hydro line

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In This Issue

Developing a Web-Based River Basin Management System in Ireland

By Myron S. Rosenberg, Alan Hooper, and Michael Waddell

A river basin management system (RBMS), custom designed for implementation of the European Union's (EU) Water Framework Directive (WFD) in the Eastern River Basin District (ERBD) of Ireland, proves especially well suited to explicit requirements for rational evaluation of alternative management measures and stakeholder (public) participation in the decision-making process toward formulation of Programmes of Measures (POMs) to achieve "good" status in water quality by 2015.

Ireland established five river basin districts to implement WFD, as described further at www.wfdireland.ie. Dublin City Council (DCC) serves as lead local authority on behalf of 12 other local authorities for WFD implementation in the ERBD (www.erbd.ie), an area that includes the capital, the commercial and industrial heartland, and approximately 40 percent of the population of the country. Contrary to general expectations, the natural waters in Ireland are subject to a wide variety of pressures that detrimentally affect the natural ecology—and WFD includes ecology as one of the many criteria in evaluating water status. DCC retained a consultant under a six-year contract to conduct five major tasks:

- Summarize background information. This was documented in a policy, legislation, and authorities report that examined the water management setting in Ireland and informed the decision to adopt a dynamic, multiple-user Web-based system given that (1) at a minimum, the RBMS must be easily accessible to all 12 local authorities in the ERBD and several national-level government departments, and (2) the WFD requires public participation in decision making.
- Characterize the waters. This was documented in a report on 478 distinct water bodies that must be tracked with respect to achieving good status by 2015 through the application of measures to reduce negative pressures/impacts—findings that underscored the need to store, organize, analyze, retrieve, and display a massive amount of data and information to implement an effective RBMS.
- Develop a river basin management system. The RBMS comprises several elements: integration with monitoring data

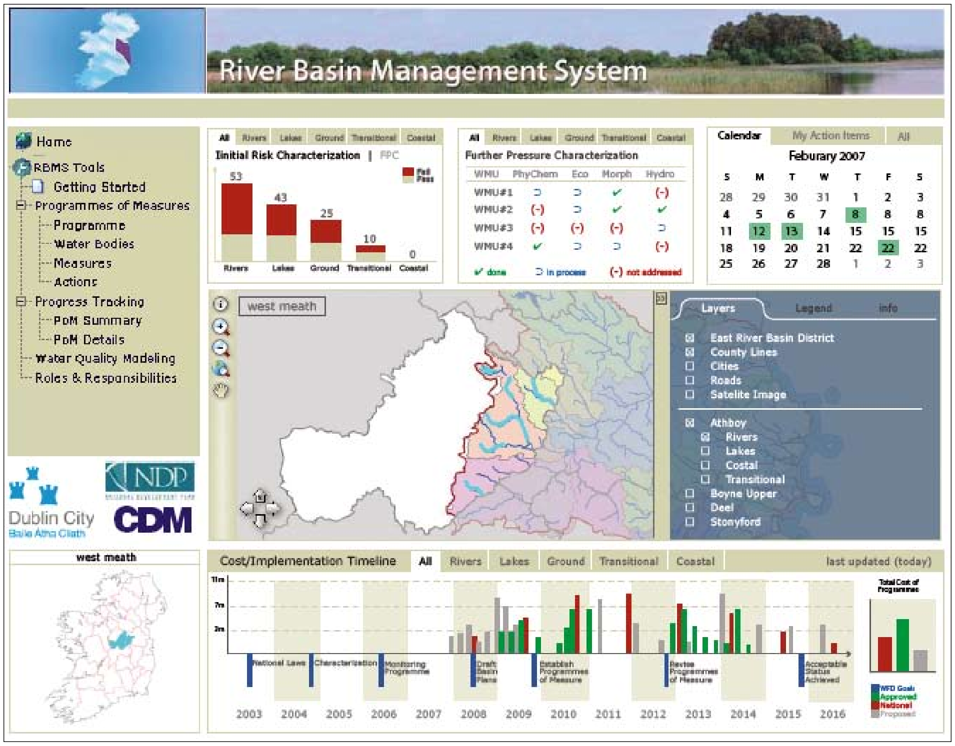


Figure 1

continued on page 6

Arc Hydro-Based Spatial Decision Support System for Nonpoint Pollution

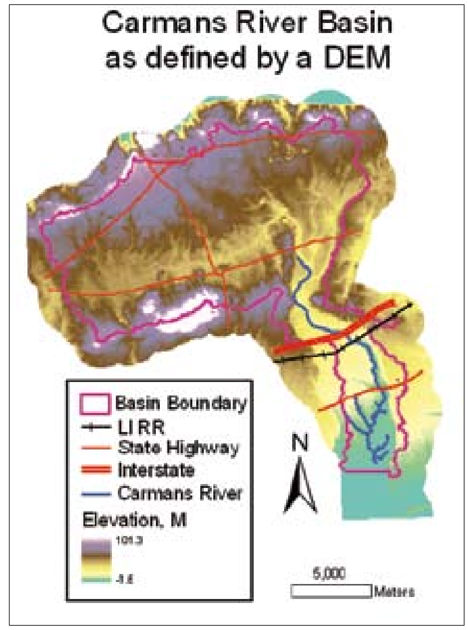
Lee Herrington and Horace Shaw, State University of New York College of Environmental Science and Forestry, Syracuse, New York
Jeff Herter, Division of Coastal Resources, New York State Department of State, Albany, New York

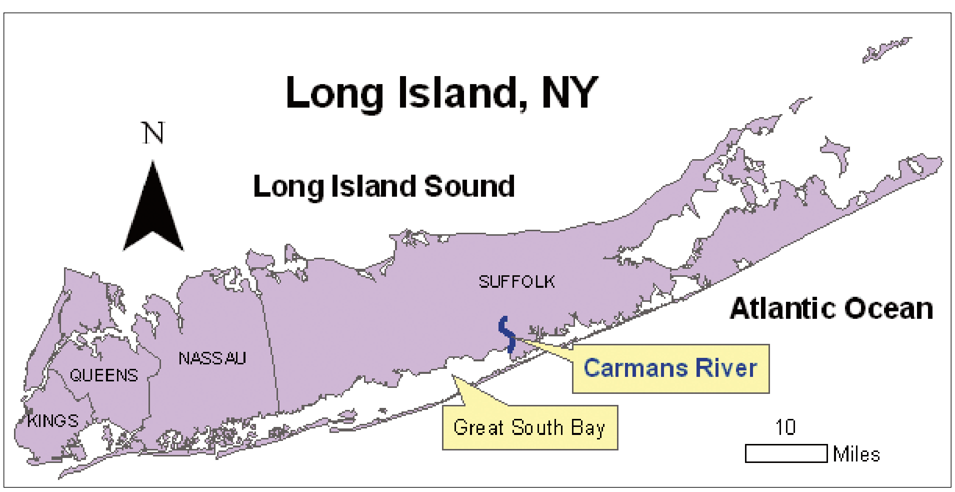
Areas that are undergoing rapid development with its associated rapid changes in land use and land cover, usually suffer increased nonpoint pollution in the downstream watershed's rivers and streams. As the agency coordinating Long Island's South Shore Estuary Reserve, the New York State Department of State's Division of Coastal Resources initiated development of a Spatial Decision Support System (SDSS) to project relative change in water quality due to changes in land use and land cover in river basins draining into the Great South Bay. The Laboratory for Applied GIS at the State University of New York College of Environmental Science and Forestry surveyed these rivers, and recommended the Carmans River as the focus of a pilot dynamic nonpoint model-based SDSS. The desired SDSS would estimate relative change in a river's pollution load due to land-use change and/or when best management practices (BMPs) were implemented to reduce pollution loading. Projected change would be compared to current land-use patterns and river pollution levels on a scale ranging from predevelopment conditions to fully built-out land use.

