



PDHonline Course C423 (15 PDH)

GIS Applications in Water Resources and Environmental Engineering

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2020

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COURSE CONTENT – Lecture 5

Course C423 is a practical GIS course with particular reference to applications in Water Resources and Environmental Engineering, addressing some of the basic, yet common GIS needs in these two fields. The course describes the availability of free databases and public domain GIS software, and their use in performing common GIS processing tasks that are relevant to Water Resources and Environmental Engineering. The ability to search, download and make use of such data sets and software is presented within the context of this course. The course consists of 5 lectures, which start off with introductory level material in Lecture 1, and progressively builds up through the remaining four lectures. A basic awareness of the concept of GIS is desirable but not required as a pre-requisite for this course.

The following topics are covered in this 5th lecture of Course C423:

- ❖ Case Studies:
 - ❖ GIS Water Resources applications
 - ❖ GIS Environmental Engineering applications

1. GIS Case Studies

The remaining sections of this fifth (and final) lecture in the series will focus on those previous lectures that relate to environmental engineering and water resources applications.

GIS is a powerful tool for developing solutions for water resources, such as assessing water quality and managing water resources on a local or regional scale. Hydrologists use GIS technology to integrate various data and applications into one, manageable system. There are various categories of GIS for water resources. For this reason it was decided to use the ESRI website which is well known in the GIS industry, to present a few of the case studies. The classification of water resources applications are as follows:

- ❖ Water Resources Management
- ❖ Watershed Management
- ❖ Flood Management
- ❖ Groundwater
- ❖ Water Quality
- ❖ Biodiversity and Habitat
- ❖ Pollution Prevention and Control
- ❖ Regulatory Compliance
- ❖ Sustainable Development
- ❖ Agencies and Organizations

In Environmental Engineering applications, the managers use GIS to make land-use planning decisions, monitor environmental remediation sites, and comply with environmental regulations. With GIS, they can:

- ❖ Incorporate existing foundation data—such as current land use, distance to utilities and environmental concerns, and other information—into the decision-making process.
- ❖ Include existing installation rules and regulations in the analysis.
- ❖ Develop, capture, and share a site selection process model for reuse and refinement.
- ❖ Generate automated reports and share the results.
- ❖ Provide carbon footprint accounting.

1.1 Water Resources GIS Applications

Case Study 1:

Mapping and Managing Potable Water Infrastructure Assets in Cocoa, Florida ¹

The use of GPS/GIS data collection improved efficiency in the project's data collection procedure. The City of Cocoa, located on the east coast of Florida, is one of the largest suppliers of potable water in the state. Not only does the city supply drinking water to its incorporated residents, it also supplies potable water to neighboring communities, including Cocoa Beach, Merritt Island, Rockledge, Titusville, Cape Canaveral, Patrick Air Force Base, and unincorporated Brevard County. That translates into nearly 70,000 customers consuming about 27 million gallons of potable water per day.

Keeping track of such a large utility has presented an ongoing challenge for the city's Utility Department. The Engineering Division, responsible for design and construction, and the Transmission and Distribution (T&D) Division, responsible for operation and maintenance, made the decision back in 2002 to begin mapping and managing the potable water utility using GIS.

The initial phase of mapping the system was accomplished by entering potable water assets into a geodatabase via heads-up digitizing using the city's record drawings as the source. While this was a step in the right direction, the city soon realized that the true physical location of critical assets, such as valves and hydrants, was not represented accurately in the record drawings. Knowing exactly where aboveground potable water assets are is extremely important, especially to T&D staff. Locating valves is essential during a water main break to be able to quickly cut off the flow of water to reduce flooding, water damage, and unnecessary waste. With Cocoa and its neighbors being coastal communities, this is even more challenging, as hurricanes and tropical storms are common. In light of this situation, T&D decided to purchase two Trimble GeoXT GPS units and have their staff begin collecting map grade locations of the system's aboveground assets.

The project involved the use of the latest GPS and GIS technology in a cooperative effort with T&D staff to produce a highly efficient and accurate product. They would collect GPS points; edit the GIS features in real time in the field; and incorporate assistance from T&D staff for utility locations, system data, and connectivity.

Using a ruggedized laptop computer equipped with ArcGIS ArcInfo and Trimble GPS Analyst software, a link was established from the Trimble GeoXT to the

¹ <http://www.esri.com/news/arcnews/winter0809articles/mapping-and-managing.html>

laptop via a Bluetooth connection. The GeoXT was also connected to a GeoBeacon for real-time GPS correction. After the features were located and designated by T&D staff, GPS points were collected on the GeoXT and uploaded live to a GPS-enabled geodatabase on the laptop using GPS Analyst field tools. GIS features, entered previously from the city's record drawings, and were rectified immediately in the field to the GPS points using ArcInfo editing tools. T&D staff provided their knowledge to assist in system connectivity and data attribute input. A geometric network was incorporated to facilitate the efficient spatial adjustment of GIS features.

Case Study 2:

Tampa Bay Water Deploys GIS to Model Potable Water Distribution²

The highlights of this project are as follows:

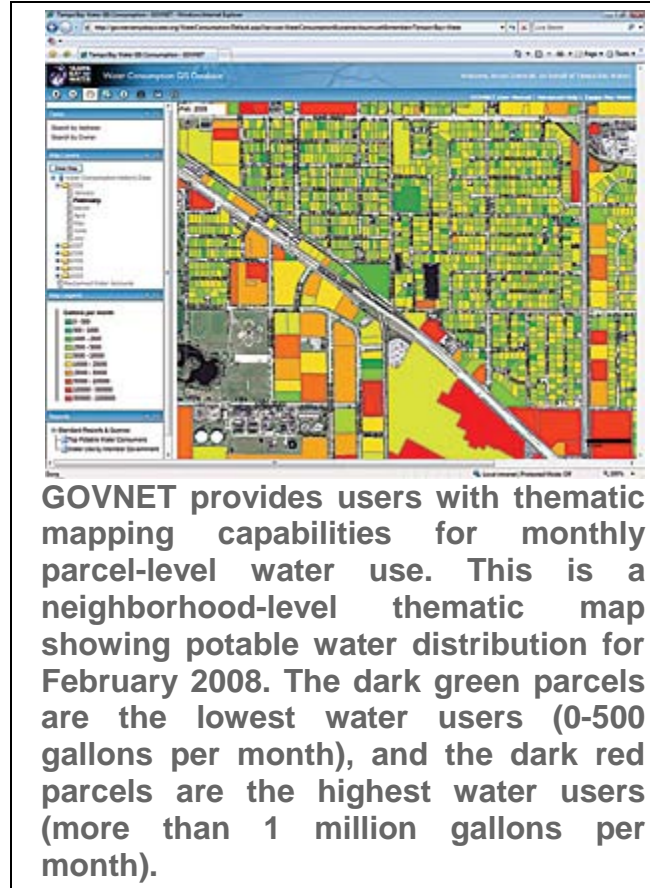
- ❖ With ArcGIS Server, GIS staff rendered hundreds of gigabytes of time-series vector and raster data in advance.
- ❖ Viewing temporal water consumption at an individual parcel level allows high-resolution thematic mapping.
- ❖ Modeling enables the board of directors to make infrastructure and capital decisions.

Tampa Bay Water, a regional water authority whose jurisdiction includes three heavily populated counties in Florida (Hillsborough, Pasco, and Pinellas), is responsible for providing potable water to the Tampa Bay area's regional member government utilities. These local governments include Hillsborough County, City of New Port Richey, Pasco County, Pinellas County, City of St. Petersburg, and City of Tampa. Tampa Bay Water's mission is to develop reliable and cost-effective water supply sources to meet the growing demands of the region with minimal impact to the environment. Tampa Bay Water staff manages a vast infrastructure of pipelines, water treatment plants, reservoirs, and the largest seawater desalination plant in North America. This infrastructure serves an area with a current population of approximately 2.5 million people growing at close to 3 percent per year.

² <http://www.esri.com/news/arcnews/winter0809articles/tampa-bay-water.html>

Tampa Bay Water relies on GIS for various aspects of its operations. Most notably, GIS is used to manage the regional water supply source rotation, which helps minimize impacts to its groundwater and surface water supplies, as well as the surrounding wetland and aquifer systems of the region.

In June 2007, Tampa Bay Water was tasked by its member governments to develop a high-resolution water distribution (consumption) application to analyze where and how the potable water was being used in the region. This application, named GOVNET, would become the basis for managing all future water conservation efforts.



GOVNET provides users with thematic mapping capabilities for monthly parcel-level water use. This is a neighborhood-level thematic map showing potable water distribution for February 2008. The dark green parcels are the lowest water users (0-500 gallons per month), and the dark red parcels are the highest water users (more than 1 million gallons per month).

GOVNET's functionality includes the ability to view, analyze, and query time-series water consumption data at various resolutions (regional, city, neighborhood, street, parcel) and retrieve charts, graphs, and reports for water demand.

GOVNET's use of temporal and spatial data heavily increases the memory and storage demands of the ArcGIS Server infrastructure. To model water distribution and consumption at the parcel level over time, Tampa Bay Water needed a reliable platform that would ensure adequate speed for data retrieval and map requests through the Web browser. With the help of ArcGIS Server technology's data caching abilities, Tampa Bay Water's GIS staff was able to render hundreds of gigabytes of time-series vector and raster data in advance for fast retrieval through the Web browser. This data is housed in Tampa Bay Water's enterprise GIS system, which includes a multiterabyte ArcSDE geodatabase server and various nonspatial SQL servers used to collect various water quality, consumption, SCADA, and wetland data.

The ArcGIS Server Web Application Developer Framework (ADF) provides users who have minimal GIS experience and training with a reliable template for GIS applications that Tampa Bay Water will use as the framework for all future application enhancements. Tampa Bay Water makes use of high-performance scalable servers to accommodate future growth of the GOVNET application, as well as simultaneous users and queries.

GOVNET also incorporates Microsoft's Virtual Earth to provide street-level photography and one-half-foot digital orthophotography from various third-party sources. Reporting tools allow a user to use statistics to view average, median, maximum, and minimum water consumption at user-defined intervals.

The successful implementation of GOVNET became possible because Tampa Bay Water had diligently collected time-series billing data from its member governments on a monthly basis from 1998 to the present at an account level. This data represents over a half million water use accounts across the region, all of which were subsequently geocoded to a physical parcel. The ability to view temporal water consumption at an individual parcel level gives Tampa Bay Water high-resolution thematic mapping abilities, which provided the base functionality for the GOVNET application. This account data is very important for regional demand planning and budgeting and is also used by Tampa Bay Water to model long-term demand forecasts for potable water, which allow the Tampa Bay Water board of directors to make decisions about future infrastructure needs and capital improvement projects.

