data bases, spreadsheets, and graphic display programs in the last several years. Complexity is more of a problem. Documentation and tutorials are still relatively poor, and have been written by those who developed the programs, thus, the obstacles to learning faced by a novice are no longer salient features of the written material. Some manuals still are written with few or no graphic images, even though the GIS program being described is primarily graphically-oriented.

Trialability, the ability to try something out on a small scale to see how well it will work on the problems of interest to a potential user, is not easy for GIS, unless it can be done under the tutelage of someone who knows how to use it. Essentially, one would either have to invest the time to learn how to use the system and then try it out, or else rely on reading what the program is supposed to do, and then make a decision based on mental images about its usefulness and value. (The latter is what I did.) Observability tends to be done in ways that are both tantalizing and ultimately frustrating. Advertisements for GIS software and papers written about the use of GIS systems tend to show final results. A potential user can look at such information and properly decide that it's wonderful. The frustration comes in being able to get to the stage of being able to actually produce that kind of output. Depending upon the problem, that could be easy or relatively difficult. The easy cases are ones in which getting digitized images into a compatible computer file is easy, there aren't many data transformations required, and procedures are available in the GIS package to enable doing what the analyst wants to do. Fortunately, there are many such problems, and in much water resources work, it is more likely than not to be the case. On the other hand, if the basic data hasn't been digitized, projections and transformations are called for, and one has to develop analytic procedures that are ingenious combinations of existing procedures, then the desired result may be quite elusive.

What does the future look like?

From minimal use of GIS 5-10 years ago to moderate use in 1992, it appears certain that most water resources investigations in the future will use some form of GIS. This may be a result of analyst preference or client preference. A significant number of public agencies are asking that some GIS system be used for all projects undertaken either by the agency or its consultants. This enables the client to integrate information from many studies in order either to do new things with data or to reduce the costs of a new investigation. Sometimes, the client will even specify the GIS system to be used. I am aware of requirements that GRASS, MOSS, ARC/INFO, ERDAS, or IDRISI be employed in a particular study (each of the acronyms refers to a particular GIS package). These decisions may or may not be well-informed, but clearly have an impact on the resulting analysis. Such requirements are also leading to the incorporation of translation modules in a particular GIS package, so that an analyst may work in one package, then translate to another, or, conversely, take information developed in one package and then perform analysis in another.

The agents of diffusion of GIS are often recent university graduates, who have had some exposure to a GIS system in a university course, usually at the graduate level. Such exposure, plus the willingness to take on new tasks and the smaller number of commitments usually placed on new employees or interns, makes them good candidates for performing this role.

Most of the consulting firms, business and industry, and government agencies who are now asking what is available, and whether they should be "getting into" GIS, will have to develop this capability to stay abreast of the field and perform the tasks expected of them. During the next stage, as the user base expands markedly, the product developers will need to have mechanisms for getting feedback from users on their needs, their capability, and for systems that are easier to learn. In the meantime, GIS is in a period of active ferment and dramatic progress. Water resources planners are fortunate to be among those targeted for immediate applications, as is evident from the modules being incorporated into packages, such as watershed delineation.

References

Rogers, Everett M., and F.Floyd Shoemaker. 1971. Communication of Innovations, second ed. New York: Free Press.