SDSS had to be easy to use for people not expert in GIS and hydrology. Another desired criterion for SDSS was that it would be a system that could be applied relatively easily to other rivers in the state.

The first phase of the study was to determine which rivers in Suffolk County that drained into Long Island's Great South Bay would be suitable for system development. A river was needed that had a variety of land uses and cover, a significant amount of undeveloped land, a United States Geological Survey (USGS) gauge, historical water quality information, nearby weather stations, and sufficient spatial data (DEMs, satellite landcover data, high-resolution orthophotographs, hydrologic data, etc.) to support model development. After reviewing several rivers in Suffolk County, the Laboratory for Applied GIS selected the 11-mile-long Carmans River. Rejected rivers had inadequate data resources, were fully developed, had many unknown pipes moving storm water around, had major pollutant sources like huge duck dung piles, or were just too small. Carmans River presented suitable resources for model development: a USGS gauge, a nearby weather station (and a NEXRAD radar facility), quite a bit of undeveloped land, and sufficient water quality data.

The next decision to be made was what modeling software to use. We decided to base the model on ESRI's Arc Hydro data model, developed by Dr. David Maidment, mainly because it provided what might be a standard New York State way of managing the river modeling data. The work Maidment and his students produced applying Arc Hydro and ArcGIS modeling to water resources proved invaluable in developing our model. In combination with ArcGIS ModelBuilder, Arc Hydro provides most functions needed to process catchments and feed the pollution loads from defined catchments into a schematic river network via hydrojunctions that are attached to catchment areas. The schematic river could have hydrojunctions at other points as well. For example, they could be located at points where tributaries entered the main stream and at dams, storm water outfalls, and gauges. Catchments could be made for any of these hydrojunctions. The schematic network and its hydrojunctions allowed both runoff and pollutant loads to be added to the main river's schematic network and, if decaying pollutants like fecal coliform were to be modeled, for decay with time and other in-transit pollutant changes.





Thus the decision was made to use the Arc Hydro data model to support SDSS for predicting the Carmans River's nonpoint pollution state. Early on, the decision was made to use land-use and soil-derived curve numbers and pollutant event mean concentrations through raster modeling to generate the pollutant load contributed by catchments in the river basin.

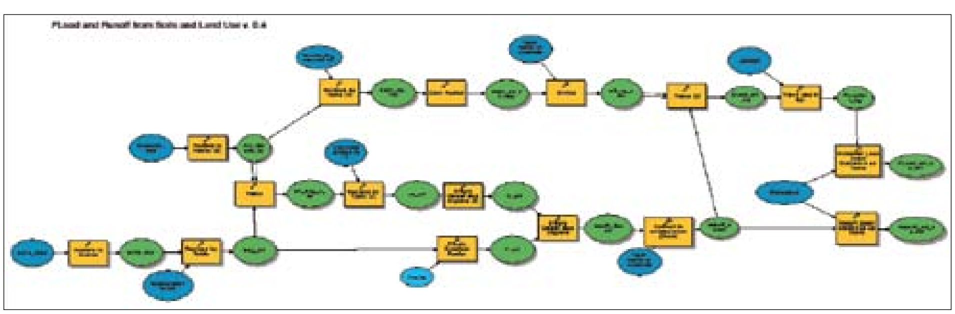
After selecting the river and the modeling software, the data preparation stage started. This was not as easy at it seems, and we quickly determined that there was no way that non-GIS and nonhydrologist people could prepare the data for use of the model on other rivers. The first problem at this stage was that the USGS blue-line hydrologic data did not coincide with the river's location as determined by high-resolution orthophotographs (2-foot resolution, 4-foot accuracy). Thus, the vector river line had to edited. The second problem was to determine the boundary of the drainage basin. With our edited river flow line and a 10-meter USGS digital elevation model (DEM) as our base data, we used the Arc Hydro terrain processing and watershed processing tools to derive a draft watershed boundary. This elevation-derived watershed boundary included a very large area in the center of the island. Though we ground truthed the lower watershed boundary using GPS technology, we weren't comfortable with the upper draft watershed (we called it the blob). Based on inspection of the river, we believe that the headwaters of the river are actually the county library parking lot, which is located very close to the point where the DEM-derived watershed blossoms into the blob!

On Long Island, soils and geology are probably more important than elevation in determining where infiltrated precipitation goes. The river's base flow is determined by the USGS and others to be 97 percent groundwater derived. We now think that it is close to that percentage for precipitation events also. Long Island's sandy soils pass most precipitation quickly from the surface to the water table. A groundwater divide running roughly west to east along the center of the island segregates infiltrated precipitation into north- and south-flowing groundwater. There was no evidence that there was any surface flow from this large area to the river. The groundwater divide's location is uncertain, however, varying from wet years to dry years. As a result, we had to make a guess as to where the watershed's northern extent was located. We decided to include catchments that intersect the groundwater divide as the northern extent of the watershed. (Later, we redelineated the watershed into smaller catchments to better analyze and display changes in impacts along the river.)

Once all the data was prepared, we proceeded to add data to the Arc Hydro data model and process it for modeling. We used ArcGIS ModelBuilder to build a number of submodels to develop and apply curve number-based raster runoff and pollutant load analysis procedures. One ModelBuilder submodel extracts and classifies tax parcels according to Natural Resources Conservation Service (NRCS) curve number groupings based on acreage ranges and land-use categories. Then, because little of the watershed is connected to a constructed drainage network, we derived land-cover percentages extracted from classified QuickBird imagery. Combining these percentages with SSURGO soils data for the watershed, we could then assign appropriate curve numbers.

In keeping with NRCS's curve number approach, we used 24-hour precipitation events, for example, a 100-year storm. By incorporating NRCS's well-known runoff equation in the submodel, we could develop spatially distributed runoff quantity estimates, which could then become an input against pollutant event mean concentration grids to estimate pollutant load.

Connections were made to the schematic river network at hydrojunction points, and the model was run. This was a lot harder than it seems but we had a working model that, in its



final step, treated catchments as the zone input to the Spatial Analyst Zonal Statistics tool to summarize loads contributed to each reach of the river.

The tricky part was creating the portion of the user interface that would symbolize the reaches of the river based on the estimated change in pollution load from current conditions. First, we developed a reference scale. The most pristine pollutant levels were based on pollutant estimates for a completely forested basin generated by a submodel that developed the curve numbers for this predevelopment scenario. Another submodel projected the worst case scenario: a complete build-out of the basin. Current land-use impacts were referenced to this range extending from least impact to most. After running these land-use rasters through the runoff and pollutant load submodel, still another submodel symbolized the impact of proposed land-use change as a percent change from the current state of the river within the range defined by the predevelopment and built-out scenarios. Thus the user's view of the state of the river's reaches was symbolized light blue for the current state (no change), bright red for a large increase in pollutant concentration, and bright green for a large decrease in pollutant concentration.

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Functional Linkage of Water Basins and Streams

ArcGIS Tools for Network-Based Analysis of Freshwater Ecosystems

David M. Theobald and John B. Norman, Natural Resource Ecology

Our goal in developing the Functional Linkage of Water Basins and Streams (FLoWS) tools for ESRI's ArcGIS was to provide a means to analyze river networks that explicitly recognized ecological processes and flows that dominate freshwater ecosystems. We developed these tools as part of a project funded by the U.S. Environmental Protection Agency's STAR program (STARMAP). A key project need was to conduct advanced spatiotemporal analyses of aquatic resources and, in particular, incorporate process-related covariates in statistical models. A common method is to incorporate spatial relationships between sites (or locations of interest) through geostatistical models. Typically, such spatial relationships are measured by straight-line distance (as the crow flies) between points, but increasingly, distance along the hydrological network (as the fish swims) is needed. In this sense, we represent river systems and aquatic landscapes as a network to recognize that physical conditions along a river are often controlled by the network geometry of the river system. "One consequence of this interplay [between pattern and process] is the formation of functional connectivity found in a landscape. The landscape pattern-process linkage produces spatial dependencies in a variety of ecological phenomena, again mediated by organismal traits." (Wiens 2002, 511)

Getting Feet Wet in the Encampment River, Wyoming

The FLoWS v1.0 toolbox consists of five toolsets (see figure 2) written in Python (v2.1) for ArcGIS 9.1. Most tools operate with the basic installation of ArcGIS Desktop, but two tools (Create RCAs and Create Cost RCAs) require the Spatial Analyst extension, and if you are creating a landscape network (which is a personal geodatabase), an ArcInfo license is required.