The success of GOVNET is not going unnoticed in the Tampa Bay region. New requests for application access from local water demand managers and conservation coordinators continue to pour in. The Florida Yards and Neighborhoods Association recently utilized GOVNET to provide basin analysis for water users around the Brooker Creek Preserve, an 8,500-acre wilderness area managed by Pinellas County.

Tampa Bay Water is exploring future applications to the GOVNET framework, including incorporating conservation program data to allow demand managers to see how responsive water consumption is to targeted conservation measures over time. Using this targeted approach to conservation will help ease water demand for Tampa Bay Water and help further its goal of a reliable and sustainable water supply for generations to come.

Case Study 3:

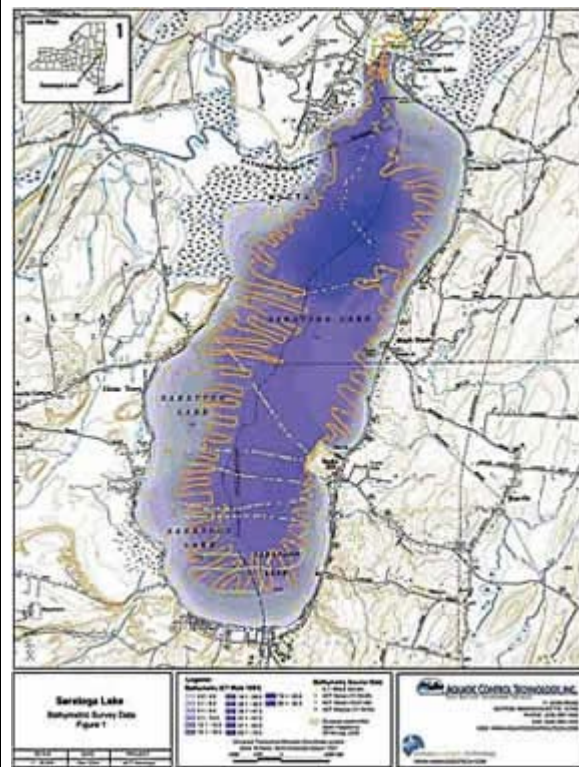
Lake Management GIS³

This project:

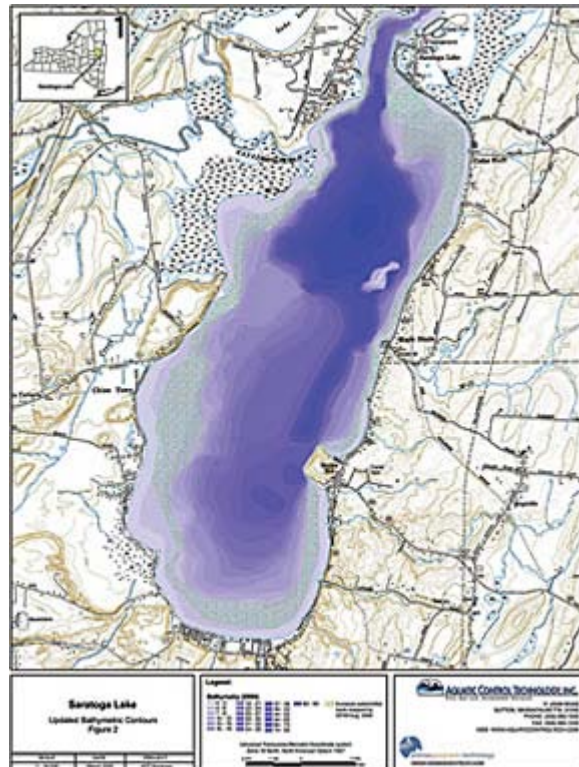
- ❖ makes use of ArcView to quickly create bathymetric data, perform editing, and create cartographic output.
- ❖ Uses ArcPad's simple API to save time.
- ❖ Helps to accurately apply herbicide to targeted areas.

Saratoga Lake is a 4,000-acre lake located in Saratoga County, New York. The highly invasive Eurasian watermilfoil weed was reportedly introduced to Saratoga Lake in the mid-1970s and reached nuisance densities by the early 1980s. Planning efforts began in 1982, and in 1986 a mechanical harvesting program was initiated to cut and remove the weed from the lake. The Saratoga Lake Protection and Improvement District (SLPID) was created in 1986 to oversee the harvesting operations. Harvesters were operated between mid-May and mid-September each year. While simultaneous watershed management efforts improved water quality, the Eurasian watermilfoil infestation became worse. By the mid-1990s, most of the lake perimeter less than 15 feet deep supported dense Eurasian watermilfoil that would grow to the surface and greatly interfere with recreational boating and swimming, not to mention adverse impacts to fish, wildlife, and water quality. The harvesting program simply could not keep up with the proliferating plant.

³ <http://www.esri.com/news/arcnews/spring08articles/lake-management.html>



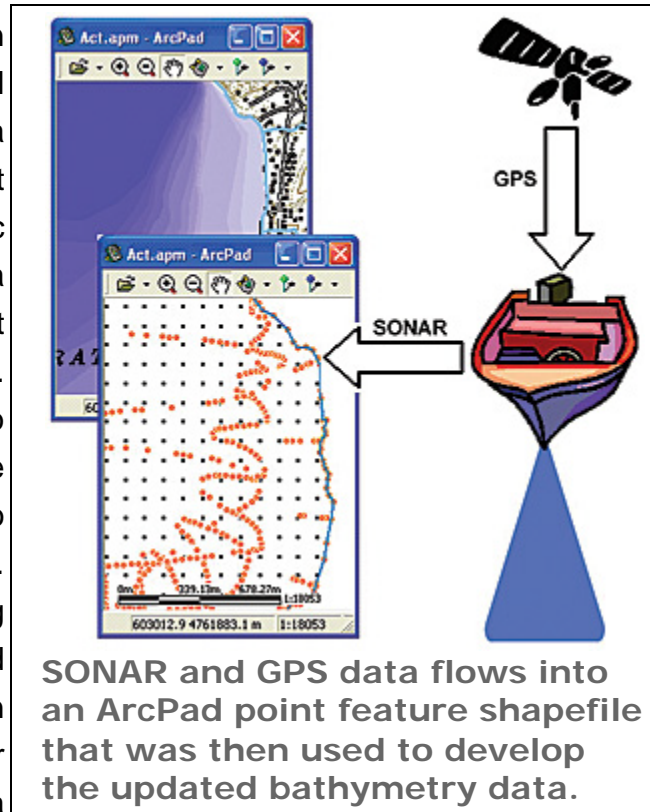
This map illustrates the presurvey bathymetry data that was collected in 1980 and the new depth measurement points.



This map shows the new postsurvey 2004 bathymetry data along with the occurrence of Eurasian watermilfoil in the lake.

SLPID prepared a comprehensive watershed management plan in the late 1990s. One recommendation was to conduct demonstration herbicide treatments to evaluate their efficacy as compared to the ongoing mechanical harvesting program. Aquatic Control Technology, Inc., an applied lake management company, was selected through a competitive procurement process to perform the demonstration herbicide treatment in 2000. Aquatic Control Technology was primarily selected for its technical approach, which included the use of real-time differential GPS navigation of the treatment boat. An ArcView and GPS interface created by Colorado-based Esri Business Partner Animas Geographic Technology was successfully used for the treatment.

Following a second demonstration treatment in 2003, Aquatic Control Technology was contracted to develop a long-term aquatic plant management plan for Saratoga Lake in 2004. Aquatic Control Technology realized it needed a better way to perform pretreatment survey activities and the treatment itself. The company also needed a way to produce accurate calculations of lake volumes at various depth thresholds to plan for the best treatment methodology. This was a challenge, because existing bathymetry data dated back to 1980 and no new depth survey work had been performed. Bathymetry is the underwater equivalent of topography and a bathymetric survey is akin to a topographic survey of the floor of a body of water. Aquatic Control Technology also needed a way to accurately navigate multiple treatment crafts in real time.



Animas Geographic Technology worked with Aquatic Control Technology to create a real-time data collection application that combined differential GPS input with sonar. Animas Geographic Technology selected ArcPad to provide Aquatic Control Technology with a lightweight and flexible data collection/navigation application. Using the application, Aquatic Control Technology was able to efficiently collect enough data to create new bathymetry data for the entire lake bed. ArcPad was selected for the simple and flexible application development interface it provided. ArcPad saved time and allowed Animas Geographic Technology to focus on data collection workflows and integrating the sonar and GPS equipment. ArcPad also offered a platform that would run on both Windows XP and Windows CE, which was important to Aquatic Control Technology since it had invested in both handheld and laptop field computers.

Animas Geographic Technology selected ArcView desktop software for data processing and editing and cartographic output. Since the field data was collected using ArcPad, the resultant GIS data was returned to the office in a readily compatible format that could immediately be used within ArcView. The superior GIS data editing capabilities of ArcView allowed Animas Geographic Technology to quickly create the new bathymetry data that was in turn used to develop volumetric calculations for the areas of invasive weed growth, as well as professional cartographic products. The new bathymetry data was then used to create a new three-dimensional spatial data representation of the lake bed detailing weed-choked areas. Aquatic Control Technology also used the real-time differential GPS capability of the application to navigate this large open water body and precisely apply herbicide to targeted areas for control of the pervasive Eurasian watermilfoil growth in 2007.



Saratoga Lake has experienced a Eurasian watermilfoil infestation that greatly interferes with recreational boating and swimming, not to mention adverse impacts on fish, wildlife, and water quality.



The Saratoga Lake Protection and Improvement District was extremely pleased with the results of the 2007 program and has committed to an even larger-scale project in 2008.

The application that Animas Geographic Technology created has automated much of Aquatic Control Technology's business process in the field and is routinely used for geospatially referenced aquatic plant surveys, as well as for real-time navigation on large treatment projects. Aquatic Control Technology selected Animas Geographic

Technology based on its experience using GIS and GPS for data collection and analysis coupled with its custom application development expertise.

1.2 Watershed Management

Case Study 1:

Creating a Watershed Stormwater Basin Inventory⁴

Data was gathered using Tablet PCs running ArcPad. Levels of total suspended solids (TSS) or particulate matter are good indicators of stream health. High concentrations of TSS can ruin habitat for fish and other aquatic life by increasing sedimentation and siltation and provide attachment places for pollutants such as metals and bacteria. This is an inventory project using GIS to gather field data on a Pennsylvania watershed that is being used for implementing stormwater management controls to lessen TSS load.

An inventory project gathered data on a Pennsylvania watershed using ruggedized Tablet PCs running ArcPad. This data provided better information about storm water infrastructure that will help communities in the watershed reduce the overall total suspended solids (TSS) load by implementing stormwater management best practices.

