PLANNING CHANGE: CASE STUDIES ILLUSTRATING THE BENEFITS OF GIS AND LAND-USE DATA IN ENVIRONMENTAL PLANNING

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ABSTRACT

A well-established protocol for planning environmentally sustainable development has yet to be agreed upon. Experiences from two highly-studied basins in the United States illustrate some early attempts, their successes, and the obstacles that continue to impede widespread adoption of environmental planning. The first, located in a heavily-populated humid region, has emphasized improvements to water quality and aquatic habitat to sustain the quality of life enjoyed by residents in the face of large projected population growth. Analyses are concentrating on detailed characterization of surface waters, and evaluation of the costs and benefits of various development strategies in terms of their impacts on water quality. The second, located in a semi-arid region, is focused on achieving sustainable yield from finite groundwater resources, and in doing so preserving perennial flow in one of the regions last free-flowing desert rivers. Analyses have concentrated on detailed characterization of the regional groundwater system, and evaluating the costs and benefits of alternative strategies for reducing current water-table declines. In cases, GIS and remotely-sensed land use data is playing, or has played, a central role in facilitating scientific analyses and environmental decision-making.

INTRODUCTION

Remote sensing and geographic information systems (GIS) have become an integral component of assessments and analyses of water resources for environmental planning efforts. They represent the technology through which data is efficiently collected, and the software that facilitates the organization, analysis, and visualization of that data. Further capitalizing on the analytical capabilities of a GIS and the wealth of data it can incorporate, a range of additional specialized tools have been developed to work within GIS software. Among these are hydrologic and landscape models, and associated analytical tools.

Despite much progress in the development of GIS interfaces for spatially-explicit models and analytical tools, much work remains to be done to develop linkages between them to facilitate integrated environmental assessment, forecasting, and decision-making. The U.S. Department of

Agriculture, Agricultural Research Service (USDA-ARS) and U.S. Environmental Protection Agency (USEPA) have started this work by entering into collaborative efforts with regional groups, which are used as demonstration projects. Stakeholder input is used to define project objectives and the research needs and goals are tailored to assist in meeting those objectives. Involvement with these projects affords researchers opportunities to evaluate the tools they develop, and to demonstrate their practical use for environmental assessment and planning.

This paper presents two such case studies where USDA and USEPA researchers participated in collaborative partnerships with organized coalitions seeking to manage development with the goal of minimizing environmental impacts. Both cases are founded on extensive data collection and monitoring efforts, and employ a number of GIS tools to assist local managers and scientists in making decisions. The GIS tools themselves are too numerous to present in detail, so emphasis is placed on their general functions and interaction with each other in support of assessment and planning efforts.

HUMID-REGION CASE STUDY

The greater Charlotte/Gastonia/Rock Hill region (Fig.1) along the North Carolina/South Carolina boarder in the southeastern U.S. encompasses 15 counties with over 75 political jurisdictions and a population of 2.1 million people. Within the region, Councils of Governments from each state cooperate to actively promote regional solutions for regional issues, and have been awarded a grant from the USEPA in support of these efforts. Specifically, their goal is to develop, implement, and expand regional efforts to protect the quality of life in the bi-state metropolitan Charlotte region. The project, called Sustainable Environment for Quality of Life (SEQL), promotes implementation of specific Action Items on Air Quality, Sustainable Growth, and Water Resources, and consideration of environmental impacts in decision-making at local and regional levels. The region plans to demonstrate that planning developed through the SEQL Grant will provide an integrated strategy that other local governments could use to address similar quality of life and environmental issues.

Although a highly desirable area in which to live, the greater Charlotte region faces many challenges, most notably air and water-quality problems associated with suburban sprawl. The rate of population growth in the Charlotte/Gastonia/ Rock Hill metropolitan area is among the highest in the United States [1], and approximately one million new residents are expected in the next 20 years. With this rate of growth it has become imperative to manage development within the region as a whole to minimize conflicts between counties and ensure that the existing regional quality of life as a whole is sustainable.