The preprocessing toolset contains miscellaneous tools that are useful in editing and converting raw datasets into appropriate inputs for other FLoWS tools. Typical data inputs include the United States Geological Survey (USGS) National Elevation Dataset and the National Hydrography Dataset. The selection tools allow interactive queries or selections on landscape networks within an ArcMap document. This allows users to create new selection sets that represent upstream or downstream topological relationships that can be summarized or used in further analyses. The analysis tools allow users to perform graph- or network-based analyses. These routines typically populate a user-defined field for a defined landscape network feature class. The export tools evaluate point-to-point relationships within a landscape network and create a comma-delimited n x n matrix of distance values between pairs of locations.

FLoWS is built around a landscape network that is a type of graph that recognizes spatial context and relationships with additional geographic information and is stored within an ESRI personal geodatabase. (This is similar to ESRI's Geometric Network, but it has a simpler representation and database structure.)

One powerful tool is the Create Cost RCA, which generates a polygon shapefile of Reach Catchment Areas (RCAs) for every unique reach (polyline) within an input hydrologic network. An RCA represents a subcomponent (polygon) of a watershed that drains directly into a given stream segment. This script requires a digital elevation model (DEM) and rasterized hydrologic features (stream reaches and water bodies). The output is a polygon shapefile that represents RCAs that can be linked to input reach features via the unique ID (field) used to generate the reach raster dataset. Rather than employing an approach that uses only flow direction generated from a DEM (e.g., use of WATERSHED/BASIN commands), we have developed an alternative approach that uses cost distance to calculate RCAs with weights developed from topographic information (including topographic wetness index and topographic position index). For example, on an analysis we completed for The Nature Conservancy in the Central Shortgrass Prairie Ecoregion, we found this approach to be much more robust and, in preliminary tests, more accurate than traditional methods.

FLoWS also offers a number of flexible tools to select upstream/downstream features. In addition to upstream, upstream main stem, and downstream selections, we created a Select Downstream Cumulative tool. This tool adds features to the selected set that are downstream from the selected

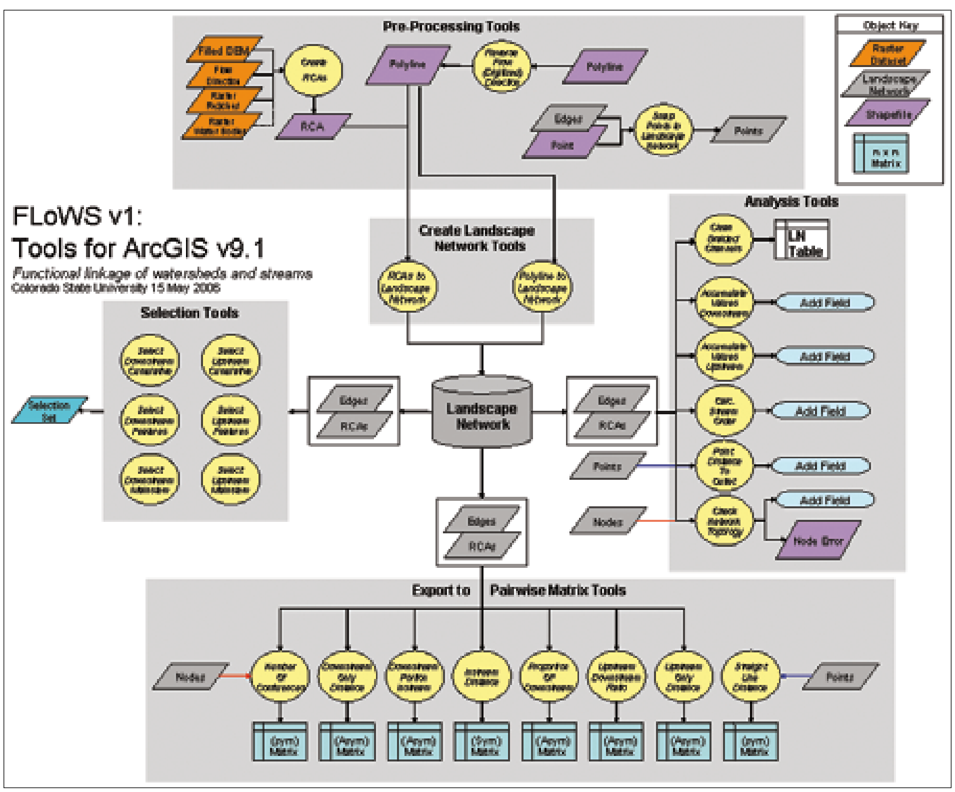


Figure 2

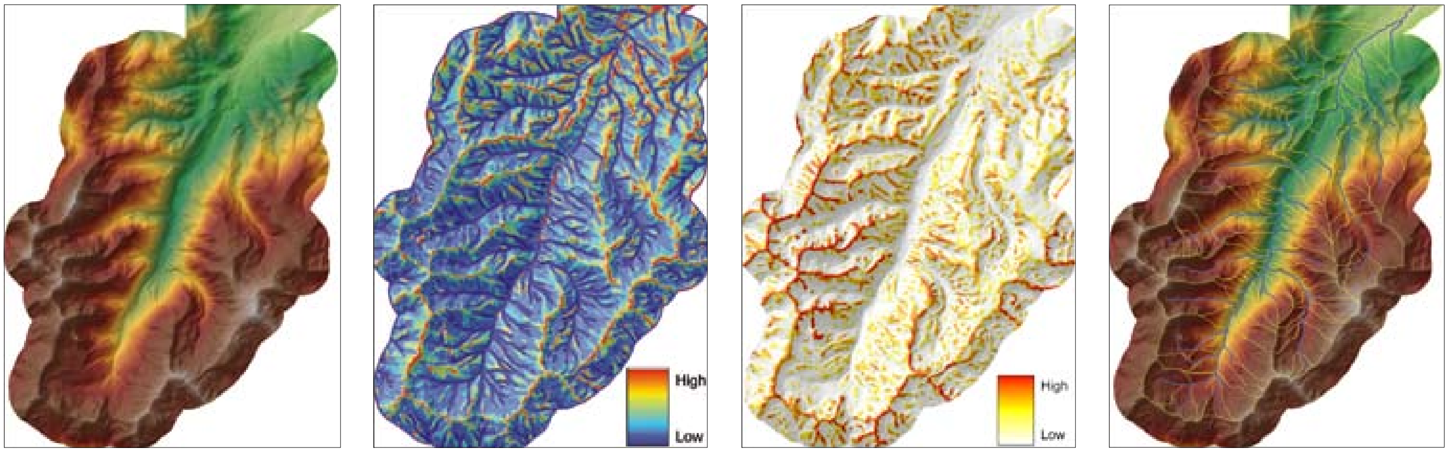


Figure 3

features (as defined in ArcMap). The user needs to define a numeric field and a threshold value such that features will be included in the selection if downstream features have a cumulative value less than or equal to the threshold value.