The Wissahickon Creek Watershed Stormwater Basin Inventory was implemented by the Philadelphia Water Department (PWD) as part of a larger watershed-wide planning initiative under way in the Wissahickon Creek Watershed (WCW). PWD began initiating intergovernmental, multijurisdictional partnerships in 1999 to create and implement watershed-focused strategies for ecological restoration and water quality improvement.

These initiatives recognize that watersheds do not stop at municipal borders. Development trends in upstream communities dramatically affect downstream waterways and natural resources. PWD initiated a watershed planning process within WCW in 2005. The Wissahickon Basin Inventory initiative presented an opportunity for implementing a mutually beneficial data gathering process between upstream and downstream municipalities.

WCW has a total drainage area of approximately 64 square miles. According to the Delaware Valley Regional Planning Commission's (DVRPC) year 2000 land-use data, more than 65 percent of this watershed area has been developed. This development has resulted in land cover that is mostly impervious to water. Furthermore, large portions of WCW experienced extensive land development prior to the implementation of stormwater management controls required by the Pennsylvania Stormwater Management Act of 1978. According to the Wissahickon Creek River Conservation Plan (2002), approximately 60 percent of the watershed area was developed prior to the adoption of runoff control ordinances that limit impervious areas or require detention of stormwater runoff.

⁴ <http://www.esri.com/news/arcuser/0708/jasoncruz.html>

The consequences of this unmanaged land development process have included severe stream bank erosion, flooding, and impairment of aquatic communities. More than 90 percent of stream segments in WCW are listed by the Pennsylvania Department of Environmental Protection (PA DEP) as impaired due to siltation. In 2003, a Total Maximum Daily Load (TMDL) for siltation was established by the U.S. Environmental Protection Agency (EPA), Region III. The TMDL program determines the safe level of loading for a pollutant—in this case TSS—and allocates that load equitably among dischargers through the stormwater permitting process.

Municipalities needed to identify sources of TSS loading and find ways to reduce the load. The Wissahickon Basin Inventory has given municipal partners updated information about their stormwater infrastructure as well as a tool that assists in planning overall TSS load reduction.

Case Study 2:

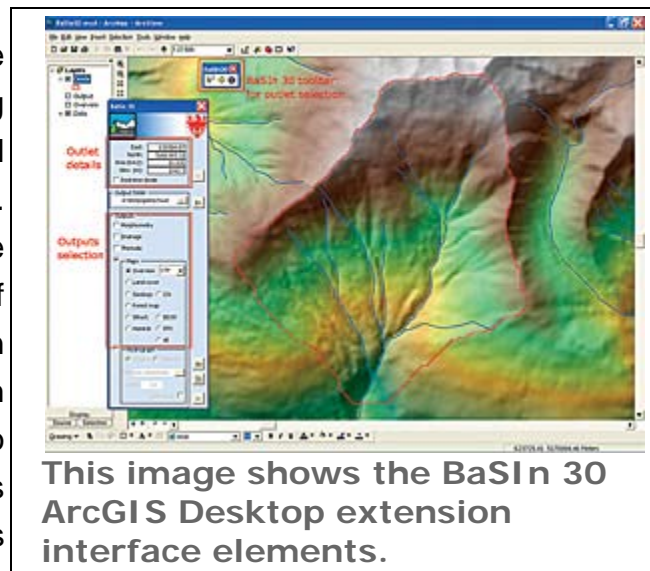
Italian Province Tackles Hydrological Hazards with GIS⁵

The highlights of the system are as follows:

- ❖ System supported by ArcGIS Desktop simplifies the planning of new hydraulic structures.
- ❖ Geodatabase stores land-use, geology, morphology, hydrologic network, hydraulic structure, and hydrologic hazard data.
- ❖ Flood managers use system to design models, generate reports, and visualize hydrologic risks.

The autonomous province of Bolzano is located in northern Italy and shares a boundary with Austria. With a surface of 7,400 square kilometers, Bolzano is mainly mountainous, its elevation ranging from 200 to more than 3,800 meters above sea level (ASL). Notably, a conspicuous 37 percent of the province's surface has an elevation of more than 2,000 meters ASL, with another 49 percent of the surface between 1,000 and 2,000 meters ASL. Urbanized and agricultural areas are therefore restricted to the valley floor along the main water streams. In the last 30 years, human activities in these areas have greatly increased; thus, so has the demand for hydraulic structures.

Bolzano's Department 30 is the province's agency in charge of resolving the conflicts between natural environment and human needs. Specifically, Department 30 manages the construction and maintenance of engineering measures for the mitigation of hydrologic and geologic hazards, such as check dams (small dams used to decrease stream flow velocity), dikes (embankments used to prevent areas from being flooded by stream overflow), and drains (used to carry away excessive storm water).



⁵ <http://www.esri.com/news/arcnews/summer08articles/italian-province.html>

The planning activity of Department 30 strongly relies on the availability of detailed, up-to-date spatial information about the environment and, more specifically, about the watershed where hazards need specific mitigation. For this purpose, in the past years, the province has designed and implemented several GIS geodatabases that include generic datasets, such as digital elevation models, land cover, land-use maps, and orthophotography. Also included were more specific datasets, such as the inventory of historic floods and debris flood events and the inventory of the hydraulic structures already in place.

While creating and maintaining a geodatabase with all the datasets needed by the planners is fundamental, it is also important to make those datasets easily available and usable. A specific framework project called the Information System for Hydrogeological Hazards and Risks (IHR), sponsored by the European Commission among others, was devised to make the information needed in risk management accessible to Bolzano's planners in a simple and standardized way.

As part of the IHR project, the Basin System Information of Department 30 (BaSI 30) application was designed to simplify the extraction, at the watershed level, of the most relevant information for the purpose of planning new hydraulic structures.

Since most of the department's flood managers were already familiar with the ArcGIS Desktop software platform, BaSI 30 was implemented as an ArcGIS Desktop extension. The input data required by BaSI 30 is all spatial and includes general layers about land use, geology, and morphology and more specific layers about the hydrologic network, hydraulic structures already in place, and hydrologic hazards.

When a user in Department 30 has selected a suitable outlet, on the basis of a digital elevation model (DEM), BaSI 30 extracts the divide of the watershed and visualizes it. At that point, the user can select the desired outputs, and BaSI 30 clips the required input layers based on the watershed divide. Then, the clipped layers are processed to extract the information required to produce the desired reports.

The outputs include information about several characteristics of the watershed in the form of maps, statistics, synthetic indexes, and charts. These characteristics include watershed morphology (elevation, slope, and aspect); watershed drainage (drainage density and hierarchical stream classification); and other thematic relevant aspects, such as land use, geology, hydraulic structures inventory, historical flood events, and

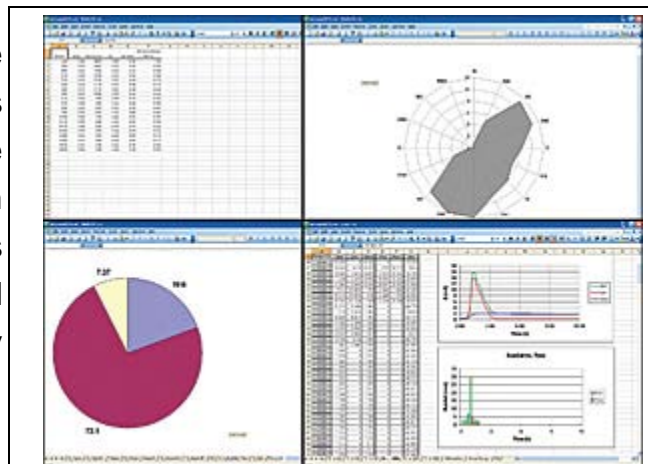
hydrologic hazards. In addition, by means of hydrologic simulations, details about the response of the watershed and rainfall are also provided.

All these outputs are presented to the managers at three different levels, with increased structuring. At the first level, outputs include spatial layers about the watershed (simply obtained by the clipping operations), database tables, text, and image files obtained by querying and processing the spatial layers. Although these particular first-level outputs present the highest granularity and detail, they are nonetheless unstructured and require a good GIS and hydrologic knowledge to be properly understood and used.

At the second level, outputs include several Microsoft Excel spreadsheets containing both a selection of level-one outputs and extra information in the form of mainly statistics and charts. At this level, the outputs are already structured enough to be immediately utilized by managers.

Outputs in the third level include a well-organized report containing a selection of level-one outputs combined with a selection of indexes and charts from the second-level spreadsheets, organized in chapters and subchapters. Third-level reports contain the most relevant information to characterize the watershed for planning purposes and can be used as is or opened in a word processing system for further editing.

The ArcGIS Desktop reports generated in BaSI n 30 are meant to become part of the standard documentation of every new project managed by Department 30 involving the construction of new hydraulic structures.



A selection of BaSI n 30 output spreadsheets reporting about various characteristics of the watershed being investigated: elevation, slope, geology, hydrological response.

Case Study 3:

The State of Louisiana Develops Watershed Implementation Plans with GIS⁶

Hurricanes Katrina and Rita have devastated the United States Gulf Coast region. The work described in this article was done before that disaster. As ArcNews goes to press, some of the individuals cited in the article are providing assistance to various agencies working on disaster relief and damage assessment including the U.S. Department of Energy, the U.S. Environmental Protection Agency (EPA), the U.S. Coast Guard, the Federal Emergency Management Agency, the National Oceanic and Atmospheric Administration, and the Texas Department of Environmental Quality. The effect of Katrina and Rita on the state's wetlands has been substantial, and GIS tools will be used to support the restoration efforts for the region.

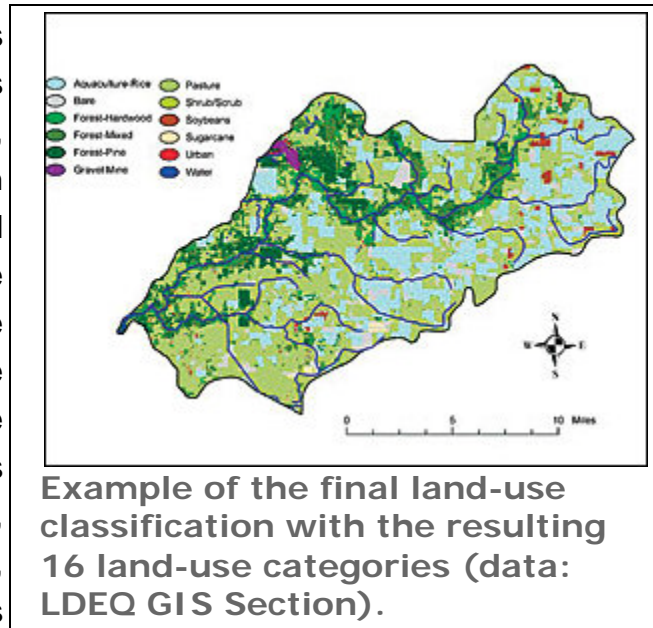
Situated in the southern United States on the shore of the Gulf of Mexico, Louisiana is a low-lying state with a diverse landscape that includes rolling hills in the north and bayous in the south. With a mean elevation of only 100 feet, Louisiana is traditionally home to a strong agriculture-based economy, which produces soybeans, cotton, sugarcane, rice, corn, and timber. Natural resource extraction includes oil and natural gas. This human activity on the land, combined with hot summers, low water flow, and sluggish bayou conditions, strains the state's capability to meet water quality standards established by the EPA Clean Water Act (CWA). The Act provides a structure for regulating pollutant discharge, surface water contaminants, and implementing pollution controls for United States water bodies.

