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New Tools to Protect Water Quality

Computerized Maps, Decision-Support Systems, Use High-Tech Methods to Safeguard Water Supplies
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At a time when it seems as if there are more environmental risks than ever before' new weapons are needed to safeguard water quality.

Fortunately' tools are being developed to do just that.

The arsenal includes new ways to look at and interpret data through the use of computerized maps called Geographic Information Systems (GIS). Work is now underway to develop computer simulation modeIs to take advantage of the new technology. For example, charts and animation are now being developed to display which low-lying areas might first be flooded by hurricanes. Unlike hand drawn maps, a GIS lets users represent many different features at once including land uses, soil types, water quality characteristics, topography (slopes), rivers, lakes and streams. A valuabIe byproduct of developing a GIS application is the production of sophisticated data bases that can provide better inputs to simulation

Texas A&M University Agricultural Engineer Mary Leigh Wolfe utilizes computers to build a GIS. In the project, Wolfe is using a GIS to study the impact of dairies on water pollution and to assess whether dairies are located too close to streams and sensitive aquifers.

models.

Another major tool is DRASTIC which is a methodology that can be used to identify groundwater systems that might be most vulnerable to industrial, agricultural and municipal pollution. DRASTIC has been used by the Texas Water Commission (TWC) to produce a series of easy to understand color maps that show groundwater systems that may merit special attention. The TWC is using DRASTIC as a management tool to provide an initial screening of problem areas.

For those who are unfamiliar with terms such as GIS or DRASTIC, or computers in general, easy-to-use programs are being developed to help explain the concepts. For example, pointing at an icon on a computer screen takes users to other screens with in-depth scientific information and graphics.

At the regulatory level, programs which emphasize citizen involvement have been implemented by the TWC to protect drinking water wells. The U.S. Geological Survey (USGS) is using GIS techniques to provide input to and display output from computer models that simulate pumping of the Edwards Aquifer and may use GIS to target lands that may be impacted by land subsidence in the Houston area. The TWC is among the state's leaders in DRASTIC work and the TWC and the State Soil and Water Conservation Board are now using GIS technology to evaluate major watersheds.

Universities throughout Texas are leaders in developing and applying these new technologies.

At Texas A&M University, GIS techniques have been utilized to estimate coastal erosion, to evaluate runoff from dairies and to forecast the impact of new federal agricultural chemical regulations. Researchers at Texas A&M are also developing complex object-oriented programs that could be used with a GIS to more accurately replicate how water and pollutants flow across and through soils. Rice University recently developed a decision support package called the OASIS system. OASIS contains detailed information about hydrogeology, water pollution, chemicals and groundwater cleanup methods but is still easy to use and understand. At the University of Texas in Austin (UT), investigations have focused on developing three-dimensional images from GIS maps to better simulate water flow, and on building expert systems to help new users select the GIS that best fits their needs. Combining GIS technology with satellite imagery is the focus of work at both the University of North Texas (UNT) and Texas Christian University (TCU). Researchers at UNT have just begun using GIS applications to develop computerized DRASTIC ratings for the entire state and have used GIS technology to study the impact of land use changes on water quality. At TCU, students are taught how to use basic GIS techniques on Macintosh computers and researchers are examining how urbanization impacts runoff and how septic tanks and agricultural runoff affect the quality of urban lakes.

GETTING STARTED WITH GIS

Perhaps the easiest way to understand the basics of what a GIS can do is to imagine a series of individual maps on transparencies that could be displayed on an overhead projector. One map or layer might contain rivers and lakes, another sold types and groundwater systems, and yet others will detail land uses, locations of businesses and industries, and other data. By placing the transparencies on top of one another you could deduce potential problem areas.

For example, an industry manufacturing a hazardous chemical might be located too near a stream or on top of a setting where pollutants could easily reach groundwater.

Inputs to GIS include both spatial data (information linked to a particular area) and non-spatial information (lists or descriptions of locations and addresses). Data input to a GIS is typically specified in three ways: by its geographic location, its features (a lake may be described by such attributes as its name, depth, water quality, species of fish and plants that live in the lake, water chemistry, water color and other properties), and its relationship to other items on the map (how is the lake and its ecosystem affected by various pollutants). Increased ability to analyze relationships between features is one of the areas where GIS technology has advanced most in recent years.

