An Introduction to GIS Applications in Hydrology

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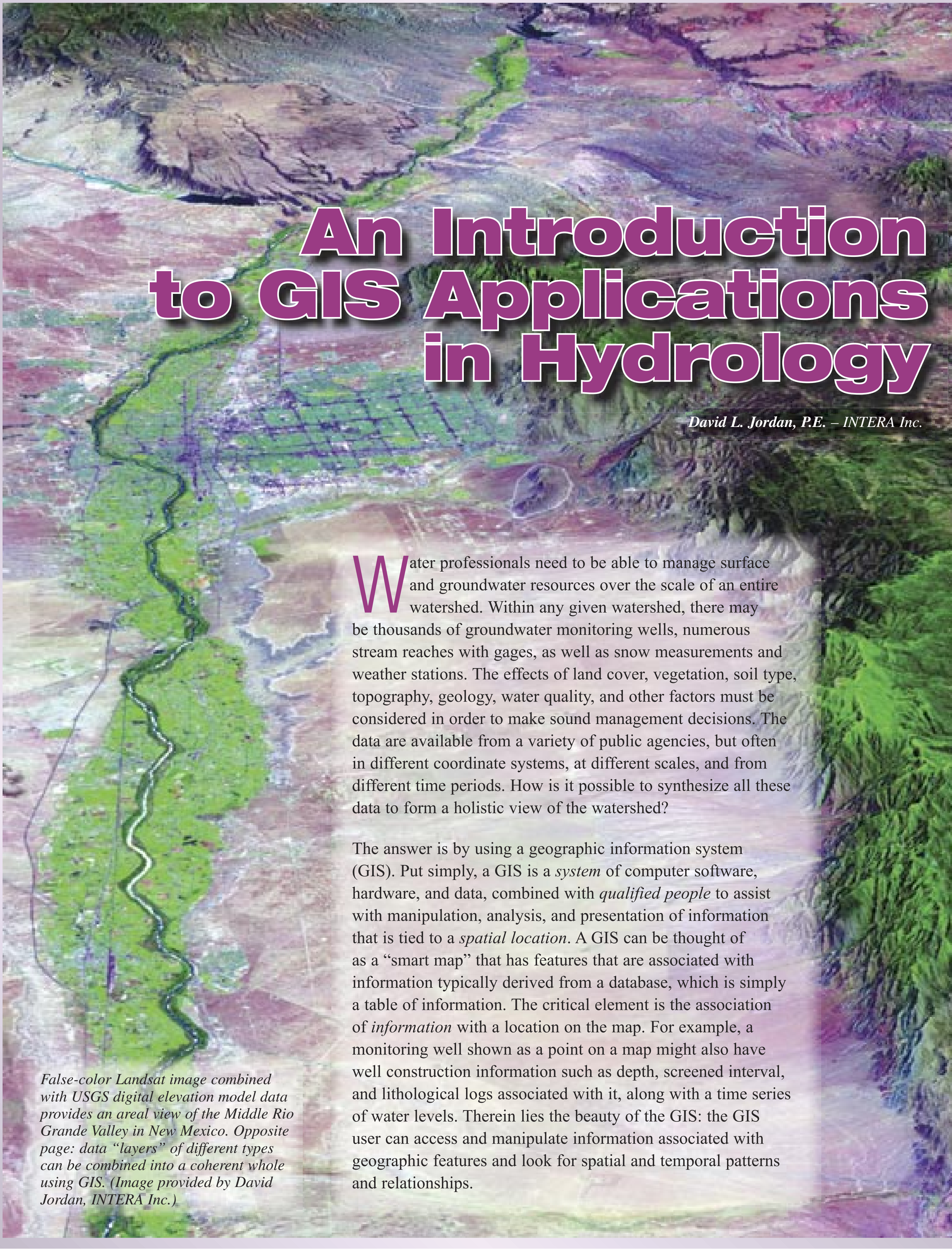
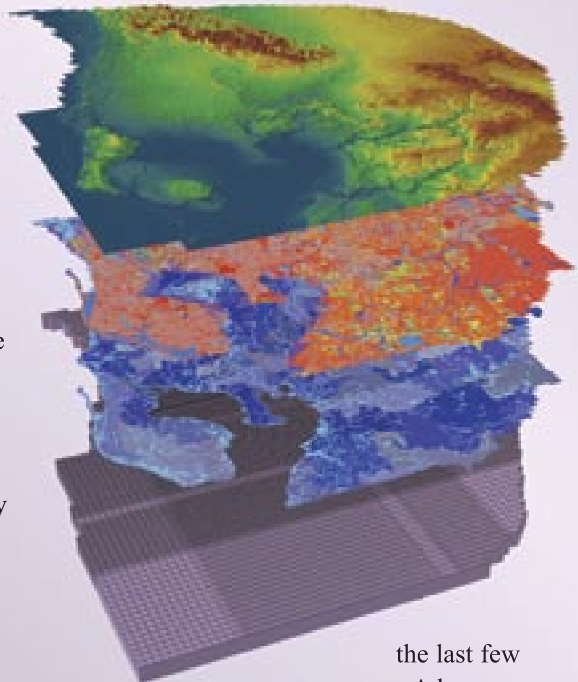
Water professionals need to be able to manage surface and groundwater resources over the scale of an entire watershed. Within any given watershed, there may be thousands of groundwater monitoring wells, numerous stream reaches with gages, as well as snow measurements and weather stations. The effects of land cover, vegetation, soil type, topography, geology, water quality, and other factors must be considered in order to make sound management decisions. The data are available from a variety of public agencies, but often in different coordinate systems, at different scales, and from different time periods. How is it possible to synthesize all these data to form a holistic view of the watershed?

