

Overview

Geographic Information System (GIS) technology, and the integrally related mapping and remote sensing technologies, that is based on computer processed, spatially related data files, are now being used by thousands of organizations. It is almost impossible to keep up with all of the developments when GIS applications are growing at an estimated rate of 25 to 40% per year and industry revenues may soon reach over a billion dollars per year. At the same time the techniques have become increasingly important to solving problems related to water resources management, construction sites, soil and ground water contamination, waste management, geological and geotechnical investigations, resources exploration, and environmental site characterizations. The GIS activities involve many natural science and engineering disciplines collecting basic data and performing evaluations in accordance with ASTM standards. However, the proliferation of GIS systems, interpretations, and applications, along with related mapping and remote sensing techniques, have emphasized the need for development of voluntary consensus-type standard methods, practices, guides, specifications, and terminology in order to ensure high quality and interchangeable products for those techniques.

To develop information needed for an accelerated standards development effort, ASTM and the U.S. Geological Survey cosponsored an International Symposium on Mapping and Geographic Information Systems in 1990. This Special Technical Publication has been published as a result of that symposium. The purpose of the symposium was to bring together an interdisciplinary and international group of scientists and engineers to provide a forum to exchange experiences and to address areas in which standardization of GIS elements could be helpful to facilitate the use of the technology. The type of GIS activities exemplified previously were addressed together with the fundamental tasks of mapping and remote sensing that are relevant to the spatial data of most GIS applications. The symposium was an outgrowth of the GIS, mapping, and remote sensing standards development already under way in ASTM. To involve additional expertise in this effort, a number of organizations heavily involved professionally in GIS, mapping, and remote sensing, were invited to cooperate in developing the symposium. The cooperating organizations included the American Society of Photogrammetry and Remote Sensing, American Congress on Surveying and Mapping, AM/FM International, Association of American Geographers, Urban and Regional Information Systems Association, Canadian Geosciences Advisory Committee, and International Association of Hydrological Sciences.

This publication provides 26 of the 31 papers presented at the symposium together with discussions taking place during the sessions relevant to specific papers, as well as a panel discussion. The papers are arranged in chapters concerning standardization and applications. The applications chapters of the publication provide examples of basic technology, of soil investigations and geologic explorations, and of ground water and environmental studies. The subject of standardization is addressed in many of the papers. The organizations and user groups already setting some type of standards for computer hardware and operating environments in which the software will function, as well as GIS data exchange formats, are addressed among the introductory papers. Standardization topics and needs to be considered for discipline applications are recognized from the viewpoints of practicing scientists and engineers.

The compilation of papers in the STP can be of interest to people considering entering for the first time into use of a GIS and related maps and remote sensing imagery. However, the publication probably is of particular interest for professionals involved in integration of GIS technology in practical science and engineering project applications or involved in standards development. Several types of projects that in the past were handled by conventional means are discussed. For example, separate drafting of maps and attribute descriptions in typed reports now have been brought into the GIS environment. The GIS adaptations have been achieved by relatively easy digital filing and processing steps for which a multitude of commercial software now is available. The presented experience of most value for entry into the field of GIS applications is the emphasis on defining and controlling data quality and compatibility. Also the empirical knowledge and awareness of data standards is valuable for everybody active in GIS.

The need to identify standards not only for computer hardware and software operations but also for controlling the quality of data has been recognized within agencies concerned with implementation of large GIS programs. A series of papers in that regard prepared by representatives from the U.S. Geological Survey and Environmental Protection Agency are included in the STP. These papers include; G. E. Ulrich and M. W. Reynolds, "Towards Digital Geologic Map Standards: A Progress Report," J. L. Fulton, "Development of Spatial Data Guidelines and Standards to Support Hydrologic Analyses in the U.S. Geological Survey," H. J. Rossmessli, "The Spatial Data Transfer Standard," and Mason J. Hewitt, III, Heather F. Stone, and E. Terrence Slonecker, "Overview of the Use and Formulation of GIS Standards Within the U.S. Environmental Protection Agency." The following paragraphs provide brief highlights of all papers, subdivided by the titles of the chapters in which the full papers are presented.