⁶ <http://www.esri.com/news/arcnews/fall05articles/state-of-louisiana.html>

In addition, CWA requires that all states develop a list of impaired water bodies that do not meet water quality standards, even with current pollution controls in place. CWA also requires that a total maximum daily load (TMDL) be developed as a priority for each of these water bodies that is not meeting the designated uses (i.e., for fish and wildlife propagation and recreation). TMDLs establish limits for the pollutant load, from both point and nonpoint sources, that can be discharged into water bodies and still meet water quality standards

and maintain the designated use(s). TMDL becomes the water quality management tool for establishing permit limits for point source discharges and load reduction goals for all nonpoint sources at the watershed level. U.S. EPA Region Six has a court-ordered schedule to complete all TMDLs for Louisiana by 2011, and the state is a partner in meeting that schedule.

In 1999, the Louisiana Department of Environmental Quality (LDEQ) began using Esri's ArcInfo and Esri Business Partner Leica Geosystems' ERDAS IMAGINE software to devise a process for developing watershed implementation plans for the nonpoint source component of TMDLs. LDEQ has been using ArcInfo and ERDAS IMAGINE together since 1992.



1.3 Flood Management

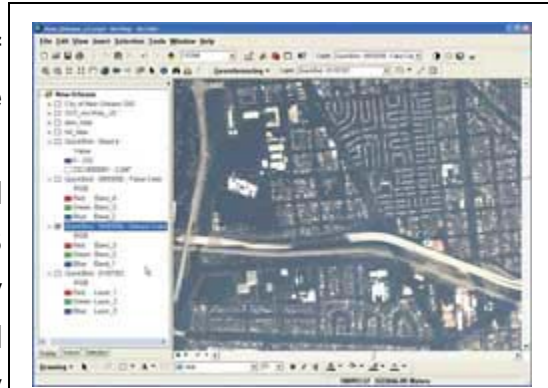
Case Study 1:

Making More Information Available in Emergencies⁷

In an increasingly urbanized world, the effects of disasters such as hurricanes and tsunamis are more acutely felt. As coastal areas, in particular, become more densely settled, more people and property are threatened by these events. GIS benefits all aspects of the emergency management cycle from planning, mitigation, and preparedness through response and recovery by integrating complex data in a geographic framework that produces actionable information.

The value of GIS was demonstrated earlier this year when Hurricane Katrina, a Category 5 hurricane, devastated portions of Louisiana, Mississippi, and Alabama. GIS provided a common operational picture or shared vision of the incident that helped organizations and individuals work more effectively.

Even before the hurricane made landfall on August 29, 2005, GIS was helping emergency management personnel and volunteers model its probable effects as described in another article in this section, "Predicting Hurricane Katrina's Storm Surge Using ArcScene." HAZUS-MH, a risk analysis software application that incorporates ArcGIS, was also used to generate wind damage estimates. Understanding where wind and storm surge damage were likely to occur helped managers position resources out of harm's way but near enough to respond quickly.



Distinguishing flooded areas using only a natural-color satellite image is challenging.

⁷ <http://www.esri.com/news/arcuser/1005/umbrella29.html>

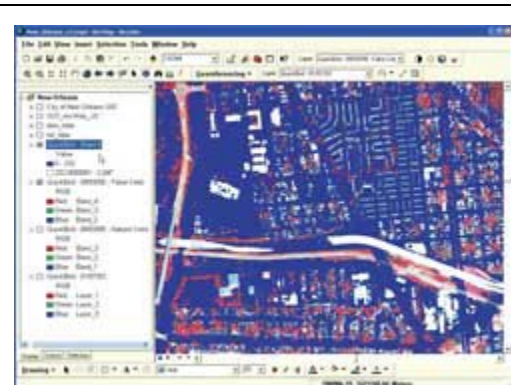
In response to Hurricane Katrina, Esri actively supported local, state, and federal agencies and private organizations with software, mapping, and analysis services, technical expertise, field GIS, and Web services. The Esri Hurricane Maps and Help Web site was a clearinghouse for GIS resources-people, data, software, and hardware. Organizations and GIS users, regardless of platform, could request assistance from Esri at the site. Those who wanted to offer help could describe the products and services offered. Nearly 100 Esri business partners, Esri corporate alliance partners, hardware vendors, and consultants registered at the site.

The site also directed GIS users who wished to volunteer their GIS skills to the Urban and Regional Information Systems Association (URISA) GISCorps site. This nonprofit organization provides short-term volunteer-based GIS services to underserved communities throughout the world.

Several deployments of GISCorps assisted at the Mississippi Emergency Operations Center in Jackson and other locations in the state. In addition to geocoding victim locations, GISCorps volunteers along with volunteers from Mississippi state agencies, the Mississippi University system, and Esri generated a wide range of map products for responders and decision makers. Learn more about the work done by the GISCorps and other volunteers in Mississippi in another article in this issue, "GISCorps Aids Hurricane Response."



Using the multispectral DigitalGlobe QuickBird image, it is possible to drop the blue band and change to a false-color image that greatly enhances the clarity. GIS data processing tools take full advantage of the capabilities of the high-resolution satellite camera sensor.



Using GIS methods, the near infrared band (or all bands) can be quickly classified to create a flooded water mask (shown in blue).

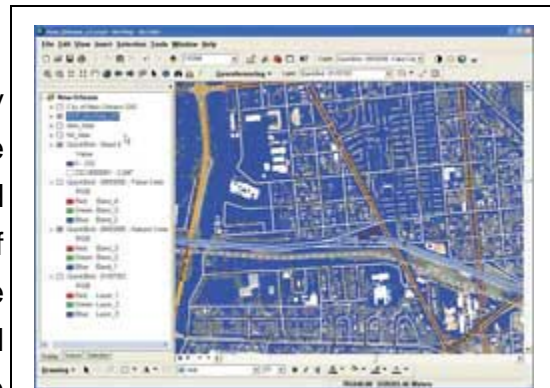
GIS-generated maps have become a common part of disaster response activities. However, this event underscored the larger role played by distributed GIS on the Internet. New tools have been developed for this broader GIS Internet environment. Spatial portals help manage, locate, share, and use the geographic knowledge created and maintained by local, state, and federal governments and other organizations. During Hurricane Katrina and Hurricane Rita response efforts, the Geospatial One-Stop (geodata.gov) portal provided central access to data, maps, images, and resources for organizations involved in hurricane-related activities.

By integrating, managing, and processing many types of geospatial data, GIS makes far more information available to decision makers and others responding to emergencies. Analysis of imagery taken of the aftermath of Hurricane Katrina captured by DigitalGlobe's QuickBird satellite illustrates the ability of GIS to integrate data and create actionable information.

The first image shown at the top of this page is a view of New Orleans captured as a four-band multispectral image. The natural-color version is similar to satellite images of New Orleans, Louisiana; Biloxi, Mississippi; and other affected

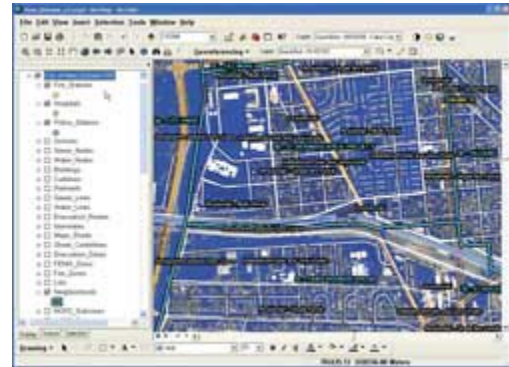
areas that were available from various Web sites almost immediately after the disaster. Like many of these images, this image is dark and details are difficult to discern owing to the collection angles used when capturing the imagery and the presence of smoke, haze, humidity, and other environmental factors that adversely affect image clarity. Although the public, largely unfamiliar with remote sensing data, could relate to these images easily, these images failed to answer the most urgent question, "What areas are flooded and damaged?"

Using GIS, a wealth of information can be learned from this DigitalGlobe imagery. Not only do decision makers and responders want to know where floodwaters are, but they also need to know where flooding is in relation to infrastructure, assets, and population.



Overlaying street network datasets supplied using commercial Web services with the classified flooded areas makes it easy to communicate which areas are flooded.

A geospatial analyst knows that more data can be gleaned from the near infrared band than natural-color imagery and will use a false-color image that drops the blue band to greatly enhance the clarity of the image. Applying GIS data processing tools yields more information. The color stretches of the 11-bit imagery can be enhanced to take full advantage of the capabilities of the camera sensors and see more detail. Using GIS methods, the near infrared band (or all bands) can be quickly classified to create a flooded water mask.



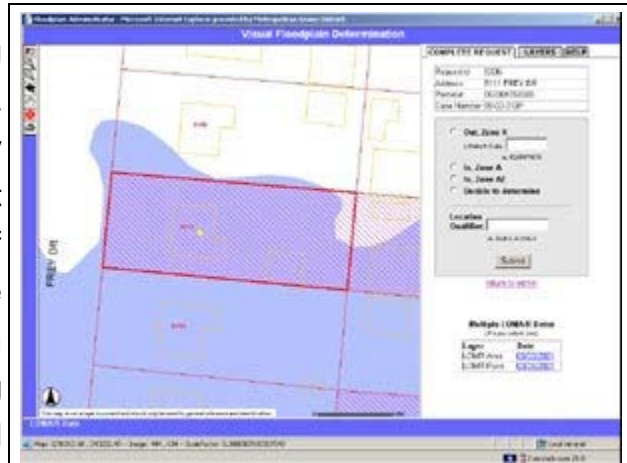
Combining the imagery, classified flooded areas, and GIS data from the city of New Orleans shows flooding in relation to assets and infrastructure.