GIS technologies refer to spatial information in one of two ways . Raster-based or grid systems arrange data in horizontal and vertical columns like a huge multi-colored checkerboard or a TV screen. In a grid system, each square or pixel represents a specific area. Raster-based GIS technologies can be somewhat limited if large areas are represented by each pixel. For exampIe, individual features may be lost if users have to choose whether a single pixel should denote a river, road, or slope (it can't represent all three) . Vector-based systems are composed of lines and polygons that are strung together to more accurately depict landforms such as rivers, lakes and highways. A vector-based GIS can more accurately describe specific locations, but data analysis or topology is much more time- consuming and complicated.

A number of "user friendly" software packages are available for GIS work. Public domain programs like GRASS are popular for use by universities because the software is inexpensive and is well-supported, while ARC/Info is probably the commercial GIS most often used by government agencies and private consultants. Macintosh programs such as Map II are available for undergraduate teaching and research.

Initially, the most expensive and time-consuming component of developing a GIS is entry of spatial data. Although limited electronic maps are available, data entry typically consists of tracing features from paper maps so they can be put into a computerized system.

TEXAS AGENCIES BEGINNING GIS WORK

Many federal and state agencies are either using or planning to implement GIS technology.

The TWC and the Texas Water Development Board (TWDB) are in the initial stages of developing a modern GIS. TNRIS (the Texas Natural Resources Information System) is a part of the TWDB and is expected to play a key role in coordinating GIS efforts among state agencies.

The USGS is also in the early stages of GIS work. Efforts have included using GIS databases to provide input to and display output from models that mimic groundwater pumping in the Edwards Aquifer as well as studies of subsidence in the Houston area.

The State Soil and Water Conservation Board is working with the Texas Agricultural Experiment Station (TAES) at Temple and College Station and the Texas Agricultural Extension Service on a project to develop a GIS application for the entire state. Results may be utilized to project agricultural runoff' soil losses' and agrichemical pollution.

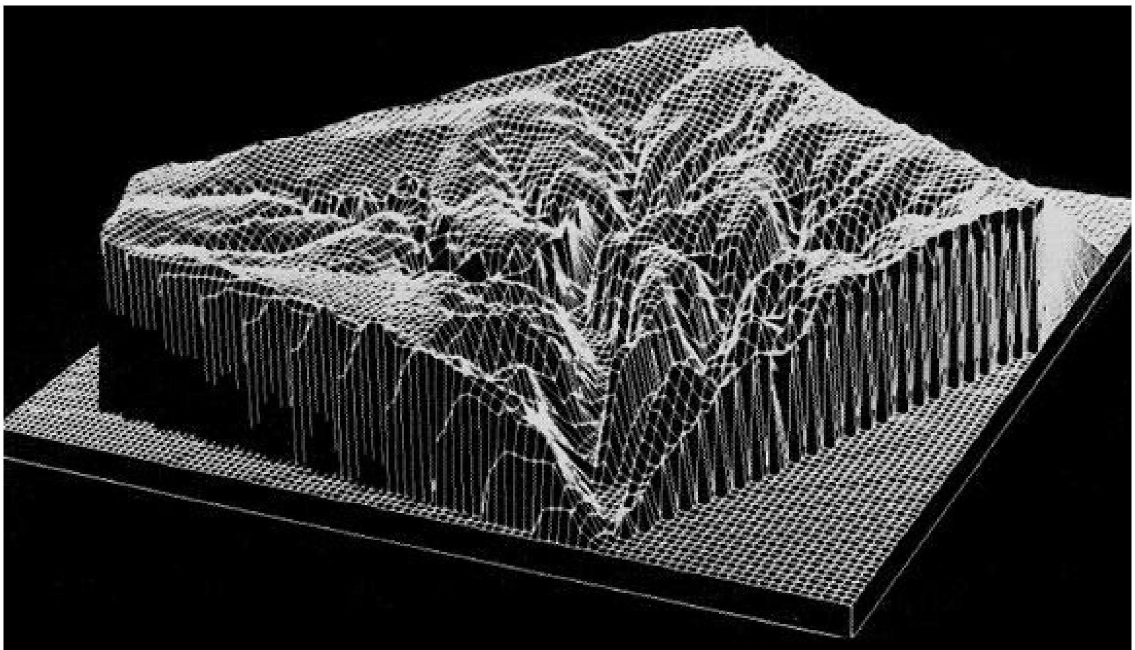
In the Dallas area' the North Central Texas Council of Governments (NCTCOG) has developed a GIS comprised of such data as floodplain elevations' water and wastewater systems, urban land uses, and locations of wells (Brush, 1989). NCTCOG planners will use the information to estimate flood losses from alternative development scenarios, to establish wellhead protection areas, and to determine if parks and recreation facilities can be safely sited along the floodplain. The City of Dallas is working with scientists at UNT to analyze how land use changes may affect its water supplies.