Standardization

The leadoff paper by **Dangermond** logically provides a definition of GIS and descriptions of the elements that make up such systems. The author defines GIS as "an organized collection of computer hardware, software, and geographic data designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information." He points up that GIS is an extremely powerful technology having application to nearly every discipline and field of work. He briefly mentions that the interaction between related spatial variables were first included in digitally processed computer files in the 1960s and modern vector and raster based GISs evolved in subsequent years. Additional history is provided in one of an interesting series of articles in the June 1991 *Photogrammetric Engineering and Remote Sensing Journal*. Faust, Anderson, and Star¹ state that modern GIS computer analysis began in the middle 1970s at the Harvard School of Landscape Design with Carl Steinitz. These three authors point up that author **Dangermond** was one of the early students in the Graduate School of Design and later a founder of Environmental Systems Research Institute (ESRI) and its ARC/INFO GIS. **Dangermond** concludes that GIS is so complex and so rapidly developing that the job of developing standards will be monumental and lengthy.

The acceleration of geologic map production, application of earth science data in complex GISs, and needed reduction in publication costs are factors requiring that national standards be developed for digital geologic cartography and computer analysis of earth science data according to **Ulrich, Reynolds, and Taylor**. The authors conclude that the development of

¹ Faust, N. L., Anderson, W. H., and Star, J. L., "Geographic Information Systems and Remote Sensing Future Computing Environment," *Photographic Engineering and Remote Sensing*, Vol. 57, No. 6, 1991, pp. 655-668.

modern standards is prompted by the need to improve the scientific and cartographic quality of geoscience map products, digital or conventional, and to provide guidance and scientific discipline to aid communicating geologic information to map users. They then discuss a variety of USGS Geologic Division standards development activities related to geologic maps, such as positional accuracy, terminology, symbols, and description of lineage of a map. They note that an important reason for written standards is that they also provide a ready reference on current policy and procedures in map preparation and reduce the time and cost of thematic map publication.

Spatial data analysis has become an integral part of hydrologic investigations within the Water Resources Division of the U.S. Geological Survey according to **Fulton**. Because one of the largest costs in applying spatial data analysis is the cost of developing the needed spatial data, this author concludes standards are required for the spatial data in order to allow for data sharing and reuse. He notes that the USGS has concentrated on developing standard guidelines for documenting spatial data sets to aid in the assessment of data set quality and compatibility of different data sets and then proceeds to describe those USGS standards development activities. The author concludes that some of the automated data documentation tools will need to be incorporated into the software of GIS vendors in order to meet the requirements of GIS users who need to manage and share spatial data.

Carrying on the theme of the value of data interchange standards, **Rossmeissl** and **Rugg** point up that it currently is difficult and inefficient for the large variety of users to use a given set of data. They list five major forces causing concern about incompatibility: (1) increasing amounts of spatial data are being generated and must be stored, cataloged, and retrieved, (2) progress and expansion in the area of spatial data processing is rapid, (3) increasing amounts of related and useful data are being obtained in digital form, (4) increasing sophistication in the ability to register digital images with maps, as well as the analysis of multiple sets of data, is resulting in a call for more digital data, and (5) much of the map automation effort may be duplicative and redundant. The authors describe the efforts of a Federal Interagency Committee on Digital Cartography, chaired by the USGS National Mapping Division, to develop the present Spatial Data Transfer Standard (SDTS). They state that the use of such standards has many advantages to the data collector, processor, and user—particularly those users who need data from several sources. They also note that availability of quality information will provide users details about the data—including lineage, completeness, accuracy, and logical consistency—in order to evaluate the fitness of the data for a particular use.

The U.S. Environmental Protection Agency (EPA) has introduced GIS into the decision making process. As described by **Hewitt**, **Stone**, and **Slonecker**, the regulatory nature of EPA's business requires very rigorous decision making, and the agency has an obligation to ensure that GIS technology is used in the most deliberate and responsible manner. Therefore, there is a strong desire to work with ASTM to provide the base for standardizing the use of the technology in the broad ASTM forum of users, general interest, and producer participants. The standards will provide a new language to convey environmental problems and results. There are five expressed reasons for standardization: consistency of use, cost, decision quality, integration, and data exchange. In addition, priority areas for standardization within EPA are Quality Assurance and Quality Control for GIS data.