By overlaying current street network data from a commercial Web service, such as Tele Atlas/TomTom, with the flooded areas, the extent of the flooding can be determined. Combining the image and water mask with GIS data from the city of New Orleans that includes the locations of assets (such as hospitals and fire stations) and infrastructure (such as water lines and building footprints) lets emergency managers assess damage to the community. While visualization is an important aspect of communicating geospatially referenced information, GIS provides capabilities for data integration and analysis that generate specific, actionable information. As part of the response to Hurricane Katrina, GIS helped direct rescue efforts, quickly apprise decision makers of complex situations, and collect information to locate missing persons.

Case Study 2:

Web-Based Floodplain Determination Served on the Web With GIS

Situated in a low-lying fluvial plain along the Ohio River, Louisville, Kentucky, has a long history of flooding. In the last century there have been several major floods that have cost the community millions of dollars in damage. As a result of the catastrophic flood of 1937, flood protection structures have been placed surrounding Louisville's urban core. Today's flood concerns are directed toward other low-lying areas adjacent to natural streams and ditch networks, which were constructed to drain what were once wetland areas and ultimately empty into the river. As of 1994, property development within the community has been regulated according to the United



The floodplain administrator viewer is opened by clicking the appropriate link in the floodplain administrator list. It is used to identify the property's flood zone, to submit the findings, and to complete the request.

States Federal Emergency Management Agency (FEMA) guidelines that primarily affect those areas.

With the release of the Metropolitan Sewer District (MSD) Web-based Floodplain Determination Service, obtaining floodplain information for individual properties in the community has become easier. Owners of properties within the floodplain who have a federally backed mortgage are required to purchase and maintain flood insurance. The floodplain is defined by the normal channel of rivers, creeks, streams, and areas where overflow occurs when the capacity of the waterway is surpassed during a 100-year flood event. The Flood Insurance Rate Map (FIRM) was created by FEMA to delineate these floodplain boundaries. MSD has been performing floodplain determinations in accordance with FEMA guidelines for more than 10 years and has identified the following as core customers of this service: condominium associations, home owners, insurance professionals, lenders, state and local officials, and surveyors.

In the predigital days, MSD staff performed floodplain determinations manually using hard-copy FIRM maps. FIRM was offered digitally for the first time in the community in 1994 as the result of a countywide restudy by FEMA. This effort served as a model project for FEMA in methods of utilizing GIS to maintain data. A workstation-based application was developed in-house by the Louisville/Jefferson County Information Consortium (LOJIC) GIS, in which MSD is a partner, to automate much of the flood determination process utilizing digital data.

That application served its purpose well for several years. In that time, as the volume of floodplain determination requests increased, a full-time technician was needed to process the requests. It became apparent that a new solution was needed. Recently, MSD initiated a businesswide study to streamline work flows and increase efficiency. Floodplain determination was identified as a task that could be reengineered to free up personnel for other core services.

Web-Based Solution

MSD GIS and LOJIC staff teamed up with the goal of implementing a new solution with the following objectives:

- Reduce staff resources.
- Shorten response time to customers.
- Increase availability for customers.
- Automate request tracking.



The screenshot shows the 'Floodplain Determination Administrator' web interface. At the top, there is a logo for MSD and the title 'Floodplain Determination Administrator'. Below that, it says 'Visual Determination Requests' and '© 2004 MSU, All rights reserved. February 5, 2004'. There are navigation links: 'Home', 'Floodplain Determination', and 'View PDF map'. A table lists several requests with columns for ID, Address, Parcelid, Customer, and Phone.

ID	Address	Parcelid	Customer	Phone
5327	4710 LEHIGH DR	081001310000	B B	555-555-5555
5324	3616 FOUNTAIN DR	081300580001	T T	456-456-4569
5321	4812 FOUNTAIN DR	080006500000	B B	522-222-2222
5323	3616 FOUNTAIN DR	081300560001	TEST TEST	111-222-3333
5328	5111 FRY DR	080001700000	A B	555-151-6903

The floodplain administrator page lists all incomplete requests that require a visual determination by MSD staff.

MSD and LOJIC are no strangers to Esri software, and the technical team recognized early on that the project should be implemented as an ArcIMS solution. In fact, two applications were developed to accommodate this project: the Floodplain Determination Application and the Floodplain Administrator Application. The Determination Application serves as a front end to an ArcIMS map service that allows the user to enter property and contact information. The location information is used to perform a series of spatial queries against the ArcIMS map service, and the results form is returned in PDF format. A majority of the requests can be automatically determined, and the corresponding results are immediately displayed on the customer's computer screen. The remaining requests require a visual determination because of the accuracy required for the floodplain determination and the time lag involved in updating the county's planimetric/topographic basemaps in the GIS. These requests are tracked in the Administrator Application, which is accessible only to MSD staff.



Showing a completed floodplain determination form required by lenders and insurance representatives.


In the Administrator Application, the MSD staff reviews each request by clicking its corresponding link, and an ArcIMS viewer quickly appears zoomed to the property's location with appropriate layers visible. To complete the request, the MSD staff reviews the map, determines the flood zone, and submits the findings. Once the request is completed, the form is generated and a link to it is automatically e-mailed to the customer's e-mail address, if one is provided. If an e-mail address is not available, the request is printed out and faxed back to the customer.

The Determination Application page includes links to FEMA, MSD's Floodplain Management Plan, and MSD's Stormwater and Sanitary pages for quick reference. Also included are an instructions page and an FAQ page for the Determination Application and Help documentation for the Administrator Application.

Measure of Success

This ArcIMS solution has successfully accomplished the following objectives:

- ❖ Reduced staff resources: MSD staff time spent on flood determinations is now less than one-quarter of what it once was. In fact, 87 percent of all requests are now automatically completed.
- ❖ Provided quicker response time: In most cases the results are returned to the customer immediately, in contrast to within two business days as before.
- ❖ Increased availability: The Web service is available 24 hours a day, seven days a week, in contrast to normal business hours previously.
- ❖ Automated request tracking: All request information is automatically inserted into MSD's customer request management system.



The screenshot shows a web browser window titled "Floodplain Determination - Microsoft Internet Explorer provided by Metropolitan Sewer District". The address bar shows "http://www.bsc.org/food/user/defa...". The page content includes the MSD logo, a navigation menu with links for HOME, INSTRUCTIONS, FLOODPLAIN MANAGEMENT PLAN, SUBMISSIONS, SANITARY, FEMA, and MSD. The main heading is "JEFFERSON COUNTY, KENTUCKY FLOODPLAIN DETERMINATION". Below the heading is a text block explaining the request process: "Please enter the information requested below. Once the personal and location information is entered click the **Submit Request** button to proceed. You may also click on the **Clear** button to clear the form to start over. If a determination cannot be made for your request, then further review by MSD staff is required. Once MSD staff has completed the review, the determination will be sent to you **within 2 business days** via the provided Fax number or E-mail address. If both are provided then the E-mail address is given precedence." There are two tabs: "Locate by Address" (selected) and "Locate by Parcel ID". The form fields include: First Name, Last Name, Phone Number (with a note "(i.e. 502-540-6000)"), Fax Number (with a note "(i.e. 502-540-6000)"), Email (with a note "(Max 50 characters)"), and Company Name (with a note "(Max 50 characters/spaces)"). There are asterisks indicating required information. Below the fields is a note: "* Required Information ** Either Fax Number or E-mail are Required Information". There is an "Address" field. At the bottom of the form are "Submit Request" and "Clear" buttons. A footer note says: "Please review our [Frequently Asked Questions](#) page for more information. Copyright © 2003 by the Louisville/Jefferson County Metropolitan Sewer District (MSD) Louisville, Kentucky 40203".

The floodplain determination main page is where the user enters location and contact information and then submits a floodplain determination request.

With the new service in place, MSD is taking steps to phase out accepting floodplain determination requests via fax to further reduce staff time. The Web-based floodplain determination service is free for public use.

1.4 Groundwater

Case Study 1:

Florida Aquifer Vulnerability Assessment Uses GIS⁸

Highlights of the project are as follows:

- ❖ Stakeholders agreed that any tool must take advantage of recent advancements in GIS.
- ❖ Input datasets were developed with ArcGIS Desktop extensions.
- ❖ The ArcGIS Desktop platform proved to be defensible and science based, yet flexible.

Recently developed GIS-based aquifer vulnerability models provide valuable groundwater protection tools with wide-ranging applications throughout Florida. Intended to enhance protection efforts for Florida's fragile drinking water resources, the models provide new options for community planners, public works staff, environmental professionals, storm water and wastewater engineers, and local governments. These models are extensively used in many areas, including land-use planning, identification of recharge areas, wastewater planning, wellhead protection, identification of environmentally sensitive areas, storm water management, and spring protection.

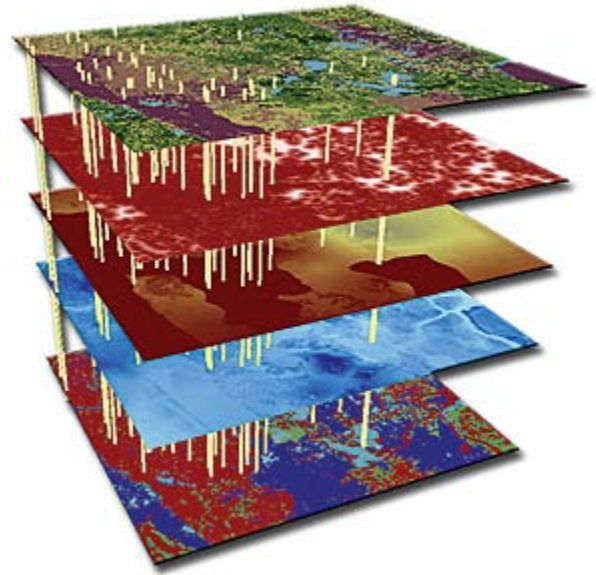
⁸ <http://www.esri.com/news/arcnews/winter0809articles/florida-aquifer.html>

Aquifers are among the most important sources of drinking water in the United States. In Florida, an estimated 90 percent of drinking water is derived from aquifers, so identifying areas where aquifer systems are more vulnerable to contamination is an essential component of a comprehensive groundwater management and protection program. The Floridian aquifer system is the most important source of water in Florida, supplying the state with literally billions of gallons of water per day. In addition, the Floridian aquifer system is the source of several hundred freshwater springs, which are valuable resources from a tourism perspective, bringing thousands of visitors to the state per year.

Groundwater protection efforts in Florida are supported by five water management districts, the Florida Department of Community Affairs (FDCA), Florida Department of Environmental Protection (FDEP), Florida Department of Health, and numerous local environmental agencies. Having a reliable tool that prioritizes areas of higher aquifer vulnerability for both water resource and growth management is a critical requirement for these organizations. Aquifer vulnerability modeling meets this requirement, allowing a proactive approach to the protection of aquifer systems, saving significant time and increasing the value of protection efforts.