In San Antonio, the Edwards Underground Water District (EUWD) has begun developing a GIS application for the Edwards Aquifer. The GIS will allow EUWD to assess the pollution potential of new developments by determining if the projects are near sensitive recharge areas. Other potential uses include providing maps of areas impacted by drought management plans, evaluating the impact of underground storage tanks on groundwater quality, and analyzing water quality changes.

GIS RESEARCH AT TEXAS UNIVERSITIES

Widespread use of GIS techniques is now most intensive in basic and applied research at Texas universities.

A number of projects are being carried out by the Agricultural Engineering Department at Texas A&M University. Mary Leigh Wolfe is conducting a project funded by the Texas Water Resources Institute and TAES to determine the impact of dairies on water quality in north central Texas (Deliman and Wolfe, in press). Wolfe (see cover) is incorporating such information as locations of dairies' rivers and streams' soil types, topography, and other data into a GIS that could be used to select environmentally safe sites for new dairies or to estimate the impacts of dairies on runoff and groundwater pollution. Wolfe is also working with Richard Shumway of the Agricultural Economics Department in a study that will combine DRASTIC and GIS methodologies to assess the impact of changes in federal farm policy on agricultural chemical use and groundwater quality. Dale Whittaker of the Agricultural Engineering Department is working with Wolfe and Joe Folse of the Wildlife and Fisheries Department to develop object-oriented simulation techniques that can run in a GIS environment. In the project, (Whittaker, et. al, 1990) agricultural fields are divided into units with individual hydrological characteristics such as infiltration rates and water flow based on soils and the type of crop that is grown. Realistic results could be displayed in dynamic animation. Steve Searcy is investigating whether GIS maps could guide high-tech tractors to specific areas of afield that need fertilizer, pesticides or herbicides.



This 3-dimensional map that displays the slope and locations of streams in the Cypress Creek watershed near Austin was created by researchers in the Center for Urban Affairs at Texas A&M using a GIS. Steep hills leading to a stream are in the center of the drawing. A GIS will be used to analyze the amount of sediment and pollutants that run off erodible soils into streams.

Studies are also underway in other departments at Texas A&M. Harlow Landphair of the Center for Urban Affairs is developing an integrated GIS that incorporates models simulating rainfall, urban stormwater flow and water budgets (Steenberghen, et al., 1989). The rainfall model is run first and results are used to predict rainfall for a given month. A hydrologic model is then used to forecast areas likely to be flooded and water budgets are developed. Results include animation and maps that are easier to communicate than traditional tables and charts (see Figure 1). Landphair has also worked with the Lower Colorado River Authority to develop maps and databases of the Cypress Creek watershed near Austin (see Figure 2). Results will assess the impact of land use regulations on controlling runoff. Ken White of the Center for Engineering Geosciences has developed a system titled "HAZMAP" which simulates the impact of hurricanes on the Texas coast. The system uses real time weather data and meteorological models to predict hurricane strength, storm surges, rainfall and where and when storms will come ashore. The GIS displays roads, businesses, and homes that are most likely to be impacted given different scenarios (White, et al., 1988). The system's graphic nature makes it ideal for TV emergency telecasts or public meetings. White is also working to combine GIS techniques and satellite images to study the impact of petroleum exploration on groundwater quality. In the Geography Department, Rick Giardino is comparing whether the combined use of GIS and aerial photography is a better method to study coastal erosion on South Padre Island than traditional hand-surveying. In the Range Science Department, Doug Loh is developing a computerized "knowledge shop" titled IRMA (Integrated Natural Resource Management Automation). IRMA integrates GIS technology with an expert system, a database management system, and a connection management system (Loin, et al., 1988). IRMA is now being used to evaluate and recommend best management practices for controlling runoff in national forest lands near Crockett.