GIS spatial information may be obtained by various technologies including computer aided drafting, digitizing or scanning photography, and image processing. In addition, GIS generally includes tabular database files, and possibly also word processing texts. For the spatial input a longstanding division has existed between systems based on vector data, which is the conventional system for mapping, and the raster systems used in remote sensing technology. **Ehlers** describes how the integration of raster based remote sensing analysis systems and vector based GIS is of great promise for urban and regional planning, management of natural resources and

agricultural studies, mapping, engineering, hydrology studies, and geologic exploration. One important recognition is that today's GIS and today's remote sensing systems are both aspects of a single data collection and analysis system at different levels of abstraction. A requirement for the successful integration of these technologies is the development of a database system capable of handling the different data and converting from one data form to another.

Applications—General Technology

Wright and Yee describe a regional management organization designed to foster data sharing among federal and state resource management agencies in Oregon and Washington. A memorandum of understanding and charter were initiated by 19 federal and state agencies to encourage regional sharing of data and cooperative data collection projects, sharing of GIS and other system resources, and study the feasibility of an integrated regional database and the means for accomplishment of the database. Excellent cooperation was developed by the various agencies in achieving the goals of several pilot projects. The following critical issues were identified: (1) development of a digital index; (2) data resolution (due to different map scales); and (3) hard copy versus digital format of the data available from the agencies. It is interesting to note that one project did some comparative testing of the Global Positioning System. Due to the high expense of data collection and data manipulation systems, it appears that such regional cooperative data sharing efforts will become more and more needed in the future.

Software for GIS has been provided traditionally by the computer industry companies. However, consulting companies in engineering and other fields are becoming involved increasingly in providing the operational interface in the application of existing databases of analytical methods in the GIS environment. **Chang, D'Antoni, and Pettersson** describe development of GIS application packages in the planning, design, operation, and management of water resources and utility infrastructure systems. Critical areas identified for GIS application development efforts include up-front recognition of the type of user, accuracy requirements, compatibility with other GISs, flexibility in system application, and maintenance requirements.

The next paper also discusses problems encountered in dealing with types of regional data, in this case in the large St. Lawrence River Basin. The difference from the Wright and Yee paper is that the Basin is essentially contained in one Canadian province. However, the needed data presumably had to be collected from a large number of Canadian organizational sources. **Lamarche** describes the St. Lawrence Centre that was established and how agreements of understanding were developed for a cooperative effort between governmental and nongovernmental agencies, industry, private firms, and universities. As with other papers, the author notes that the need for documenting the various data sets became obvious, as did also the need for a centralized database.

A commonly used database program and a spreadsheet/plotting program were found by **Rubin** to be a useful and simple GIS for organizing, displaying, and analyzing geographically coded data with multiple attributes. Although the author recognizes that the system does not substitute for a full-function GIS, he concluded that his simple system may help to solve a significant portion of GIS requirements at a very small cost. Undoubtedly the quality of the displays would be subject to database quality just as with the sophisticated GISs.

The spatial registration of data from various sources in a GIS can become one of the worst obstacles in the use of the technology. Repeated ground surveys, which can be costly and time consuming, may be required to check object positions and resolve conflicts. Satellite-based Global Positioning Systems (GPS) can be used autonomously to determine latitude, longitude, and altitude of separate points, or to determine relative positions between locations. As described by **Lange**, one of the advantages of GPS is that the data can be collected quickly and

after reformatting be exported directly to a GIS database. Several areas of possible need for standardization in the use of GPS are recognized, including definitions of accuracy terms, standard procedures for testing GPS sets, and procedures for defining the accuracy to avoid improper data use in the GIS.

Applications—Soil and Geologic Engineering

The USDA's Soil Conservation Service has been developing a county level spatial soil data set for use in a GIS known as Soil Survey Geographic Data Base (SSURGO). **Franchek** and **Biggam** report attribute information has been developed to describe certain soil characteristics and soil properties usable to many types of projects and disciplines. A map unit identification symbol is a unique identifier for a particular soil in a state. Their database contains information on more than 25 soil properties and on soil characteristics such as depth to water table and depth to bedrock. Interpretation maps were made through their GIS to show limitations for septic tank absorption fields and annual flooding frequency. They found that some county data sets could be so large they could swamp the ability of the available hardware platform used.

Although a major ecological issue of importance to the world is soil erosion on agricultural lands, accurate estimates of soil erosion are not available for most regions. **Blaszczynski** reports on RUSLE/GIS system developed at the Bureau of Land Management, which promises potential adoption to accurate soil degradation predictions on a global scale. The system interfaces the Revised Universal Soil Loss Equation information with a Geographic Information System. Raster processing capabilities of the Map Analysis and Processing System is utilized to overlay data themes containing spatially distributed values for the RUSLE factors—rainfall, soil type, terrain, vegetation, and erosion control practice. The author believes that the RUSLE/GIS system has potential value for development of a standard.