The analysis tools allow users to perform graph- or network-based analyses. The analysis tools also allow network topology to be checked and to clean braided channels so that other analysis tools are not compounded by braided stream interactions. One main analysis tool is the Accumulate Values Downstream tool, which accumulates values from a user-defined field downstream and populates the values of a new field for each feature with its downstream accumulated value. If an additional weight field is supplied, then accumulated values going into a given edge or RCA will be multiplied by the value of the additional weight field.

The export tools evaluate point-to-point relationships within a landscape network and create a comma-delimited n x n matrix of distance values between pairs of locations. These tools are useful in generating n x n matrices as input to statistical models that incorporate networkwide weight relationships. For example, collaborating with our colleagues at the Alaska Department of Fish and Game and Oregon State University in their work to understand distributions of salmon, we developed a series of tools to create flow matrices that allow powerful geostatistical models to be generated using biologically relevant distances.

For more information about the FLoWS tools, visit www.nrel.colostate.edu/projects/starmap/.

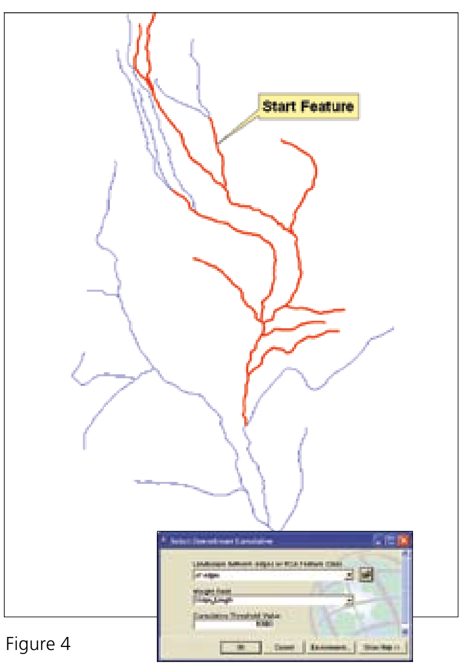
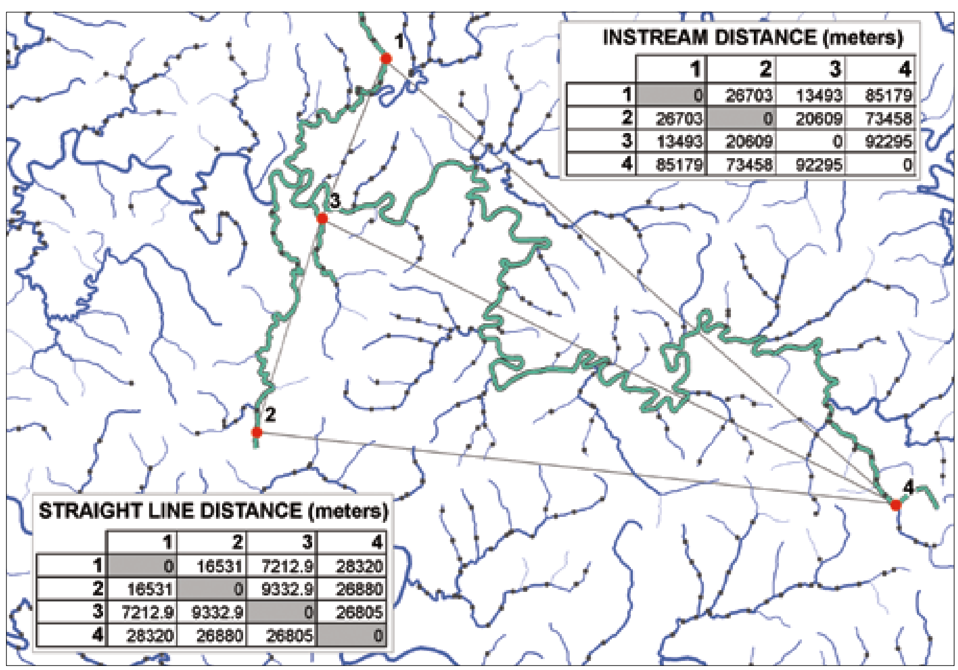


Figure 4

Acknowledgments

The work reported here was developed under the STAR Research Assistance Agreement CR-829095 awarded by the U.S. Environmental Protection Agency (EPA) to Colorado State University. This document has not been formally reviewed by EPA. EPA does not endorse any products mentioned herein.



INSTREAM DISTANCE (meters)

	1	2	3	4
1	0	26703	13493	85179
2	26703	0	20609	73458
3	13493	20609	0	92295
4	85179	73458	92295	0

STRAIGHT LINE DISTANCE (meters)

	1	2	3	4
1	0	16531	7212.9	28320
2	16531	0	9332.9	26880
3	7212.9	9332.9	0	26805
4	28320	26880	26805	0

Figure 5

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Theobald, D. M., J. B. Norman, E. Peterson, and S. Ferraz, May 2006. *Functional Linkage of Watersheds and Streams (FLoWs) User's Manual: Network-Based ArcGIS Tools to Analyze Freshwater Ecosystems.* www.nrel.colostate.edu/projects/starmap

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Developing a Web-Based River Basin Management System in Ireland

sources and GIS technology, decision support for the development of POMs to meet water quality objectives, facilitation of public awareness and consultation, and development of environmental management system (EMS) concepts.

- Implement the river basin management system.
- Prepare a river basin management plan.

Key data management efforts within the context of developing the RBMS are as follows:

- To harmonize and systematize water-related data collection and monitoring among local authorities and national agencies, collaboration with the Local Government Computer Services Board and the Environmental Protection Agency (EPA) will leverage the power of the national environmental data exchange network (EDEN), which will link all local authority data with all other environment-related data gathered in Ireland, as illustrated by figure 3 (section A).

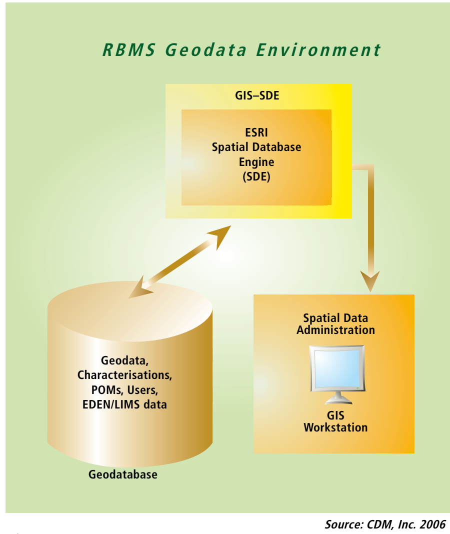

Figure 2

- To provide quality control and assurance of water quality data—which involves sampling, laboratory analysis, validation, import/export, etc.—laboratory information management systems (LIMS) in several labs are being integrated into the RBMS to ensure that only valid data becomes part of (and is used by) the RBMS.
- To conform with EU reporting requirements and provide a flexible system that can be queried by a variety of users for a range of needs and in a real-time manner, a dynamic, Web-based GIS is essential to support development of all required maps, reports, and analyses (including water quality modeling). Figure 3 (section B) illustrates the geodatabase as the core repository of all RBMS spatial and nonspatial data.
- The geodatabase supports user interactions while performing a variety of GIS operations via the Web browser. User action flows from the browser through business objects to the data layer. The graphical user interface (GUI) accepts navigation, selections, and actions that accomplish user tasks, as depicted by the user's dashboard view in figure 1 (on cover). The GUI is composed of a combination of GIS objects rendered using ArcGIS Server 9.2, statistical charts, and tabular information.
- ArcGIS and the ArcSDE technology within ArcGIS Server are used to maintain GIS data through manual and automated data loading and editing sessions, as shown in figure 3 (section B). The overall system conceptual architecture with dataflows is shown in figure 3.