At the University of Texas at Austin, researchers are improving the ability of GIS programs to accurately predict streamflows and runoff, and are designing expert systems to help developers be aware of and comply with environmental regulations. David Maidment of the Civil Engineering Department is investigating the use of triangle- based terrain models (TINs) to better simulate patterns of water flow and drainage because existing GIS packages often cannot accurately replicate actual patterns of water flow. Maidment is developing complex mathematical formulas that could be used in combination with TlNs to simulate what he calls "marble rolling theory" (Maidment, 1989). The idea is that if you release a cluster of marbles over a watershed, they will roll downhill until they reach an outlet. By tracing back along the roll paths, watershed drainage patterns can be automatically determined. This principle could be used to quickly determine which direction pollutants might flow in a watershed and how water moves around buildings and over and through streets and drainage works. Maidment is also developing a decision support system titled "Site Code" which will provide a data base of municipal site development regulations for use in computer-aided design (Straw and Maidment, 1989). Builders could use Site Code to learn which environmental regulations applied to a specific parcel of land with special characteristics (a steep slope or land near a floodplain, for example) and could recommend the best options to comply with the statutes.

David Eaton of UT's LBJ School of Public Affairs has developed an expert system for Macintosh computers that helps users select the type of GIS that best fits their needs. The program, titled "MapAccess," requires inputs such as the purpose for constructing the GIS, budget restrictions and equipment limitations (Roule, et al., 1990). The software then recommends an appropriate GIS package, takes the user through a tutorial, and helps the user create databases and maps. Eaton's students have utilized GIS technology to create maps of the Rio Grande, Mexico, and other areas.

Combining satellite imagery and GIS technology is the focus of research at the University of North Texas (UNT) and Texas Christian University.

At UNT, Sam Atkinson and Ken Dickson of the Center for Remote Sensing and Land Use Analyses have begun work on a project to develop computerized DRASTIC ratings for the entire state using a GIS framework.

DRASTIC is an acronym for inputs such as Depth to the watertable, Recharge, Aquifer media, Soils, Topograhy, Impact of the vadose zone (how fast pollutants travel through the unsaturated zone) and hydraulic Conductivity. The DRASTIC system is often used to assess how vulnerable groundwater systems are to pollution. Typically, DRASTIC ratings are calculated by hand. However, it is difficult to share detailed information developed for DRASTIC for other purposes and it is tedious to update the DRASTIC maps as new information is obtained. UNT's approach (see Figure 3) is to enter each DRASTIC parameter as an individual layer on a GIS and then to compute DRASTIC ratings by summing the computerized data.