Coordinating the scientific efforts associated with the assessment and analysis that is necessary to support planning and policy decisions for the SEQL project has proved a significant challenge given the number of administrative agencies involved. Scientific and technical organizations associated with the region's many local governments have done outstanding work in support of local decisions, but have been less successful at coordinating regional-scale analyses. To assist

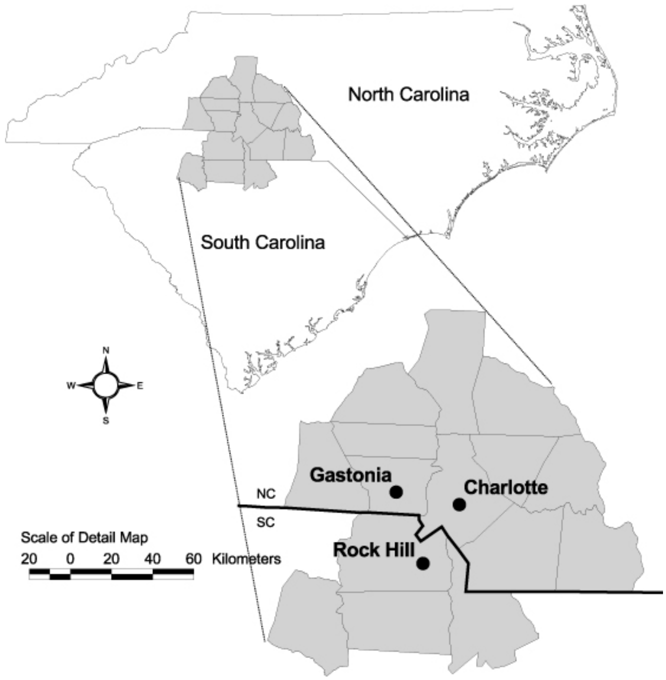

Fig. 1 Location Map Showing the SEQL Project Area, and Detail Map Showing the three Principle Cities. Both maps Show County Borders

with regional-scale analyses, the USEPA Office of Research and Development (ORD) has committed to the development of regional datasets, and the application and evaluation of a number of new models and assessment tools that are designed for use at a regional-scale.

USEPA efforts on behalf of SEQL are being coordinated by the Regional Vulnerability Assessment (ReVA) program, which is an approach to regional-scale, priority-setting assessment [2]. ReVA is designed to identify those ecosystems most vulnerable to being lost or permanently harmed in the next 5-25 years, and to determine which stressors are likely to cause the greatest risk. Operating at the regional scale, the goal of ReVA is not exact predictions, but identification of the undesirable environmental changes expected in the coming years so that they may be avoided.

ReVA's efforts in the SEQL region have begun with the collection, management, and analysis of multiple data sources, both field-based and remotely sensed. Data from all sources are managed using a GIS. A collection of analytical tools and models, also developed for use in a GIS, are employed to evaluate relationships between stressors and observed ecological conditions that can be applied regionally. Existing conditions can be evaluated with confidence using this approach, but predicting future environmental risk is more challenging. To help with this goal the ReVA program has integrated distributed, process-based models, which are most suitable for use in areas where observations are limited, and for predicting responses to future conditions. Three models in particular have been identified as promising means to predict the regional hydrologic impacts associated with future land-use/cover scenarios: the Soil and Water Assessment Tool (SWAT), Hydrologic Simulation Program Fortran (HSPF), and GFLOW 2000.

GIS-Based Process Modeling

SWAT is a hydrologic model developed at the USDA-ARS to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time [3]. A GIS interface for SWAT, the Automated Geospatial Watershed Assessment (AGWA) tool will be used to parameterize SWAT. AGWA is designed to automate parameter estimation to the greatest extent possible from nationally available, standardized spatial data; land use/cover, soil, and precipitation [4]. The ability to simulate and compare the effectiveness of spatially explicit management actions using AGWA-SWAT is of particular importance to the SEQL project, and automated tools that will facilitate the creation and analysis of management scenarios are being developed.

HSPF is a comprehensive package for simulation of watershed hydrology and water quality for both conventional and toxic organic pollutants [5]. A GIS interface developed by the USEPA, the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) will be used to parameterize and run the HSPF model. BASINS is a multi-purpose environmental analysis system that integrates a GIS, national watershed data, and environmental assessment and modeling tools. Application of HSPF for the SEQL project is focused on evaluating land-use management impacts on water-supply reservoirs. It is hoped that threshold levels of urbanization can be defined to ensure that the quality and quantity of the water supply can be sustained.