The answer is by using a geographic information system (GIS). Put simply, a GIS is a *system* of computer software, hardware, and data, combined with *qualified people* to assist with manipulation, analysis, and presentation of information that is tied to a *spatial location*. A GIS can be thought of as a “smart map” that has features that are associated with information typically derived from a database, which is simply a table of information. The critical element is the association of *information* with a location on the map. For example, a monitoring well shown as a point on a map might also have well construction information such as depth, screened interval, and lithological logs associated with it, along with a time series of water levels. Therein lies the beauty of the GIS: the GIS user can access and manipulate information associated with geographic features and look for spatial and temporal patterns and relationships.



False-color Landsat image combined with USGS digital elevation model data provides an areal view of the Middle Rio Grande Valley in New Mexico. Opposite page: data “layers” of different types can be combined into a coherent whole using GIS. (Image provided by David Jordan, INTERA Inc.)

A key advantage of GIS is its ability to integrate, manage, and analyze large volumes of data, particularly over very large areas. GIS enables data to be integrated and viewed on the scale of an entire watershed, allowing a holistic approach to water resources management. These same integration capabilities also make GIS useful for local-scale analyses, where many diverse types of data must be considered.



Getting Started

Identifying a Suitable Project: GIS applications in hydrology are particularly useful for watershed-scale analyses such as integrated surface and groundwater modeling, regional groundwater modeling, and water quality analyses. Recent advances in integrated surface and groundwater modeling have created a need for analysis of a diverse range of data on a regional scale. The models require large volumes of input data such as weather, topography, and land cover type, as well as water levels and geologic data from thousands of groundwater wells. The ability of GIS to integrate data from multiple sources such as boreholes and wells, subsurface isopach (or structure contour) maps, and surface geology maps also allows data to be used simultaneously to develop a groundwater model. Water quality issues associated with regional changes in land use, such as urbanization and large-scale agriculture, can also be analyzed effectively using GIS. On a local scale, GIS can be useful for landfill siting and the selection of groundwater development and artificial recharge sites. These local-scale analyses also must consider a wide range of data such as land use, property ownership, geology, soil types, and distance from the source (such as distance from the water source for an artificial recharge site). See pages 24 to 29 for more examples of applications.

Software Purchase: The advent of sophisticated desktop GIS and the rich availability of data from a wide variety of public sources have provided water resources professionals with powerful tools for data management, data analysis, visualization, and model building in just the last few years. A large number of GIS products are available on the market, ranging from free programs with limited but easy-to-use functions to programs costing several thousands of dollars that are capable of highly complex analyses. Some of the most popular programs are reviewed on pages 16 and 17. Many of the software packages are friendly enough to require little or no training by the user, while others require more intensive training to realize their full benefits.