River Basin Management System for ERBD
Systems Architecture–Logical View

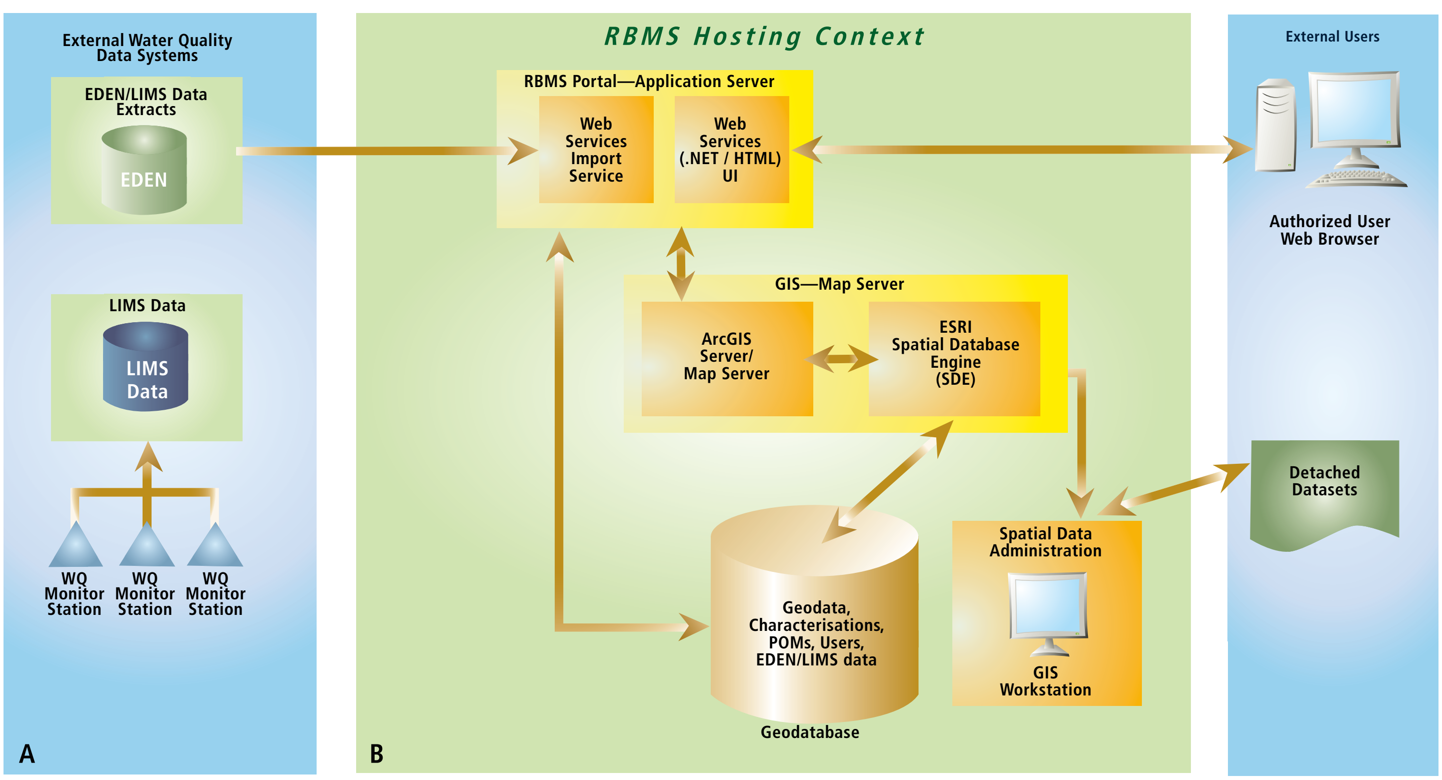

Figure 3

Source: CDM, Inc. 2006

An ISO-consistent EMS—the purpose of which is to integrate organizational processes and technology to prevent pollution and provide for continuous environmental improvement—has been applied to the RBMS design and operation for the ERBD project. As such, it provides a method to plan the program of measures, assign responsibility and schedule for each measure, check results via automatic auditing and reporting, and act on new findings and revise the program in a manner consistent with WFD's six-year planning cycle by providing high-level organizational oversight. Much of the user experience is derived from using mapping interfaces to simplify management of almost 500 water bodies and the resultant several hundred water-body-specific measures that have to be planned, implemented, reviewed, and updated.

WFD requires that river basin management plans be completed by March 2009—plans that meet high standards for public participation and, moreover, are in accord with the principles of cost-effectiveness and "polluter pays." The interplay between how pollution abatement costs are borne by different economic sectors (industries, municipalities, and agriculture) and potential economic and environmental benefits from such cleanup is illustrated conceptually in figure 4.

Because measures will be costly and because different sectors of the economy and society may share in the benefits and costs differently, depending on what measures are selected, a key objective of the RBMS is to foster consensus by providing understandable and useful information in transparent, consistent, and repeatable ways. To do that in the ERBD, the selection methodology for the program of measures has three distinct components: (1) modeling and/or monitoring pollutant loading; (2) selecting POMs, taking account of cost-effectiveness and any social/political constraints; and (3) interacting with decision makers and the public.

Water quality modeling is undertaken at a planning level using the Danish Hydraulic Institute's MIKE BASIN. One of the key benefits of this package is that it operates within an ArcView environment, allowing ready manipulation of the various datasets. For example, pollutant sources and measures can be investigated at a subcatchment scale or at field level, depending on the particular scientific, economic, and political circumstances of the area.

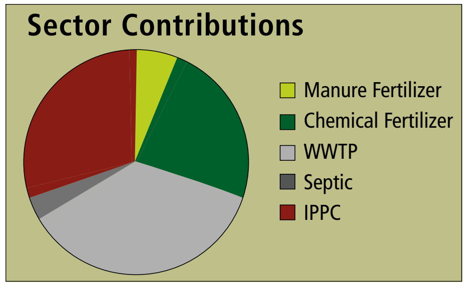

Figure 4

From experience thus far, the conclusions that can be drawn to effectively implement WFD in Europe are that an RBMS must

1. Be accessible to many users and public stakeholders through a system that is Web based, user-friendly, and built on industry-standard platforms that support data-intensive applications.

2. Be designed for expansion and maintenance over time to accommodate changes in EU requirements and new information, as monitoring data becomes available and effects of measures are evaluated.

3. Be defensible by facilitating consensus decisions about POM selection based on information and analyses that are transparent, repeatable, and consistent.

4. Include the ability to simulate water quality results and therefore predict/analyze effects before selecting and implementing (spending for) specific measures.

Overall, the RBMS brings order to a data-intensive effort that is critical to sound decision making in setting programs of measures via a selection process that is fully consistent, reproducible, and transparent in spite of the massive amount of data and information involved.

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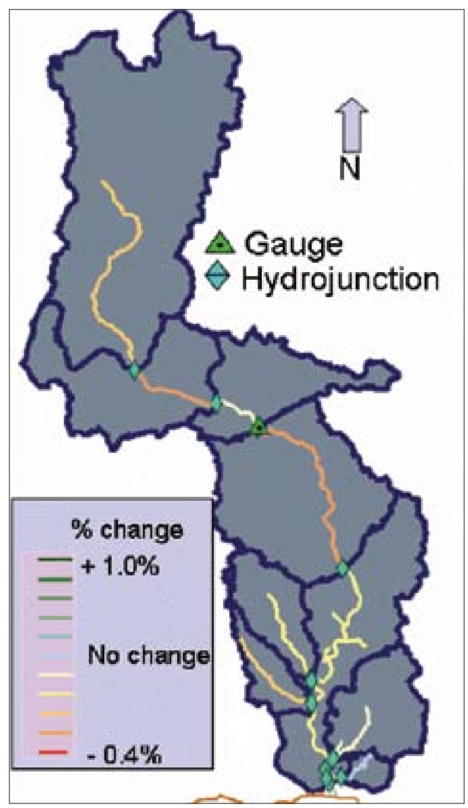
Arc Hydro-Based Spatial Decision Support System for Nonpoint Pollution

Creation of the graphic user interface for the user was the next step. We hired a professional ArcGIS programmer to construct an interface that would allow people to select a tax parcel or group of tax parcels, change their land use, and run the model to see what the change in river water quality would be downstream from the selected parcels. Using ArcGIS Engine Software Developer Kit, the programmer designed a simplified interface that will access the Arc Hydro and raster databases, run the appropriate submodels, and display results graphically to help users understand relative impacts on the river. Best management practices for nonpoint pollution may then be applied to the land-use change to highlight benefits of mitigation strategies. Alternative scenarios may be stored and compared to help in the decision-making process.