Various stakeholders throughout Florida agreed that a new, modern tool was necessary to meet the need to protect groundwater resources. The consensus of many stakeholders was that any tool must take advantage of recent advancements in GIS, be easy to implement, and rely heavily on the state's wealth of geographic and water-resource information that has been carefully collected over the years.

The project that emerged, the Florida Aquifer Vulnerability Assessment (FAVA), was undertaken by the Florida Geological Survey of FDEP. Stakeholders from all of Florida's five water management districts; FDCA; FDEP; Hazlett Kincaid, Inc.; SDII Global Corporation; and the United States Geological Survey (USGS) acted as advisers to the project. The stakeholder group also peer-reviewed the final model to



This conceptual model shows the three main components of an aquifer vulnerability assessment: the upper four layers represent soil conductivity; density of sinkhole features, material overlying the aquifer, and estimated aquifer recharge; yellow extruded lines are training points (monitor wells); and the lower layer is the model output, or aquifer vulnerability map.

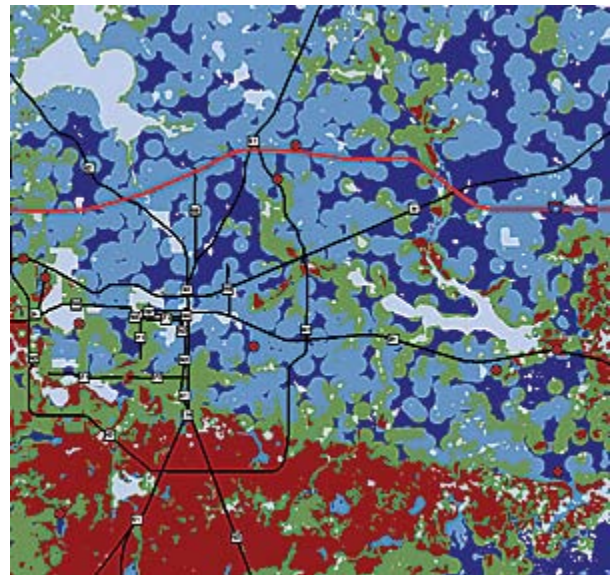
help strengthen its defensibility, and many of these stakeholders now regularly use FAVA results to complete agency tasks.

The primary goal of the FAVA project was to provide a scientifically defensible water resource management and protection tool that facilitated land-use planning to help minimize impacts on groundwater quality. The project's designers sought to generate meaningful and useful tools to help ensure balanced protection and future use of groundwater resources by characterizing the natural vulnerability of aquifer systems.

ArcGIS Desktop was selected as the development platform for the FAVA project because of the state's existing investment in the software suite. After careful assessment of available modeling techniques that would best suit an aquifer vulnerability analysis, the Arc Spatial Data Modeler, or Arc-SDM, was also selected. Arc-SDM was programmed by Don Sawatzky under the direction of Dr. Gary Raines of USGS and Dr. Graeme Bonham-Carter of the Geological Survey of Canada. Arc-SDM requires ArcGIS Spatial Analyst and is currently available on Esri's ArcScripts Web page: arcscripts.esri.com/details.asp?dbid=15341. Analytic techniques of Arc-SDM are being evaluated for inclusion in future versions of ArcGIS Spatial Analyst.

Arc-SDM consists of geoprocessing tools used to generate predictive maps describing probabilities of occurrences of specific events in a study area. The preferred Arc-SDM modeling component selected for the FAVA project was Weights of Evidence; this method is data driven and involves the combination of diverse spatial data to describe and analyze interactions and generate predictive models.

Critical to the success and defensibility of the FAVA project were reliable, consistent datasets. The initial phase of the FAVA project comprised acquisition, development, and attribution of various GIS datasets representing natural hydrogeologic conditions. This input data included digital elevation, aquifer recharge, subsurface material properties, sinkholes/karst features, soil properties, and water quality. The latter was developed to train the FAVA model, as Weights of Evidence requires a training point dataset, and water quality can be indicative of vulnerability in an aquifer system. For example, naturally occurring oxygen and nitrogen are generally considered ubiquitous at land surface; further, relatively low concentrations of these analytes occur in well-protected aquifer systems. Where these analytes



Training points are necessary for the Weights of Evidence analysis in Arc-SDM (shown here in red) and are used as indicators of aquifer vulnerability.

occur above natural background concentrations in aquifers, one can assume a good interaction between land surface and the aquifer; in other words, vulnerability is higher.

Development of input datasets required heavy use of ArcGIS Desktop extensions, including ArcGIS Geostatistical Analyst, used with borehole point data to generate models of subsurface materials; ArcGIS Spatial Analyst, used to process digital elevation data, extract suspected sinkhole features, and execute the model; and ArcGIS 3D Analyst, used to conceptualize input data layers and generate slides and figures.

The modeling phase of the FAVA project relied on use of Weights of Evidence to generate aquifer vulnerability response themes, which are expressed as probability maps. Probability values of these maps are classified into groups and assigned intuitive names reflecting relative aquifer vulnerability and thus become meaningful to the end user. These final maps are based on the spatial relationships between the input data and the training points—or points of known vulnerability—and express the likelihood that an area is more or less vulnerable. Maps were generated for all three of Florida's major aquifer systems: the Floridian, intermediate, and surficial aquifer systems.

Following completion of the project and release of model results, three members of the FAVA research team from the Florida Geological Survey formed Advanced GeoSpatial Inc. to meet the growing demand for more aquifer vulnerability modeling projects, specifically for the Floridian aquifer system, the state's most heavily used water resource. Several local projects were initiated along with an ongoing second phase of the FAVA project intended to improve results of the first project. Currently, six Florida counties—Alachua, Citrus, Leon, Levy, Marion, and Wakulla—have aquifer vulnerability assessments in use in various groundwater protection efforts.

Implications and use of aquifer vulnerability models are widespread and include development of wastewater guidelines, spring protection mapping, establishment of best management practices, and design of nitrate loading models. Local agencies have extensively applied the results of local scale analyses. For example, the Marion County aquifer vulnerability model is used to prioritize watershed management projects in sensitive areas. The Leon County aquifer vulnerability model is used to augment extension of sanitary sewer service and to protect Wakulla Spring, located south of the county. The Alachua County model was adapted into an aquifer-protection zone map complete with other natural features like springshed areas and sinking streams.



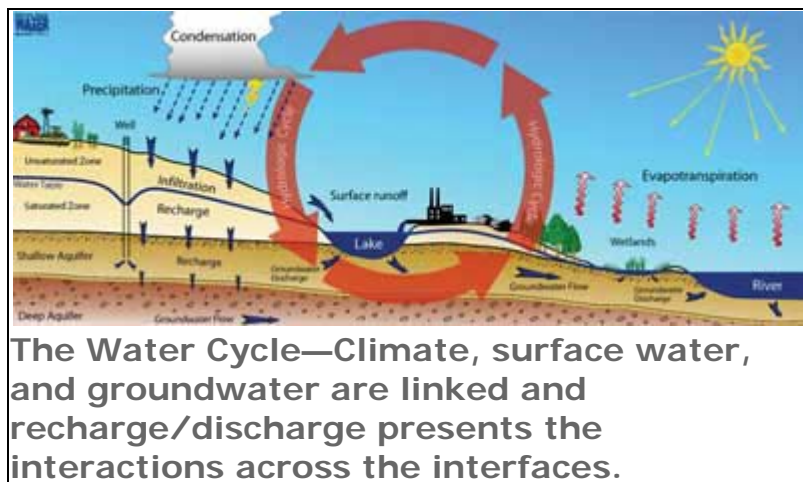
The Floridian aquifer system is the most important freshwater resource in Florida and is also the source of several hundred freshwater springs. Cypress Spring in northwest Florida is a pristine example of these unique natural features. (Photo credit: Kevin Defosset of the Northwest Florida Water Management District, 2003.)

Case Study 2:

Making Groundwater Recharge and Discharge Estimate Maps in One Day⁹

In Summarizing, Water moves on, above, and below the earth's surface changing state from liquid to vapor to ice. This continuous movement is known as the water cycle or hydrologic cycle. The importance of understanding recharge and discharge processes within the hydrologic cycle has led the National Research Council (NRC) to characterize research on these processes as a critical national research priority. NRC is part of the private, nonprofit institution that provides science, technology, and health policy advice to improve government decision making; increase public education; and better the understanding of science, engineering, technology, and health. The authors have developed a GIS-based tool for better understanding of these processes.

Community leaders and engineers tasked with managing water supplies must understand where the water is and how it moves through the hydrologic cycle. Among the least understood pathways are groundwater recharge and discharge, whose rates and spatial distributions define the relationships between groundwater and the other components of the hydrologic cycle such as precipitation, evapotranspiration, and surface water.

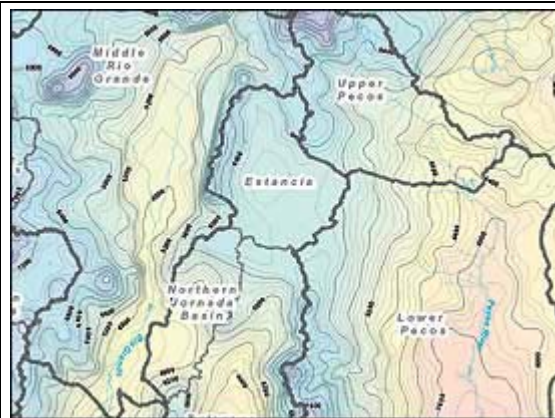


Unfortunately, recharge and discharge rates and patterns are difficult to characterize and cannot be estimated using a single method for all practical applications. This adds uncertainty to the management of water resources. Conventional recharge and discharge studies usually require field characterizations that are labor intensive and require months to complete.

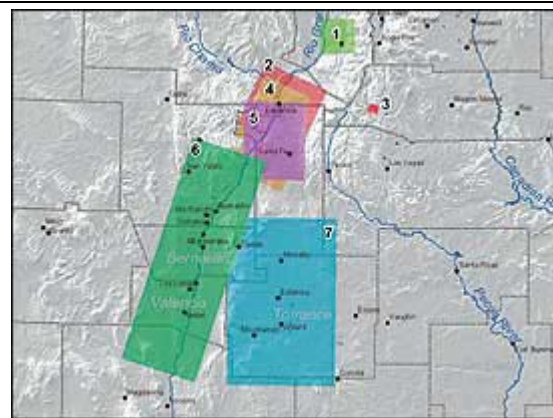
⁹ <http://www.esri.com/news/arcuser/0408/groundwater.html>

Case Study 3:

Surface and Groundwater Resources Assessment¹⁰



Water Level Map With Surface Basins and Subbasins



Groundwater Models

Water Level Map With Surface Basins and Subbasins

New Mexico has identified 12 river basins that include 18 subbasins as water resource assessment areas. Except where a river basin is subdivided, all of these boundaries are drainage divides. Surface water flows toward either the main stream or a central playa lake in a subbasin without a river.