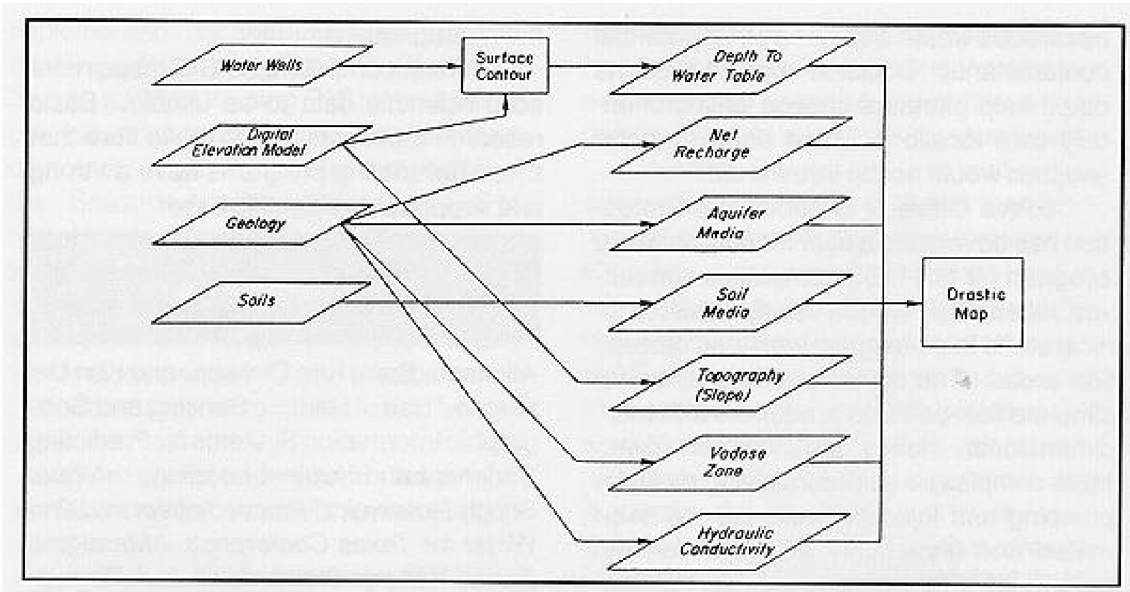
UNT scientists also utilize GIS technology to measure land use changes in Dallas area watersheds to determine if urbanization increased pollutant loads to rivers and streams. In many of the projects, satellite imagery and aerial photography are captured, displayed, and analyzed utilizing a GIS. For example, a satellite image of a known land use such as a forest has a unique "signature" or color pattern. By identifying different elements on the imagery and comparing different images over time, analysts can determine the extent of land use change. Once land use changes are known, conventional simulation models can estimate the amount of runoff and erosion various land uses are likely to cause, can identify critical areas where intense nonpoint source pollution is occurring, and can help devise strategies to control runoff. Studies have been performed on a number of Dallas-area watersheds including Lake Ray Roberts, Lake Lewisville, Lake Grapevine, the Elm Fork of the Trinity River (Atkinson, et al., 1989a), and Cedar Creek Reservoir (Atkinson, et al., 1989b).

Other GIS work at UNT includes three-dimensional modeling of the extent and movement of groundwater pollution at a Corpus Christi chrome-manufacturing facility, interpreting regional public opinion on public works projects such as the expansion of the Dallas-Fort Worth Airport (Whalley, 1989), developing plans to protect endangered species, and training EPA personnel in how to use GIS technology.

At the Center for Remote Sensing at Texas Christian University, both teaching and research are emphasized. Undergraduates, many of whom are novices at computer usage, are taught how to use basic GIS technologies on Macintosh computers with an easy to use program called Map II. Many research projects at TCU involve utilizing GIS technology to analyze satellite images and aerial photography. Investigations have involved determining the extent to which urbanization (the conversion of farm lands to paved areas such as highways and parking lots) increases urban runoff (Plunk, et al, in press), identifying critical erosion areas near Lake Arlington (Morgan, et al., 1987) and projecting the impacts of septic tanks and agricultural runoff on water quality in Lake Weatherford (Hayes, et al., 1990). A new GIS study will analyze the impact of the Dallas Area Rapid Transit light rail system on wetlands and wildlife habitat near D/FW Airport.

DRASTIC

DRASTIC, as mentioned earlier, is a method to identify groundwater systems that may be particularly vulnerable to pollution. In basic terms, properties of soils, aquifers, and rainfall are ranked in terms of their influence on potential groundwater contamination.