At present, we are in the process of integrating the models and the user interface to generate the finished Carmans River Nonpoint Pollution SDSS.



Use of ArcGIS and ModelBuilder to Evaluate Irrigated Acreage and Agricultural Water Use in New Mexico

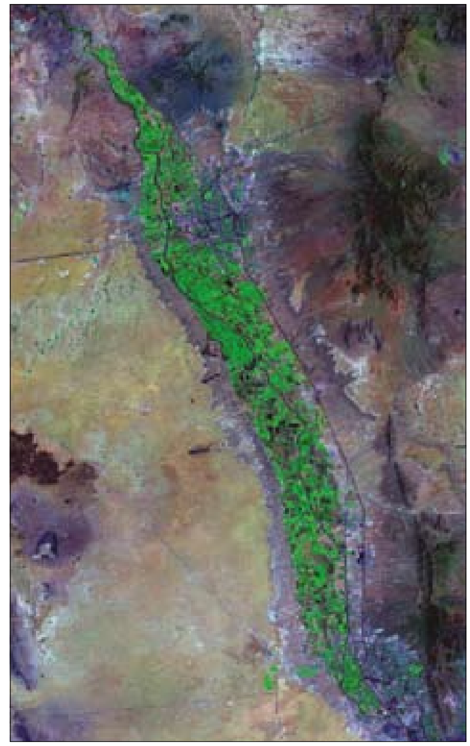
By David L. Jordan, PE
INTERA Incorporated

New Mexico governor Bill Richardson has funded a series of innovative water projects intended to advance solutions to water supply and quality problems throughout New Mexico under his Water Innovation Fund program. INTERA was awarded a grant to apply a remote-sensing-based method to evaluate irrigated acreages and agricultural water use in southern New Mexico. This project meets a specific goal outlined in the New Mexico State Water Plan, which is to apply remote-sensing technology for the purpose of water accounting, management, and conservation. The New Mexico Office of the State Engineer (NMOSE) and the New Mexico Interstate Stream Commission (NMISC) published the Plan on December 23, 2003. One of the implementation strategies is to acquire "the technology and scientific tools necessary for efficient administration and management." Specifically, the plan calls for development of "consistent standardized remote-sensing technologies."

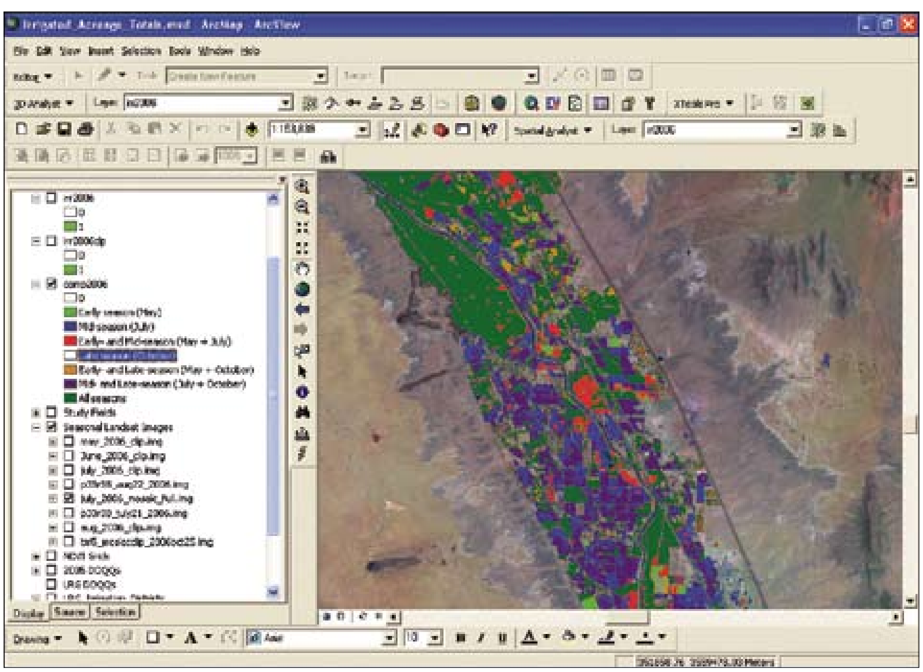
This project involved applying and refining a remote-sensing-based method developed by the NMISC and performing an accuracy assessment of the method using crop data collected in the field during the active growing season, which was compared against remotely-sensed data. In addition, statistical relationships were developed between a remote-sensing-derived vegetation index and more traditional measures of crop growth and consumptive use, namely crop coefficients and crop evapotranspiration (ET).

Motivation

According to the United Nations World Water Development Report, it is estimated that 70 percent of all water used worldwide is for agriculture. In the United States, according to the U.S. Department of Agriculture (USDA), this figure is approximately 80 percent. Thus a key focus area in water resources management is accurate accounting of agricultural water use. Many irrigation districts in the West are large (100,000 acres or more) and present a challenge with respect to water usage accounting. However, readily available satellite imagery such as Landsat, coupled with desktop GIS tools like ArcGIS, provides the water resources manager with powerful tools for water resources management over large irrigation districts. Landsat images can provide broad overview data of an entire irrigation district, while ArcGIS allows analysis and accounting of irrigated acreage and concomitant water usage.



Landsat Image of Irrigated Lands in the Mesilla Valley Portion of EBID in Southern New Mexico



Colors differentiate time periods within which fields were irrigated during the season.

Study Area—The Rio Grande Project

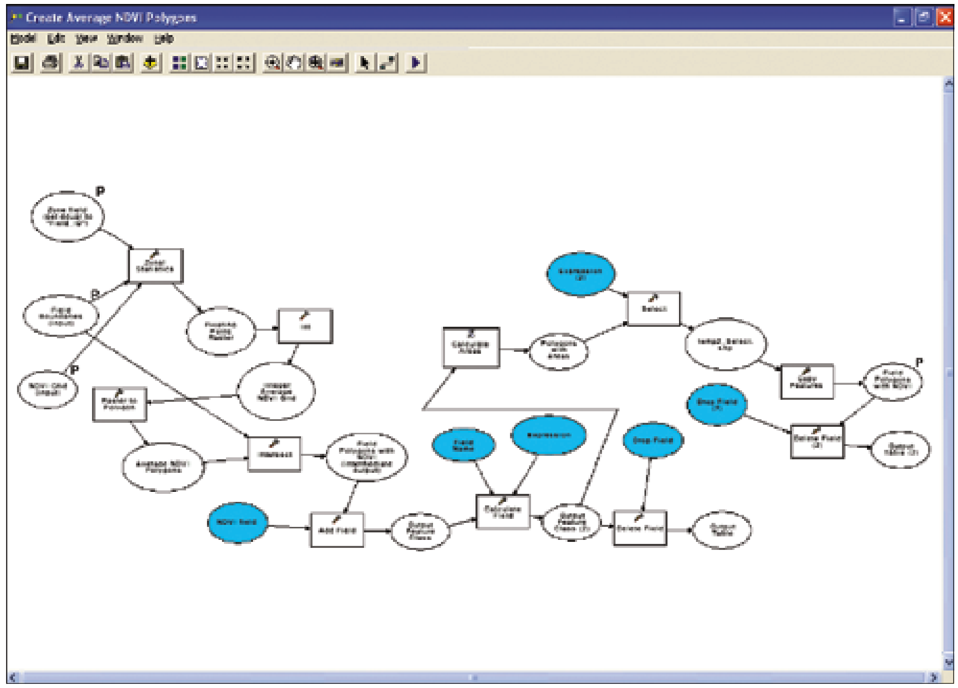
The area of focus for this study was the Elephant Butte Irrigation District (EBID) portion of the Rio Grande Project, which consists of approximately 100,000 acres of irrigated lands in southern New Mexico. The Rio Grande Project supplies irrigation water to a total of about 178,000 acres of land in New Mexico and Texas. Irrigated lands included in the project occupy the river bottom land of the Rio Grande Valley in south central New Mexico and western Texas. About 60 percent of the land receiving water is in New Mexico and 40 percent is in Texas. Water is also sent to Mexico by the International Boundary and Water Commission—United States Section to irrigate approximately 25,000 acres in the