GIS Data: The ability of GIS to integrate data from multiple sources such as satellite imagery, vegetation and land cover, boreholes and wells, subsurface isopach maps, and surface geology allows all of these data to be used simultaneously to develop a clearer understanding of surface and subsurface water movement and their interactions. Many of these data are available free or at very low cost from government entities. Surface data such as USGS digital elevation models (DEMs), USGS digital orthophoto quarter quadrangles (DOQQs), and Landsat imagery integrated into the GIS also provide visual clues for determining surface and subsurface processes. Additional sources of data are listed on pages 30 and 31.

Integrating the Data: Data used for GIS come in two types, or structures: raster and vector. Raster data are grid-based and made up of pixels. Examples include satellite images, scanned historical aerial photography, scanned historical maps, and DEMs. Vector data are made up of points, lines, and polygons—the usual types of geometric features commonly seen on maps. Examples include well and soil boring locations (points); roads, streams and rivers (lines); and property and municipal boundaries (polygons).

Geographic data are useful only when all of the sources are projected into the same coordinate system and scale so the data layers can be combined. Some GIS software requires the user to reproject these data from their native projection into a consistent coordinate system for all the data. Newer GIS software provides "project-on-the-fly" functionality, which automatically does this.

Some data may require georeferencing if they are not in any sort of "real world"

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coordinate system. An example might be an historical aerial photograph that is scanned in, then registered to known map features that are present both in the scanned photo as well as to another data layer in the desired projection.

Stumbling Blocks: While advances in software and hardware have made GIS much easier and more affordable, developing proficiency with many GIS packages often requires some training. Commonly encountered difficulties are associated with file formats and coordinate systems, and database quality control. Since standards for platform-independent operability are just beginning to be developed (see page 20), the GIS user may need to reconcile many different file formats from different software packages such as Cad packages (such as AutoCad or Intergraph Microstation), raster file formats (TIF, JPEG, ERDAS Imagine, etc.), and database file formats (MS Access, Dbase, etc.). Coordinate systems also can be confusing to a new GIS user due to the number of parameters that typically describe a given coordinate system. These include the type of projection (Universal Transverse Mercator (UTM), Albers Conical Equal Area, etc.), the datum (North American Datum 1927 or 1983), the UTM zone (essentially the east-west location), and the spheroid—the mathematical representation of the shape of the earth (GRS 1980, Clarke 1866, etc.), which is not perfectly spherical.

Finally, database integrity issues can plague almost any GIS. While the greatest strength of a GIS is that the underlying information is contained in a relational database, this can also be its greatest weakness. Significant time and effort may be required to develop a comprehensive and accurate database, and implementing a strict quality assurance/quality control program for any data development is of utmost importance. In addition, one should never assume that data from third parties are entirely correct; these data should be subject to scrutiny as well.

Using the GIS

Once the GIS is built, analysis can begin. The GIS can be used for such tasks as data management and retrieval, data modeling (e.g., contouring), spatial analysis, and presentation. Data modeling functions include contouring of groundwater levels or dissolved contaminant concentrations, and terrain modeling for watershed analysis. Data modeling also can be used to develop subsurface structure for a groundwater model or a stream network within a surface water model. Beyond data modeling, the real strength of GIS is in spatial analysis, determining relationships between different information in a spatial context. Inherent in spatial analysis is the process of overlaying different datasets to determine relationships between them. An example might be an analysis of regional land use (which might be a grid-based raster dataset), and its effects on groundwater quality (a set of contours resulting from modeling of point sample data). Adding a temporal component to both datasets allows the user to analyze the effects of changes in land use over time on groundwater quality. Once the analyses are complete, and the results and conclusions have been developed, the GIS can be used to present results, particularly to develop graphics and presentations for audiences such as nontechnical managers and the general public. In short, GIS allows management, analysis, and integration of complex datasets, while providing a presentation tool for communicating the results of these analyses to a wider audience.

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