GFLOW 2000 is a highly efficient stepwise ground-water flow modeling system. GFLOW 2000 uses the analytic element method to model steady-state flow in a single heterogeneous aquifer, and is particularly suitable for modeling regional horizontal flow [6]. A GIS interface for GFLOW coordinates data input and visualization of model output. For the SEQL project GFLOW will be used to investigate wellhead protection delineations under current and future land use, and to evaluate the risk of contamination from existing underground storage tanks. Linkages will be developed between the ground-water and surface-water models to account for changing recharge associated with the development scenarios. In addition, the ground-water model will be used to help calibrate the subsurface flow components of the surface water models to improve estimates of impacts to the base flow of streams under the different development scenarios.

Future Scenarios and Planning

All regional-scale assessment and modeling for the SEQL project is intended to assist the partnership in making decisions about local actions that will improve water quality and aquatic habitat, and minimize environmental impacts of growth. This will be accomplished by evaluating the likely result of various alternative future land-use/cover scenarios and management actions. Remotely-sensed, classified cover maps are a common input to all assessment and modeling tools being applied to the project, and manipulation of these maps is the most convenient means of representing possible development scenarios. A set of future scenarios was agreed upon by the SEQL partnership, and they are being translated into regional land-use/cover maps for the year 2025.

Ecological analyses will be reevaluated using the future scenarios, and can draw on the output from process-based hydrologic models in the absence of observational data. Despite being just a snapshot of potential future conditions, assessments and model simulations based on these scenarios can be directly compared with those based on the existing conditions to evaluate the relative merits and faults of each scenario at a regional scale. Results may be further used iteratively to refine the spatial extent and type of mitigative management, or the spatial pattern of land use in future scenarios until a suitable scenario is defined. It is anticipated that these analyses will assist the SEQL partnership with the development of multi-jurisdictional land-use regulations that can be used to improve the sustainability of future development.

SEMI-ARID REGION CASE STUDY

Approximately 114,000 people live and work in seven incorporated towns and several unincorporated communities in the two countries within the Upper San Pedro Basin (USPB). The basin is located in the semi-arid borderland of southeastern Arizona and northeastern Sonora (Figure 2). It possesses variety of characteristics that make it an exceptional outdoor laboratory to address a number of challenges in the physical, ecological, social and policy sciences. The area represents a transition between the Sonoran and Chihuahuan deserts with significant topographic and vegetation variation, and has a highly variable climate. It is an international basin with significantly different cross-border legal and land-use practices. The USPB supports the second highest known number of mammal species in the world. In addition, the riparian corridor provides habitat for more than 400 bird species. The USPB is judged by numerous organizations as a globally important ecosystem [7]. In 1988, the US Congress established the San Pedro Riparian National Conservation Area (SPRNCA), the first of its kind, to protect riparian resources along 60 km of river north of the US-Mexico border.

Principal economic drivers in the valley include the US Army Fort Huachuca, the largest employer in S. Arizona (nearly $1 billion economic impact, [8]) and the copper mines near Cananea in Sonora, Mexico, which produce 2-3% of the world’s copper [9]. Water for these entities and the riparian system are derived from the regional groundwater aquifer. Great concern exists regarding the long-term viability of the San Pedro riparian system and ranching in the face of continued population growth. The threat of excessive groundwater pumping to this riparian system prompted the first application of international environmental law within the U.S. via the North American Free Trade Agreement [9].