Land planning is important to a region like Switzerland where natural resources are rare and the main population is concentrated in the lowlands, which represent only 30% of the country. **Blaser, Lyon, and Lanz** describe a study to evaluate how classified Landsat-5 TM images can contribute efficiently to upgrading a land-cover/land-use database through integration into a GIS. The authors describe the results of using the system to study a test area and reported good results at identifying areas with different proportions between deciduous and coniferous trees. They conclude that SPOT HRV stereo images may be worth trying to determine these parameters.

Data integration has been performed for ages by geologists using traditional analog and visual techniques. The use of digital information and computer based display and analysis techniques have provided for a tremendous increased flexibility and efficiency in the old applications as well providing for new enhanced modeling and analyses approaches. **Hornsby and Harris** describe how GIS technology used in conjunction with Image Analysis Systems (IAS) has enhanced the use of remotely sensed data for geologic mapping and exploration. Geologic spatial databases developed by visual or automatic classifications can be included in the GIS together with thematic and attribute data for point locations. GIS techniques are useful in mineral exploration at both reconnaissance and detailed investigation stages.

A database system managed by microcomputer was developed to evaluate the relationship between ground conditions and earthquake damage in Mexico City. **Kawamura, Arai, and Ozawa** describe how the city was divided into sections and datablocks with attributes describing soil and ground-water conditions based on field data. Dynamic analyses was performed and compared to observed records in order to predict the ground motions at sites representing different ground condition zones.

Large civil engineering projects require efficiency and timeliness of data collection and anal-

ysis and the quick and accurate transfer of data between users. As discussed by **Paul and McDonald**, this was recognized by the U.S. Bureau of Reclamation management for a large dam construction project. A GIS was implemented to store, display, retrieve, and analyze data used by many different disciplines including planning, hydrology, geology, and engineering. Accurate measurement and data integration techniques were important as information was obtained from various sources including maps, aerial photography, and other remote sensing information. To further the project, use of GIS improvements are needed in the ability to share data between different systems, to avoid limitations due to specific computer requirements; and to increase user access to the system.

Applications—Ground Water and Environment

The GIS technology allows management of hierarchically structured classification of vegetation and terrain forms. As described by **Cameron and Emery**, digital cartographic techniques have been applied in wetland studies. The data files include variations in the spatial distribution of vegetation, soil type, hydrology, geology, and peat characteristics. The information can be shown as a series of maps with related data tables or the information from different data layers can be integrated. The digitized data can be rapidly available for a variety of uses, such as resource or land use analysis, and civil engineering or environmental studies.

An inexpensive approach to GIS technology is described by **Varljen and Wehrmann** who utilized the AutoCAD computer aided drafting program along with mapping information for ground-water quality studies. One basic element in the system is the commercially available AutoCAD drawing files created from U.S. Geological Survey digital databases, which contain information on terrain elevations, location of transportation and water features, and names of cities, towns, and major landmarks. Using these drawing files as base maps, a graphical hydrogeological database for a particular area can be assembled and any desired combination of layers can be displayed concurrently by importing different types of geologic, hydrologic, and chemical information. The authors point up that their system is not intended to replace real GIS packages, their approach at least allows many of the benefits of GIS technology to be more available to a wide range of potential users.

GIS methods were applied by **Clarke, Sorensen, Strickland, and Collins** to EPA's Hazard Ranking System (HRS) to evaluate the vulnerability of ground water to contamination from actual or potential releases of hazardous materials at waste-disposal sites. Computerized maps of hydraulic conductivity, sorptive capacity, depth to ground water, and net precipitation data were derived for the southeastern United States and were compared at 28 hazardous waste sites with corresponding values assigned by EPA's field investigation teams. The best correlation between paired data sites was for the net precipitation factor where 79% of the GIS-derived values were within the same HRS scoring range. The authors conclude their GIS methods can be used to prioritize hazardous waste sites for remedial action, although more detailed site evaluation by professional hydrogeologists or engineers would be required for final decisions.