Contours depict the generalized, predevelopment water table. In most areas of New Mexico, the shallow, often stream-connected water table aquifer is the most commonly developed groundwater source. This map portrays water levels before significant groundwater pumping occurred.

Groundwater Models

New Mexico has developed computer groundwater flow models for selected aquifers. Each model is a continuing collaborative effort between the state engineer, U.S. Geological Survey, and other hydrologists. These flow models are crucial in defining critical areas for well drilling restrictions, analyzing development impacts to existing water resources and predicting long-term benefits/problems to water use policy changes.

¹⁰ http://www.esri.com/mapmuseum/mapbook_gallery/state1/nm1.html

1.5 Water Quality

Case Study 1:

Improving Regional Water Quality Assessment - Geodatabase improves data management and analysis capabilities¹¹

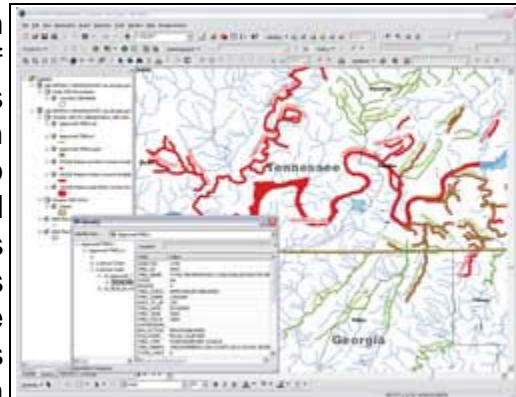
A geodatabase developed by the U.S. Environmental Protection Agency (EPA) Region 4 Water Management Division (WMD) manages georeferenced water quality assessment data from the region's eight southeastern states for various years far more efficiently than the previous system.

In accordance with the Clean Water Act, each state environmental agency tracks the status of water quality for water bodies located within its boundaries. Every even-numbered year, an assessment is made of each water body to determine whether it is meeting its designated uses. Each state agency tracks the status assessments in a local database and generates GIS datasets that depict the locations of these water bodies. Each lake, estuary, or river reach is called an assessment unit (AU) and assigned a unique identifier. While the EPA suggests recommended formats for assessment data and complementary GIS data, states often deviate somewhat from these formats to meet local needs.

Eight southeastern states submit assessment data and GIS files to EPA Region 4. These files are then forwarded on to EPA national headquarters

for eventual input into the national Assessment and TMDL Tracking and Implementation System (ATTAINS). *[The Total Maximum Daily Load (TMDL) program determines the safe level of loading for a pollutant.]* The GIS files are addressed by river reach to the 1:100,000-scale National Hydrography Dataset (NHD) and incorporated into EPA's Watershed Assessment, Tracking and Environmental Results System (WATERS). This system integrates various EPA water-related databases via reach-addresses of the NHD.

Over the years, the staff of EPA Region 4 have obtained numerous assessment databases and GIS datasets from its eight southeastern states that were furnished in assorted and incompatible shapefiles, tables, and Microsoft Access databases. Using these datasets to analyze water body status for more than one state or year was difficult and time consuming even for experienced GIS users.



Users can use the Identify tool to click on a feature and view records about those features stored in related tables or activate the hyperlink to the EPA database record for the feature.

¹¹ <http://www.esri.com/news/arcuser/0309/h2o.html>

In 2007, EPA Region 4 staff explored the possibility of using a geodatabase to better manage water quality assessment data. Although data is eventually reformatted by contractors at EPA headquarters into consistent formats for inclusion in ATTAINS and WATERS, the obvious roadblock in creating a geodatabase for Region 4 was the variety of assessment data formats and GIS data used by the states.

Region 4 contracted with Research Triangle Institute to develop a prototype geodatabase and populate it with reach-addressed versions of the states' assessment datasets. Region 4 staff then generated tables detailing the status of each AU from ATTAINS (then called the National Total Maximum Daily Load Tracking System). Relationship classes were created to relate the point, line, and polygon AU features to the assessment status tables using the AU identifier field. This was a one-to-many relationship because the AU is sometimes listed multiple times in the assessment status table if it has been tracked for several cycles and/or multiple water quality standard impairments (e.g., failures to meet swimming designated use because of high levels of pathogens).

Although this geodatabase format functioned fine, Region 4 staff soon realized it might be advantageous to populate it with the original state of GIS shapefiles rather than reach-addressed versions. While many states use NHD as the basis for their assessment units, some have reasons for not doing this.

For example, because Florida has mostly flat topography, and its complex, highly modified hydrography is not well depicted at the NHD 1:100,000 scale, the Florida Department of Environmental Protection prefers to use its own water body identifiers (WBIDs) that depict small contributing drainage areas. If Region 4 staff is reviewing assessment data for Florida in a GIS, it is helpful to be able to view and use WBIDs instead of a reach-addressed approximation of those features.

However, Region 4 recognizes the value of having all state assessment GIS data in a consistent NHD-based format and continues encouraging states to adopt the NHD format as the framework for AUs. Some states, such as Florida, are exploring using a higher-resolution version of NHD to meet this need.

Because the region wanted to populate the geodatabase with GIS features from the states, the tables from each state GIS dataset had to be reformatted to a consistent format. The essential component for each AU record was an AU identifier because it was used to relate back to the ATTAINS tables. Features were also dissolved by the AU identifier so that there was only one feature per AU. Water body name and type fields for the AU were populated if the information was readily available in the state GIS dataset. A hyperlink field provides a link to the EPA



Complex queries may be made in the detailed tables, then the relationships to the point, line, and polygon feature classes may be activated to display the locations of the results.

Web page describing that water body. Length in miles was calculated for linear features and area in acres for polygon features.

The assessment data feature classes, tables, and relationship classes have been loaded into the ArcSDE server for Region 4. This provides a stable, fast-drawing platform. Having all state data and cycles in one feature dataset allows staff at the region to build various layer files pointing to these feature classes, which are just different definition queries. A layer depicting locations of approved TMDLs was also developed. Using the Identify button in ArcMap or ArcReader, a user can click on an impaired water body and see its impairments for all cycles and see the TMDLs that have been established for it. The built-in relationships give users the ability to query 303(d) listings or approved TMDLs by certain parameters, such as all pathogen-impaired waters, and activate the relationship classes to display those features in the GIS. *[A 303(d) listing identifies those lakes, wetlands, streams, rivers, and portions of rivers that do not meet all water quality standards for that state.]*

The geodatabase relationships between various assessment unit features and detailed tables provide WMD GIS staff with powerful and versatile analytic capabilities. By integrating disparate data formats from different states into a common structure, the geodatabase makes multiyear, multiple-state spatial analysis much easier than before. Answers to complex management requests or environmental progress reports can be generated in far less time than when georeferencing was contained in unmatched shapefiles.

Now new GIS data files are modified to fit the table format and loaded into the appropriate feature class. The tables from ATTAINS with the water body assessment status are periodically updated. Serving the data via ArcSDE also gives the region the ability to include these layers in ArcReader projects or other applications.

Although the Region has made great progress in managing its assessment GIS data, there is still much work to be done verifying the quality of the data and populating the ATTAINS database with assessment decisions. New organizational restructuring and procedures should help address these issues.

Reformatting the historical GIS files into this new consistent tabular framework involved a lot of work, but the resulting product has proved well worth the effort. GIS users can perform complex queries in related tables and activate the related features or simply use the Identify tool, click on AU features, and see the related tabular information. Relationship classes linking the ATTAINS tables of impaired waters and approved TMDLs have created a much more powerful and versatile analytic dataset that can generate useful information in a fraction of the time previously required.

Case Study 2:

Enterprise GIS Streamlines Water Quality Assessments

Highlights of the project are as follows:

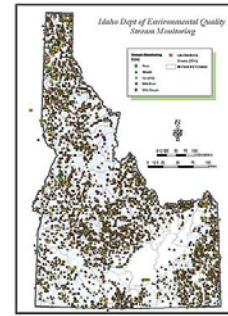
- ❖ A statewide enterprise GIS was implemented to manage the massive amount of water quality data.
- ❖ ArcSDE and ArcIMS provided indispensable functionality.
- ❖ In-house customizations were seamlessly integrated.

With more than 92,000 miles of rivers and streams and more than 1,000 lakes and reservoirs, Idaho lists water as one of its most important resources. Idaho's rivers, lakes, streams, and wetlands not only provide great natural beauty, they also supply the water necessary for drinking, recreation, industry, agriculture, and aquatic life.

The Federal Water Pollution Control Act Amendment of 1972 (Clean Water Act) requires states to provide, every two years, an assessment of the quality of all their waters and a list of those that are impaired or threatened. To efficiently meet this charge, the Environmental Protection Agency (EPA) recommends that states, tribes, and other water quality monitoring collaborators use a combination of monitoring and assessment techniques to reliably estimate the overall condition of all waters within a state, assess changes over time, and measure progress toward the "fishable-swimmable" goal of the Clean Water Act.

The Idaho Department of Environmental Quality (DEQ) is responsible for assuring Idaho's streams, rivers, lakes, reservoirs, and wetlands meet their designated beneficial uses. DEQ must also prioritize site-specific assessments needed to confirm the location of both high-quality and impaired waters, as well as support control, restoration, and prevention actions under the Clean Water Act.

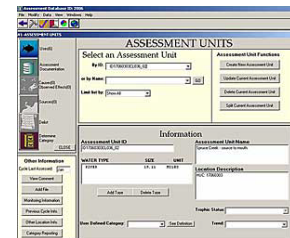
Since 1993, DEQ has monitored and assessed nearly 63,000 miles of Idaho's waters, collecting biological, habitat, and chemical samples from more than 7,100 river, stream, and lake locations. In order to manage and efficiently utilize the massive amount of water quality data being collected, DEQ implemented a statewide enterprise GIS in 2001, integrating its water quality monitoring databases with ArcSDE SQL Server and ArcIMS. Idaho's water quality standards, or beneficial use identifiers, were



IDEO's Stream/Lake sampling and monitoring locations (1993–2006)



IDEO Interactive mapping (ArcIMS) and public comment web application displaying the results of Water Quality Assessments and locations of monitoring sites.



EPA's menu driven Assessment Database application (ADB) for storing and tracking water quality assessments.



IDEO's supplementary web application to ADB, (IDASA) that generates biological and habitat metrics used in assessments.