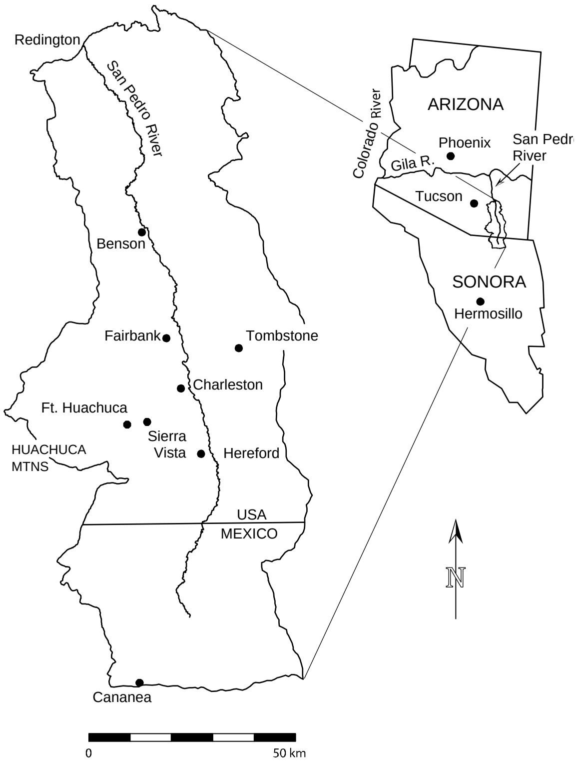

Fig. 2 The Upper San Pedro Basin

In 1998 the Upper San Pedro Partnership was formed to facilitate and implement sound water-management and conservation strategies in the Sierra Vista subwatershed in the Upper San Pedro River Basin in the US (http://www.usppartnership.com). This consortium of 21 federal, state, and local agencies, nongovernmental organizations, and a private water company are working to ensure sufficient water for current and future basin residents and the SPRNCA. GIS and remotely sensed land-cover data, and models that utilize this data, have played an important role in communicating scientific and scenario analysis to the resource managers and elected decision-makers of the USPP.

Significant efforts were undertaken by the USEPA, USDA-ARS, and US-Army to compile, collect, document, and distribute a wide array of GIS, remotely sensed data and several landscape analysis tools. The result was the San Pedro River Geo-Data Browser and Assessment Tools, which is available on a CD-ROM or via the Internet (http://www.epa.gov/nerlesd1/land-sci/san_pedro/). This spatial data set and the tools included with it have proven invaluable to numerous investigators, decision-makers, and the members of the public.

GIS-Based Process Modeling and Future Scenarios

Rapid change in basin wide land cover was clearly illustrated to the public and local planners with a multi-decadal analysis of remotely-derived land cover spanning a 25 year period [10]. During the period from 1973 to 1986 mesquite woodlands increased by over 400% and a comparable increase in urbanized area occurred between 1973 and 1997. The hydrologic impacts of this change were demonstrated and visualized using AGWA [11]. Not surprisingly, substantial increases in relative runoff yield were observed in urbanizing portions of the basin. This brought to light a novel water-recharge strategy, which urban planners are attempting to exploit. In humid regions, increases in impervious area due to development, typically reduces recharge potential. In arid and semi-arid regions with large potential evapotranspiration to rainfall ratios, recharge from upland and hillslope areas is rare. In these regions, the majority of recharge occurs when flow is concentrated in ephemeral stream channels or depressions [12]. Planners and decision-makers of the USPP are thus attempting to enhance recharge by directing increased runoff from urbanized areas into ephemeral channels and detention structures that are well connected to the regional aquifer.

This strategy was further investigated using AGWA for a watershed bisecting the city of Sierra Vista. High-resolution soils, DEM, and land cover GIS data were employed for pre-development and post-development conditions and it was found that the potential exists for increased recharge from urbanization. The spatial location of runoff generation and where it might best be directed for recharge is thus critical information for decision-makers in deploying flood control and drainage structures. This analysis can be extended into possible future scenarios of basin growth and development. Initial assessments of future landscape change scenarios have been conducted [13, 14]. The first assessment concentrated on groundwater, riparian, and viewshed impacts on the San Pedro while the second concentrated on the impacts of future alternatives to surface waters and sediment. Both of these studies demonstrate the power of combining spatial data and distributed process models for planning and natural resource management. With alternative futures that are derived in consultation with basin residents, the use of GIS-based landscape scenarios allows decision makers and resource managers to assess the relative merits of alternative options enabling more informed choices.