Juarez Valley. Physical features that are part of the project include the Elephant Butte and Caballo dams, 6 diversion dams, 139 miles of canals, 457 miles of laterals, 465 miles of drains, and a hydroelectric power plant.

Analysis of the Data

The remote-sensing-based analysis of irrigated acreages developed by NMISC involves analyzing Landsat images to determine what areas are vegetated. Each image is analyzed using image-processing software to develop a Normalized Difference Vegetation Index (NDVI), which is a measure of the degree of vegetation. The NDVI data is then converted to grid format for analysis within ArcGIS. Since native vegetation is sparse and riparian vegetation can be masked out of the analysis, it can be assumed that the remaining vegetation is irrigated agriculture. In addition, to further refine the analysis, the NDVI data can be clipped to field boundary polygons to ensure that only farmed areas are included in the analysis.

Three Landsat images over the course of the growing season are analyzed: early season, midseason, and late season. Whether or not a grid cell is vegetated (and hence irrigated) is determined by the analyst using a threshold NDVI value. Each grid cell in the early-, mid-, and late-season grids is assigned a unique value to indicate whether it is irrigated or not: 1 for early season, 3 for midseason, and 5 for late season. These three NDVI grids are then combined into a composite grid that indicates, for each grid cell, at what time(s) during the growing season it was irrigated (early season only, early and late seasons, etc.) based on the grid cell value. This is a key attribute of the analysis, since it allows spatial and temporal analyses of irrigation patterns over a large area.

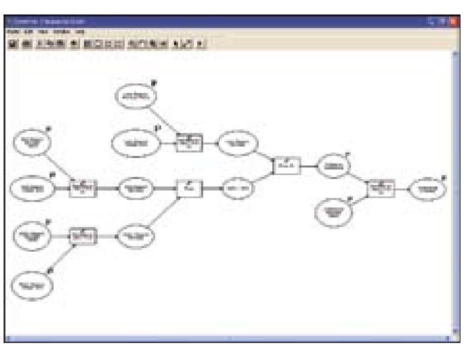


ModelBuilder Code for Development of Summary NDVI Statistics on a Per-Field Basis

The process of threshold application and subsequent combination of three NDVI grids was greatly facilitated using ModelBuilder, which automated the necessary steps used in ArcGIS Spatial Analyst. Prior to automation, the process consisted of a series of sequential analyses that could be very time consuming. After automation, all analysis steps were combined into a single tool, allowing for rapid processing and quick analysis of multiple scenarios.

In addition to combining multiple NDVI grids for analysis, ModelBuilder was used to develop summary statistics on a per-field basis for a series of fields where crop type and growth data had been collected during the growing season. The summary statistics were used to develop a per-field NDVI for each image to correlate with calculated crop coefficients and ET values throughout the season. These correlations were used to develop a regression relationship between remote-sensing-derived NDVI and crop water usage, establishing a method to measure regional agricultural water use from the satellite imagery. In ModelBuilder, the analysis steps to develop the summary NDVI statistics were very time consuming. The automation process has made the analysis much more efficient and cost-effective.

Once a regression relationship between NDVI and crop water usage was developed, maps of crop water usage (ET) could be developed from the NDVI grids. These maps can show the spatial and temporal patterns of water usage over large areas.


ModelBuilder code for the tool to combine three NDVI grids. A user-selected threshold was used to develop a composite grid indicating where and when fields were irrigated.

Conclusion

The methods applied, developed, and refined as part of this study will provide valuable water management tools for New Mexico water managers. Remote-sensing-based analysis of irrigated acreage and crop-consumptive use provides a regional tool with which to evaluate agricultural water use over large areas such as an entire irrigation district. Accurate analysis of agricultural water use can identify areas of surplus irrigation (i.e., areas where irrigation exceeds crop-consumptive use) such that the surplus water can be redirected to areas of deficit irrigation or to other uses. Redirection of surplus irrigation water to areas of deficit irrigation will provide an overall increase in farm yields without using additional water, improving efficiency. Likewise, surplus irrigation water can also be redirected to a water bank (if one exists), then to municipal or other users.

South Boulder Flood Mapping

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South Boulder Creek, in Boulder, Colorado, is currently at the center of a local floodplain controversy. Due diligence research for a major land acquisition in the South Boulder Creek watershed by the University of Colorado identified potential flooding in an area known as the West Valley that was not identified in the regulatory Flood Insurance Rate Map (FIRM). Because the West Valley was not identified as being in the 100-year floodplain, it was developed without flood protection measures. With the discovery of flood-prone areas that were not identified in previous studies, public confidence in the regulatory floodplain was lost.

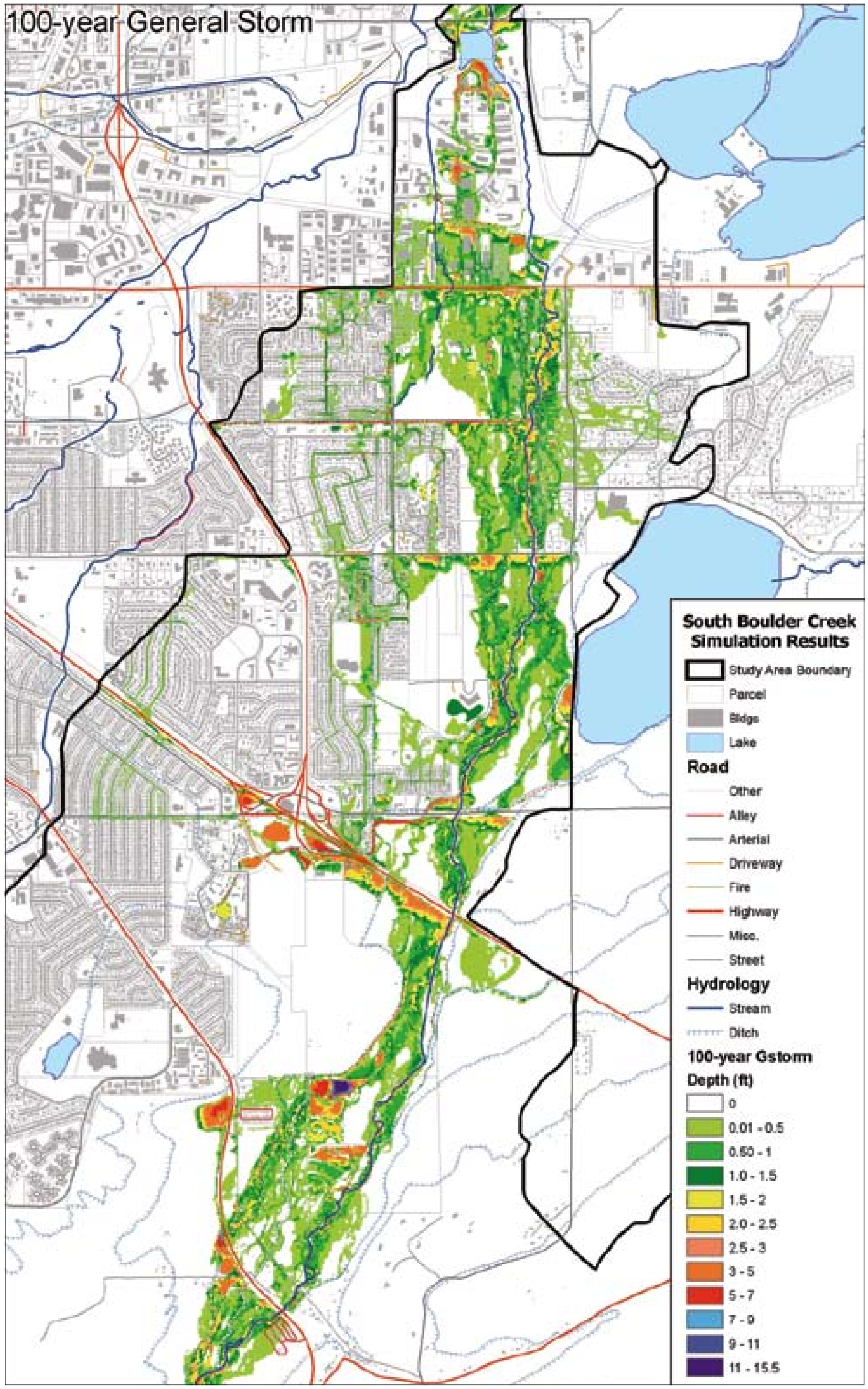
An independent review panel, made up of local flood experts, developed five critical study elements that the study contractor would have to fulfill: an online resource atlas, updated climatology, a multiapproach hydrology, multidimensional floodplain modeling, and a detailed risk assessment.