ArcGIS toolbars and menus developed with ArcObjects (VB 6) that automate & display definition queries, selection queries, hyperlinks, and automation accessing SDE & imagery datasets.

linear referenced to the National Hydrography Dataset (NHD) and used as a primary base layer for analyzing, displaying, and reporting the results of stream water quality assessments. ArcSDE provided indispensable functionality, allowing DEQ to spatially join and relate monitoring and assessment data from multiple SQL server databases to NHD within ArcSDE. The integrated results are displayed through the Idaho state wide area network with customized ArcView, ArcGIS, and ArcIMS applications to DEQ's various field offices, as well as to the public through the Internet with ArcIMS.

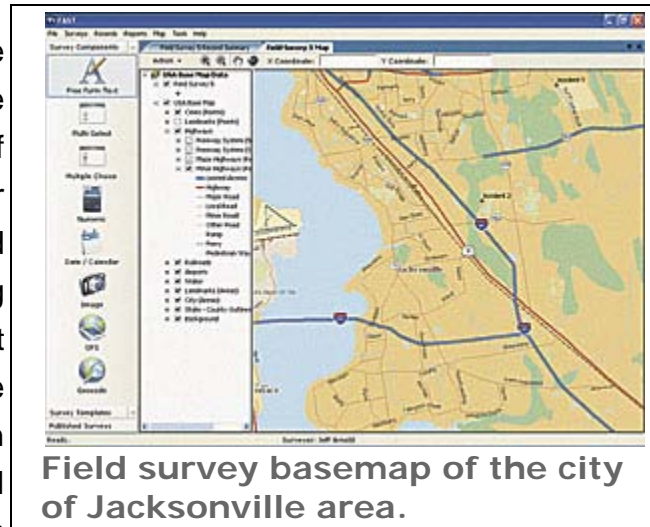
The Assessment Database (ADB), developed by Esri business partner Research Triangle Institute of North Carolina for EPA, is a relational database application for tracking water quality assessment data, including use attainment and causes and sources of impairment. DEQ's customized deployment of ADB provides water quality analysts with a user-friendly, intuitive menu-driven process for analyzing monitoring data and reporting water quality status to EPA. In-house customizations by DEQ have seamlessly integrated ADB with ArcGIS and ArcIMS, giving analysts the capability to additionally analyze stream drainage areas with current land-cover, land-use, and aerial photography geospatial data from DEQ's ArcSDE enterprise GIS.

Custom ArcGIS toolbars developed by DEQ's GIS staff provide point-and-click data automation, enabling analysts and scientists to easily navigate through Idaho's hydrography layers and watersheds, while hyperlinked features provide real-time access to water quality reports and monitoring data.

Case Study 3:

City of Jacksonville, Florida, Maps Its Storm Water System with GIS

By the early 1970s, only a third of the nation's public water resources were safe for fishing and swimming. The lack of success in developing adequate water quality standards programs, combined with ineffective enforcement of existing laws, prompted the federal government to pass a comprehensive revision of the federal water pollution control law, known as the Federal Water Pollution Control Act (FWPCA) amendments of 1972. This



act established that "the discharge of pollutants to navigable waters is not a right" and that "a discharge permit is required to use public water resources for waste disposal."

To enforce the law and encourage these principles, FWPCA created the system of permitting wastewater discharges known as the National Pollutant Discharge Elimination System (NPDES). Focusing primarily on controlling pollutants from urban and industrial storm water discharges, Phase I of the NPDES program required all municipal separate storm sewer systems (MS4s) serving a population of 100,000 or more to acquire a permit.

The city of Jacksonville (COJ), located in northeast Florida, is rich with natural water resources, such as the Atlantic Intracoastal and the St. Johns River. In June 1991, COJ, along with its co-permittees—the Florida Department of Transportation (FDOT) District II and the cities of Neptune Beach and Atlantic Beach—started the process of applying for an NPDES permit that would cover the largest MS4 in the nation. The application was accepted, and the permit was acquired in March 1997. COJ and FDOT jointly turned to England-Thims & Miller, Inc., of Jacksonville, an Esri Business Partner, to prepare their permit applications and assist in the fulfillment of the permit's requirements after its issuance.

Because the city of Jacksonville spans more than 758 square miles, the most time-consuming and labor-intensive task associated with meeting the requirements of the

permit was the mapping of the MS4. The inventory included the locations and pathways of storm water pipes, along with inlet, manhole, and outlet construction information, all of which are stored in an Esri geodatabase with submeter accuracy.

The MS4 spatial data was compiled through a process that involved both intensive field data collection and a review of design drawings and as-built drawings acquired from both the city of Jacksonville and FDOT. However, despite every effort to ensure the accuracy of the inventory, some logical gaps still exist within it. Gaps are due to a variety of reasons, including updates to the existing system, missing or inaccurate record drawings, a lack of access by field crews caused by private property rights, paved-over manholes, or any number of other real-world conditions that hinder the accuracy of any project. To correct these gaps and acquire MS4 information in areas of new or updated construction, England-Thims & Miller and its surveying partner Robert M. Angas Associates are conducting a field quality assurance (QA) program.



Using field software to collect information about a storm water structure.

To optimize this field QA process, England-Thims & Miller selected the Field Adapted Survey Toolkit (FAST) from Esri Business Partner GeoAge, Inc., of Jacksonville. COJ selected this software because it dynamically adjusts to changing data collection requirements and allows rapid design and deployment of mobile data collection forms to the field. Its designer module incorporates ArcGIS Engine technology directly so that ArcView users can view the survey locations spatially and open applicable collection forms from a map. Also, its ArcPad applet allows users to view locations of surveys on their Pocket PC mobile device. FAST also allows digital photos and GPS coordinates to be easily associated with surveys.

The old method of cross-referencing of documents and paper maps in the field was tedious and time-consuming. Using mobile devices loaded with ArcPad and FAST working together allows field crews to take data layers crucial to resolve "gaps" into the field. The field crews now have instant access to feature classes depicting the current state of MS4, planimetric data, topographic data, aerial photography of the region, major and minor basin boundaries, and hydrologic features.

The evolution of hardware and software has allowed England-Thims & Miller to greatly improve the processes associated with the NPDES permit.

"When we started data collection in 1996," explains Kim Garbade of England-Thims & Miller, "because of the state of the existing technology, we would go out with two teams: one that collected the attribute and image data and the other that collected the feature's coordinates. We would postprocess this data into shapefiles." As GIS technology has evolved, COJ has improved the process and can collect photographic, attribute, and positional data simultaneously with a one-man crew, and now stores the data in a SQL Server geodatabase using ArcSDE.

ENVIRONMENTAL ENGINEERING GIS APPLICATIONS

1.6 Biodiversity and Habitat

GIS is an essential tool for inventorying habitats, studying endangered species, correlating species and geographic relationships, analyzing change over time, and evaluating the effectiveness of conservation practices and policies.

Esri's GIS software provides a robust solution for managing extensive databases, accessing appropriate features, and responding to specific relational queries. Biologists are using GIS to monitor and manage:

- ❖ [Habitat encroachment](#)
- ❖ [Habitat loss](#)
- ❖ [Invasive species](#)
- ❖ [Wildlife](#)

1.7 Pollution Prevention and Control

Efficiently create and organize, analyze, manage, and maintain pollution geodatabases. From storm water runoff to animal waste pollutants, show complex relationships of different types of contaminants and a range of environmental features. Perform complex modeling to include factors such as absorption rates, natural filtering, weather forecasts, and soil erosion.

- ❖ [Planning](#)
- ❖ [Mitigation](#)
- ❖ [Response](#)
- ❖ [Cleanup and Remediation](#)
- ❖ [Science](#)

1.8 Regulatory Compliance

Government agencies use GIS to create and enforce environmental legislation. Services and businesses use GIS to comply with environmental regulations and mandates.

Using regulatory compliance mapping with GIS gives:

- ❖ Accurate calculations
- ❖ Flexibility to adapt to regulatory changes
- ❖ Streamlined compliance processes
- ❖ Composite and historical reports
- ❖ Visualization of regulatory bodies

In addition, cooperation between agencies is simplified by the use of a central database that can be leveraged for cross purposes such as financial information, ownership, improvements, and plans.

GIS technology allows both operators and inspectors to manage, coordinate, and report discovered threats to the regulating agency.

1.9 Sustainable Development

GIS is an important tool for helping people map out plans for successfully achieving management strategies that are sustainable both at local and global levels.

Esri supports many sustainable development efforts throughout the world. Geographic information systems provide policy makers and planning agencies with visualization tools to manage growth and change.

GIS is a key tool used in:

- ❖ Assessment
- ❖ Prioritization
- ❖ [Mitigation](#)
- ❖ [Planning](#)
- ❖ [Science](#)
- ❖ Training

1.10 Agencies and Organizations

From communities of farmers and foresters to government agencies to commodity investors, Esri's enterprise GIS provides people with access to a system that meets their needs to:

- ❖ Reduce maintenance costs.
- ❖ Diminish redundant workflows.
- ❖ Improve accuracy and integrity of data.
- ❖ Enable data sharing, distribution, and publication.

Agencies Using GIS to Monitor Earth's Resources:

- ❖ [Conservation International \(CI\)](#)
- ❖ [Federal Emergency Management Agency \(FEMA\)](#)
- ❖ [National Aeronautics and Space Administration \(NASA\)](#)
- ❖ [National Geographic \(NG\)](#)
- ❖ [National Oceanic and Atmospheric Administration \(NOAA\)](#)
- ❖ [National Weather Service \(NWS\)](#)
- ❖ [National Wetlands Inventory](#)
- ❖ [U.S. Department of Agriculture \(USDA\)](#)
- ❖ [U.S. Environmental Protection Agency \(EPA\)](#)
- ❖ [U.S. Fish and Wildlife Service](#)
- ❖ [U.S. Geological Survey \(USGS\)](#)
- ❖ [United Nations Environment Programme \(UNEP\)](#)
- ❖ [Woods Hole Research Center \(WHRC\)](#)
- ❖ [World Wildlife Fund \(WWF\)](#)

Environmental Agencies Use Web Portals to Share GIS Data Resources

- ❖ [Conservation GeoPortal](#) provides a comprehensive listing of GIS datasets and map services relevant to biodiversity conservation.
- ❖ **EPA** [EnviroMapper](#) lets you map air releases, drinking water, toxic releases, hazardous wastes, water discharge permits, and Superfund sites.
- ❖ **National Institute of Environmental Health Sciences** [Hurricane Response](#) provides information about environmental contaminants during the disaster.

- ❖ **USDA GIS Service Center Agency [Geospatial Data Gateway](#)** offers data such as orthoimagery, soils, common land units, hydrography, land cover/vegetation/plants, wetlands, and climate.