CONCLUSIONS

Despite having distinct objectives dictated by their disparate geographic settings, these examples have much in common. Both cases have, and are making extensive use of hydrologic models, and both have employed ecological models to relate changes in hydrology to impacts on ecological systems. To accomplish this, both groups have, and are still making extensive use of GIS as a means to relate human impacts, hydrologic response, and ecological impacts in space. Data requirements are substantial in both cases; remotely-sensed data provide invaluable input to the models, but instrumented monitoring continues to be essential. Spatial databases have been, and continue to be critical for to assembling model inputs and organizing model output to facilitate its use in other analyses, and to communicate results. Finally, the creation of land-use scenarios with spatially distributed projected growth has been central to both studies as a means of comparing and contrasting a range of alternative futures in terms of their environmental impacts. Collectively, these examples illustrate the need for further integration of environmental models, the organization of observed and modeled environmental information, and the successful application of integrated modeling to multidisciplinary management problems. Geographic information systems are central to this endeavor, and will continue to play an invaluable role in planning for sustainable development.

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REFERENCES

1. U.S. Census Bureau, Metropolitan Area Population Estimates for July 1, 1999 and Population Change for April 1, 1990 to July 1, 1999, URL: http://www.census.gov/popest/archives/1990s/MA-99-01.txt, 2000.
2. Smith, E.R., An Overview of EPA's Regional Vulnerability Assessment (ReVA) Program, Environ. Monitoring and Assessment, 64, 9-15, 2000.
3. Srinivasan, R.S., Arnold, J.G., and Jones, C.A., Hydrologic Modeling of the United States with the Soil and Water Assessment Tool, Water Resources Development, 14 (3), 315-325, 1998.
4. Miller, S.N., et al., GIS-based Hydrologic Modeling: The Automated Geospatial Watershed Assessment Tool**,** Proceedings of the Second Federal Interagency Hydrologic Modeling Conference, August 2002.
5. Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C., Hydrological Simulation Program--Fortran, User's Manual for Version 11, U.S. EPA report EPA/600/R-97/080, 1997.
6. Haitjema, H.M., Analytic Element Modeling of Groundwater Flow. Academic Press, Inc., San Diego, 1995.

7. World Rivers Review, Biodiversity, North America. World Rivers Review, News Briefs, Volume 12, Number 1, February 1997. International Rivers Network. http://www.irn.org/pubs/wrr/9701/briefs.html, 1997.
8. Hess, B., BRAC Decision Pleases Locals, Sierra Vista Herald, Oct. 13, 2004.
9. Commission for Environmental Cooperation (CEC), Ribbon of Life: An Agenda for Preserving Transboundary Migratory Bird Habitat on the Upper San Pedro River. Montreal: Comm. for Environmental Cooperation, 1999.
10. Kepner, W.G., Watts, C.J., Edmonds, C.M., Maingi, J.K., Marsh, S.E.and Luna G., A Landscape Approach for Detecting and Evaluating Change in a Semi-arid Environment. J. Envir. Monitoring and Assessment, 64, 179-195, 2000.
11. Hernandez, M., Miller, S.N., Goodrich, D.C., Goff, B.F., Kepner, W.G., Edmonds, C.M., and Jones, K.G., Modeling Runoff Response to Land Cover and Rainfall Spatial Variability in Semi-arid Watersheds. Journal of Environmental Monitoring and Assessment, 64, 285-298, 2000.
12. Goodrich, D.C., Williams, D.G., Unkrich, C.L., Hogan, J.F., Scott, R.L., Hultine, K.R., Pool, D., Coes, A.L., and Miller, S., Comparison of Methods to Estimate Ephemeral Channel Recharge, Walnut Gulch, San Pedro River Basin, Arizona. In: Groundwater Recharge in a Desert Environment: The Southwestern United States, Water and Science Application 9. Pub. by American Geophysical Union, 77-99, 2004.
13. Steinitz, C., Arias, H., Bassett, S., Flaxman, M., Goode, T., Maddock, T. III, Mouat, D., Peiser, R., and Shearer, A., 2003. Alternative Futures For Changing Landscapes. The Upper San Pedro River Basin in Arizona and Sonora, Island Press, Washington, D.C., USA, 2003.
14. Kepner, W.G., Semmens, D.J., Bassett, S.D., Mouat, D.A., and Goodrich, D.C., Scenario Analysis for the San Pedro River, Analyzing Hydrological Consequences of a Future Environment. J. Envir. Monitoring and Assessment, 94, 115-127, 2004.