Background

Potential flooding along South Boulder Creek is a significant concern to the Boulder community. Studies conducted in the last several years have identified the potential for South Boulder Creek to flood an area containing more than 1,000 buildings located west of the creek and north of U.S. 36, in an area known as the West Valley.

The hydrologic study of the South Boulder Creek watershed was approached from three separate perspectives: paleoflood hydrology, statistical flood frequency analyses of the Eldorado Springs gauge to determine discharges for various storm recurrence intervals, and rainfall runoff modeling.

A comprehensive computer model was developed that simulates the rainfall-runoff response of South Boulder Creek, including base flow, interflow, and overland flow contributions, for a wide range of rainfall inputs. These hydrographs will form the basis for subsequent hydraulic evaluations and the identification of risks associated with floods in South Boulder Creek.



Hydraulic Modeling

The hydraulic modeling performed for the South Boulder Creek Flood Mapping Study used the DHI MIKE FLOOD suite of models. MIKE FLOOD is a modeling environment that integrates MIKE 11, a 1D model, and MIKE 21, a 2D model, into a single, dynamically coupled system. Using a coupled 1D and 2D modeling approach enables the best features of each model to be used, while at the same time avoiding many limitations in resolution and accuracy inherent in using either a 1D or 2D model separately.

The 1D model was used to simulate flow in clearly defined hydraulic channels and through hydraulic structures such as culverts, bridges, and weirs, which cannot be easily simulated in a 2D model. Simulating the floodplain with a 1D model has limitations, the largest being that the path of flow has to be predefined. In addition, the simulation of flow is limited to being parallel to the defined channel, and the floodplain geometry is not accurately described. The 2D model overcomes these limitations by being able to simulate undefined flow paths, capturing floodplain storage and providing a more accurate representation of flooding. The 2D model is used to simulate out-of-bank flow occurring on the floodplain.

Photogrammetry was used to produce ASCII files containing the topography data. The data was provided in sc*.pnt and rd*.lin formats, where the .pnt suffix represented the mass points and .lin represented the breaklines. These formats are the ESRI default for importing DTM data. The ASCII data was imported into ArcGIS and used to create a triangulated irregular network (TIN). The TIN data was used to develop the 2D model bathymetry and the cross-sectional geometry for the channels in the 1D model.

For the model bathymetry, MIKE 21 uses a rectilinear grid. To create the rectilinear grid, ArcGIS Desktop was used to interpolate the TIN to a raster, then back to an ASCII grid file that could be imported into the model. After the bathymetry was imported, the 2D model of the floodplain was developed and coupled to the 1D model of South Boulder Creek.

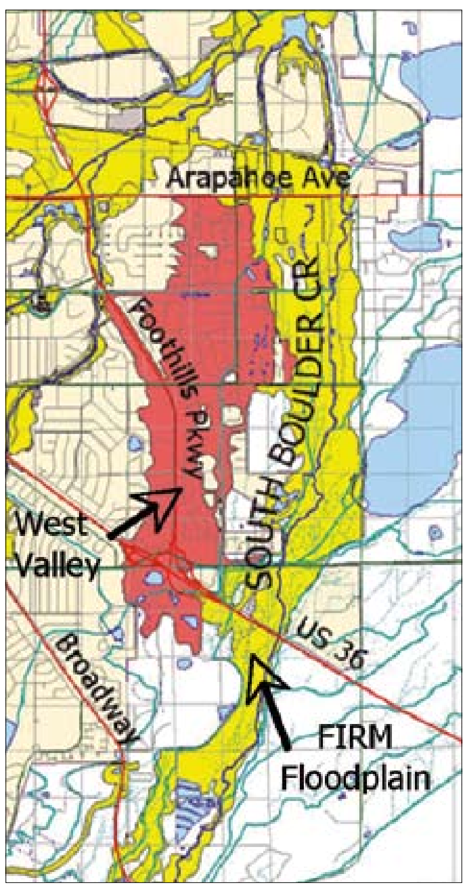
The resultant runoff hydrographs from the hydrologic model were run through the hydraulic model to define the inundated areas. The 1D and 2D results were exported to an ASCII grid format, which could be combined and imported into ArcGIS to map the floodplain.

Risk Assessment

The risk assessment develops an analysis of the watershed hydrology and hydraulic modeling results so that the flood hazard to various areas, properties, infrastructure, and buildings may be evaluated and categorized. Results offer tabulations of damage assessments, identification of greatest risk potential, quantification of high-hazard areas, and itemization of frequent flooding locations.

Risk assessment results may then be applied to floodplain management and mitigation activities deemed most appropriate by the community. This information assists in outlining the best methods and alternatives to reduce flood hazards including mitigation, master planning, regulatory restrictions, flood warning and emergency response, flood proofing, flood insurance, and self-help programs.

The risk assessment developed for the South Boulder Creek Flood Mapping Study involves, among other elements, evaluation of the flood hazard for multiple storm events; assessment of flood risks to determine damages; areas of greatest safety risk; floodplain response and performance to identify the most critical, first impacted, and most frequently impacted areas; and available response times to initial and peak flooding conditions. The use of GIS-based mapping provides an advanced element to better analyze and illustrate the results of the risk assessment.



Integration of ArcGIS with Hydrologic and Hydraulic Study

The use of ArcGIS Desktop was instrumental throughout the project delivery. ArcGIS was used to develop a resource atlas for the project. The resource atlas was a repository for all data collected and produced by this project, including hydrometeorological time series, which was associated with point type feature classes for georeferencing. DEMs and other topographical data were stored as TIN, raster, and polyline features; river cross-sections were stored as polylineZ features; and the flood inundation results were saved as rasters in the resource atlas. In addition to functioning as a data repository, the resource atlas also provided a common data source for data retrieval and presentation by all parties. The project also utilized aspects of ArcIMS to present engineering results to the public over a project Web site.

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