The Savannah River Site is required by law to prepare quarterly and annual ground-water corrective action reports containing the field hydrologic and analytical data collected from over 300 ground-water monitoring wells. As part of the reports, analytical data posting maps and potentiometric maps for each water bearing unit are required. **Hammock and Lorenz** describe the ARC/INFO GIS that was implemented in order to produce the large scale maps required for those reports. The authors describe the software and hardware involved in the present system and also that involved in a new site-wide environmental monitoring GIS that will be interfaced with the present GIS. The GIS in operation has provided a substantial savings in time and has increased greatly the quality of the maps according to the authors.

Stibitz and Hoebeinreich report on a feasibility study to evaluate the possibility of applica-

tion of a ground-water simulation model for a regional hydrogeological investigation of the southern Vienna basin in lower Austria. A GIS has been used to assemble, visualize, and compare data collected from a variety of organizations and an interface between GIS, and a complex 3-dimensional finite element ground-water model is being developed. The authors conclude that GIS was an efficient and powerful tool in the intermediate graphical data evaluation as well as for the final layout and data presentation. The data were collected from literature and archives in federal and state agencies and a variety of institutions. Included were the following data groups; topography, geology and stratigraphy, tectonics, hydrogeology, hydrology, domestic water supply, water withdrawal, climate, and hydrochemistry.

A GIS and performance assessment were combined for siting a low-level radioactive waste disposal facility for New York state. Voluminous data, collected from many sources, included geologic, hydrologic, and environmental considerations, along with social, economic, and political needs, while incorporating ideas and recommendations identified through a public involvement program. **Connolly** and **Dressen** report that the GIS was a powerful tool that permitted the digital processing of large amounts of geographically distributed data that were available in numerous forms, scales, and projections. Further, the GIS allowed these data to be available to quickly and efficiently support the decision-making process for potential sites through cartographic display and interactive analysis.

A Database Management System (DBMS) for investigation of hazardous waste sites is described by **Duplancic**, **Buckle**, and **Montejo**. The menu driven central database can be used to enter, store, maintain, update, and retrieve project information, and for report generation. A secondary database contains regulatory and chemistry information. The database program is linked to graphical programs for generation of well logs, boring logs, maps, and geologic cross sections. As the integrity of environmental data must be ensured, the security of the information is protected by passwords and by division into layers with privileged access.

The combination of graphical systems, such as CAD, with database management systems makes GIS a most valuable and effective technology for waste site characterization and remediation. **Soby**, **Connolly**, and **Folsom** describe how GIS is used in the U.S. Army's program to identify and characterize waste sites and to set priorities for subsequent remediation. The application of GIS allowed queries regarding the location of the studied site in relationship to other geographical features and seamless integration of data files with the graphical information. The user friendly system was controlled entirely by the use of the menus and data entry screens.

Setting realistic criteria for the data quality of basic information to be entered in a GIS requires an understanding not only about what is desired but also of what actually can be achieved cost effectively. **Shalla**, **Lewis**, and **Bates** describe accuracy and precision requirements of well casing surveys and water level measurements, the composite affects of the survey and measurements, and the resulting impact on water level contour maps. The authors conclude that well casing surveys should not be specified based on "order/class" standards but should be specified based on real accuracy needs in distance units or ratios and with recognition of the resulting costs.

The principal theme brought out by the symposium and papers included in this STP is, first and above all, the need to control and document the quality and history (the lineage) of data. Development and industry adaption of standardized methods and content formats for data descriptions, sometimes known as "metadata" is a high priority task. In regard to technology, the integration of raster and vector data is a most important development for natural science investigations and the close cooperation between GIS and remote sensing experts naturally is occurring.

GIS, mapping, and remote sensing technologies are being increasingly used not only for the purposes of storing, processing, and retrieving information but also for performing analyses

in a GIS environment. This integration of disciplines and tasks with GIS technology requires development of application programs or systems by organizations and private firms involved in a wide variety of engineering and scientific fields. To effectively implement GIS applications widely it is necessary to have compatible software and operating systems and to adapt standard formats for digital data transfer, not only by government agencies but also by private industry.

The ASTM committee activities provides a forum for bringing together GIS, mapping, and remote sensing professionals with engineer and scientist users to share experiences and identify the needs for standardization. Such activity can and should lead to production of voluntary consensus standards that can be referenced in federal, state, and regional guides, rules, and regulations. The editors hope this volume will inform many readers about the ASTM efforts to develop standards related to GIS, mapping, and remote sensing, and stimulate individuals and appropriate professional organizations to work with ASTM in developing the needed standards.

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