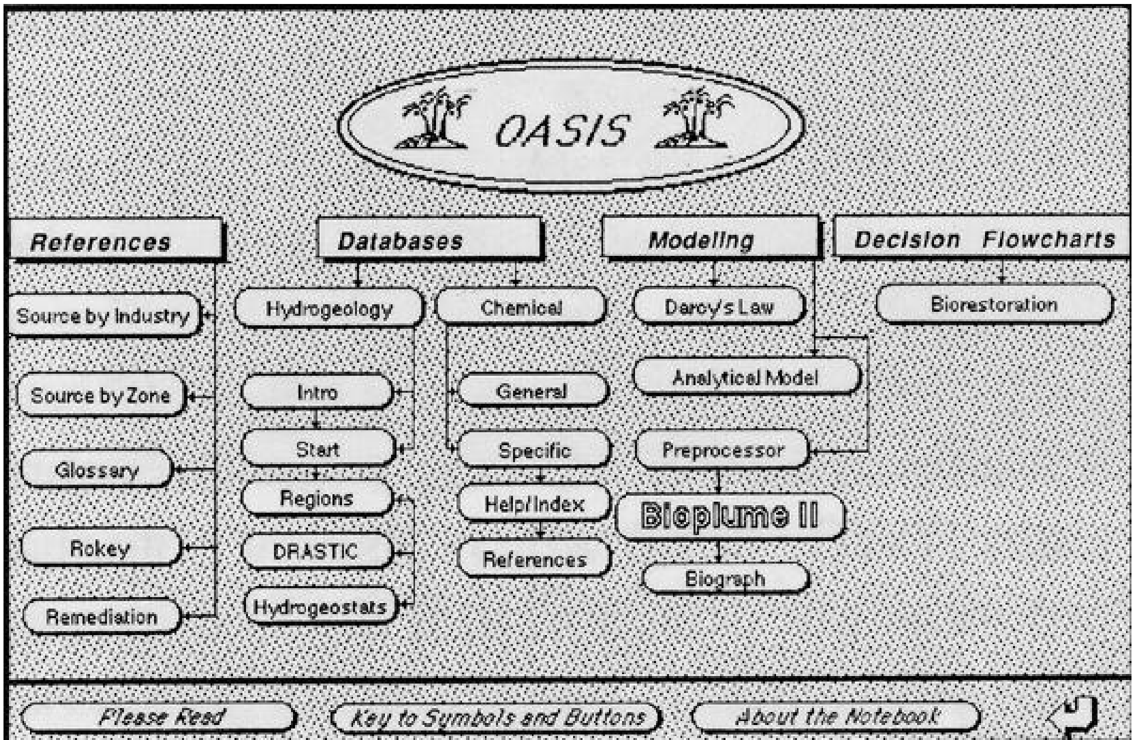


The University of North Texas hopes to use a GIS to develop computerized DRASTIC index ratings. Water wells will provide data for depth to the water table and an elevation model will generate slopes. Geologic data will be used to determine the aquifer media, the amount of recharge areas may receive and the details on the soil media. Users will be able to automatically compute site specific DRASTIC index ratings and to view how the factors are interrelated.

End products include DRASTIC index numbers and maps that give users a relative idea of the amount of protection a particular aquifer may need. The TWC has developed DRASTIC maps for the entire state (TWC, 1989) which display potential groundwater pollution that could originate from agricultural, municipal, or industrial sources. The TWC is now conducting DRASTIC assessments in many areas of Texas and hopes to use the results in groundwater conservation, underground storage tank, and hazardous and solid waste programs (Hart, 1989). DRASTIC could also be used in wellhead protection, EPA Superfund, and groundwater protection programs.

Further insights can be obtained when DRASTIC ratings are combined with known sources of pollution. For example, a DRASTIC map could constitute one of the layers of a GIS to display where pollution problems could be most severe.

Although DRASTIC may be somewhat difficult to comprehend for non-scientists, research at Rice University has developed a comprehensive computerized decision support package called the OASIS project that makes the methodology easy to understand without losing any scientific details. OASIS was developed by a team led by Phil Bedient and Chuck Newell of Rice's Environmental Engineering Department (Newell, et al., 1989) for the EPA. OASIS is easy to use because it was developed in a Macintosh hypertext format. That allows OASIS to use extensive graphics and text to explain difficult concepts (Newell, et al., 1990). Users are able to get access to related information by simply pointing and clicking at a graphic or an icon with a mouse. Users first see a screen to select information about a wide range of issues including hydrogeology, chemicals, restoring water quality in polluted aquifers, DRASTIC, and other issues (see Figure 4). Depending on their choice, they're led to other screens.



OASIS is a Macintosh-based system developed at Rice University. Users are shown a screen which allows them to choose information on pollution sources, hydrogeology, chemistry, DRASTIC, biorestoration or computer models. Pointing at any icon leads to other screens.

OASIS makes it extremely easy to compile DRASTIC ratings and to better understand the DRASTIC process. To compute a DRASTIC index, users first select the geographic area of interest by clicking on a map of the U.S. with the location of various aquifers. Follow up questions ask users to select the aquifer media and hydrogeologic settings. Graphics are shown representing potential choices and help screens are available for additional information. Based on the choices, DRASTIC ratings are computed for aquifers in both agricultural and municipal settings (users can also view the raw date in spreadsheets). If a user doesn't agree with the values the computer assigned to a DRASTIC parameter, customized numbers can be entered and the index can be recalculated.

Although OASIS is "user friendly," it's also a tool for serious scientists. Detailed information is available on 135 chemicals, numerous hydrogeologic settings and scientific references. Three models are incorporated in the program including Darcy's Law (which calculates groundwater velocities), a one-dimensional transport model, and BioPlume II which simulates the impact of bacteria on cleaning up polluted aquifers (Rifai, et al., 1989).

Other projects at Rice involve linking OASIS to a videodisc system in which users could be shown videotaped images of actual sites, and discussions of pertinent issues and problems.

WELLHEAD PROTECTION PROGRAMS

In Texas, weIlhead protection programs are being encouraged by the TWC and the EPA. Typically the programs invoIve identifying and mapping potential sources of manmade contamination by conducting inventories of solid waste management practices, abandoned and improperly constructed weIIs, septic tanks and underground storage tanks. As a result of the process, regulations that limit land uses near the wellhead may be enacted. Successful wellhead protection programs in Texas have been conducted in Del Rio (Cross, 1989), the Fort Worth area, and other areas.

Some steps are being taken by the EPA and at Texas universities to utilize computers to make wellhead protection programs less labor-intensive and easier to carry out. One idea is to use the multiple layers of maps generated with a GIS to identify areas where potential pollution problems may be most severe. Individual GIS layers may display sites of drinking water wells, vulnerable aquifer systems (either by DRASTIC ratings or other means), and sites of underground storage tanks, hazardous waste sites, and other potential contaminants. Decision support systems could help planners choose environmentally safe locations where drinking water supplies would not be threatened.

EPA's Office of Groundwater Protection has developed a user friendly software program for MS-DOS compatible computers called WHPA Code to help assist technical staffs in developing wellhead protection areas. The software allows users to simulate flow patterns in aquifers with two dimensional, steady groundwater flows. More complex situations involving multiple pumping and injection wells can be estimated and uncertainty analyses can be performed. EPA hopes to conduct training seminars in Texas this spring to teach how to use the program.

Efforts are also underway at Texas universities to computerize the weIlhead protection process. Jane Maler at Southwest Texas State University has been constructing computerized databases of water and pollution data to develop DRASTIC ratings and to define wellhead protection areas.

SUMMARY

New computer technologies may make it easier to analyze, understand, make decisions about, and communicate water quality problems.

Geographic information systems allow planners and decision makers to see the big picture - to look comprehensively at water quality issues from a number of interrelated perspectives. The next quantum leap will be increased development of sophisticated models that will take advantage of the spatial characteristics of GIS technology to accurately reflect real world conditions. Three-dimensional modeling and dynamic animation are two spinoffs from GIS research that may have particular application. In the future, time-consuming processes such as determining wellhead protection areas could be performed with increased computer support.

Decision making support systems including OASIS and Site Plan can guide planners and decision makers through complex processes such as averting pollution, restoring contaminated aquifers and complying with environmental regulations.

Major challenges may come in getting the various computer technologies to talk to each other. Different GIS systems are being promoted by private companies but many of the systems cannot work welI with other products. Hopefully situations won't arise where a tremendous amount of work goes into developing products that can't be widely utilized because users don't all have the appropriate computer.

Finally, computerized GIS maps need solid scientific data to be usable. Basic research must continue to make sure that these fascinating programs have a strong and supportable scientific base.

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