From research to management: a suite of GIS-based watershed modeling, assessment and planning tools

D.J. Semmens[a], **W.G. Kepner**[a], **D.C. Goodrich**[b], **D.P. Guertin**[c], **M. Hernandez**[b], and **S.N Miller**[d]

[a] *U.S. EPA, Office of Research and Development, Las Vegas, NV; semmens.darius@epa.gov*
[b] *USDA-ARS Southwest Watershed Research Center, Tucson, AZ*
[c] *University of Arizona, School of Natural Resources, Tucson, AZ*
[d] *University of Wyoming, Department of Renewable Resources, Laramie, WY*

Abstract: The Automated Geospatial Watershed Assessment (AGWA) tool is a GIS-based hydrologic modeling tool developed jointly by the U.S. EPA Office of Research and Development, USDA Agricultural Research Service, and University of Arizona. It was initially designed as a research tool for assessing the hydrologic impacts associated with landscape change at multiple scales, a context in which process-based models are a necessity. As potential management applications of the tool became more readily apparent and partners with specific management objectives were identified, AGWA was transformed into a highly versatile tool for environmental management and planning. A thoughtful software design facilitates linkages between different model and data types, thus promoting collaborative, interdisciplinary development. Both the development of AGWA and the tool itself are illustrative of the process of combining basic research with stakeholder-driven model and software development to build an integrated suite of management and planning tools.

1. INTRODUCTION

The AGWA tool provides the functionality to conduct all phases of a watershed assessment for two widely used watershed hydrologic models: the Soil Water Assessment Tool (SWAT; Arnold *et al.*, 1994); and a customized version of the Kinematic Runoff and Erosion model (KINEROS2; Smith *et al.*, 1995). SWAT is a continuous simulation model for use in large (river-basin scale) watersheds. KINEROS2 is an event-driven model designed for watersheds characterized by predominantly overland flow. The AGWA tool combines these models in an intuitive interface for performing multi-scale change assessment, scenario development, and results visualization. Data requirements include elevation, land cover/use, soils, precipitation, and weather data, all of which are available at no cost via the Internet. Model input parameters are derived directly from these data using optimized look-up tables that are provided with the tool.

Research that ultimately led to the development of AGWA was initiated in 1997 through an interagency agreement between the U.S. EPA Office of Research and Development (ORD) and the USDA Agricultural Research Service (ARS). The primary goal of this project was to develop methods and provide operational hydrologic modeling tools for determining the vulnerability of arid and semi-arid landscapes to natural and human induced changes in landscape pattern across multiple scale domains [Goodrich et al., 2000].

The AGWA tool was first publicly released in 2002 as an extension for ArcView versions 3.X [Miller et al., 2002]. As a result of extensive collaboration with other agencies and groups a number of improvements and new capabilities have been added since the initial release. AGWA Version 1.4 was incorporated into the EPA's Better Assessment Science Integration Point and Nonpoint Sources (BASINS; Lahlou et al., 1998) Version 3.1 in 2004. A final release of AGWA for ArcView, Version 1.5, is scheduled for April 2006

[Goodrich et al., 2006]. At present, there are more than 1200 registered users of AGWA, not including those who obtained it as a component of BASINS 3.1.

Miller et al. [2004] pioneered the first Internet-based version of AGWA. The strength of this application, its accessibility to anyone with an Internet connection, led to further investment in an improved design. Efforts to develop an extensible, Internet version of AGWA (i.e., DotAGWA) were coupled with the migration of AGWA from ArcView 3.X to the ArcGIS 9.X platform. A detailed design plan was developed to minimize redundancy in the programming for AGWA and DotAGWA by creating a suite of independent modules encapsulating their shared GIS functionality such that it could be called from either application [Cate et al., 2005]. Beta versions of DotAGWA and AGWA 2.0 (for ArcGIS) will be released by the end of 2006. Additional information and free software downloads can be found on parallel EPA and ARS web sites: www.epa.gov/nerlesd1/land-sci/agwa/ and www.tucson.ars.ag.gov/agwa/.

2. RESEARCH FRAMEWORK

2.1 Interdisciplinary Collaboration

The original research framework within which our development took place ultimately proved to be a major asset. It was quickly realized by the interagency research group that a great deal of potential remained to be exploited within the new GIS-based modeling environment. Particular attention was focused on the development of improved model parameterization methodologies, incorporating new data sources, and exploiting additional and new model functionality to improve performance. The existence of a set of core functionality facilitated such improvements and additions, and provided the basis for numerous Masters and Doctoral research projects.

The interdisciplinary nature of watershed hydrologic modeling also helped gain momentum for our application. In addition to providing a useful tool for characterizing watershed hydrology in interdisciplinary research, AGWA relies on information and techniques derived from a variety of disciplines to parameterize its component models. This interdependence led to a number of collaborative research projects exploring applications in real-time flood forecasting, soil science, post-fire assessment, ecohydrology, range management, geomorphology, and other areas.

The ability to connect with a variety of groups and disciplines thus provided fertile ground for research, as well as funding for further development.

2.2 Product Integration

The USDA-ARS has produced an extensive collection of environmental models throughout its history. Often, however, these models were written as stand-alone executable programs with onerous input requirements and limited analytical functionality. In addition, a large number of temporary, student employees produced valuable, but short-lived products that were often lost to research units after graduation. It was later recognized that if research and development were carried out within a unified modeling framework it could act as a library of 'legacy' modules that would be easier to maintain and apply. Such a framework would also promote collaborative research, integrated assessments, and facilitate stakeholder interaction and technical information transfer.

The initial AGWA design for ArcView 3.X was not intended to serve as a unified modeling framework, and suffered a number of limitations that made model integration difficult. The need to migrate AGWA to the updated ArcGIS 9.X platform and develop an Internet-based version was seen as an opportunity to completely redesign the interface and develop an extensible platform for research applications. The design plan for AGWA 2.0 and DotAGWA was thus developed with the specific objective of facilitating the incorporation of additional models and modeling tools [Cate et al., 2005].

2.3 GIS

The spatial component of distributed watershed modeling and assessment mandated the need to develop a GIS-based interface for model parameterization and results visualization. The benefits of utilizing GIS to support water resources and watershed modeling have been recognized for some time [e.g. Maidment and Djokic, 2000]. The utility of GIS, however, also includes the potential it offers to establish linkages between different types of environmental models. Inputs and outputs for virtually all environmental models are spatially dependent, and can be related to each other in terms of place and time. The human context of these inputs and outputs is also most easily analyzed, interpreted and understood in terms of

physical location. A GIS-based modeling framework can thus serve both as a means of integrating a variety of environmental models, and a vehicle for communicating results.

The ability to incorporate new sources of remotely sensed information is another key advantage of a GIS-based modeling framework. Hydrologic models are inherently data limited, and generally constructed for optimal performance according to data availability [Schultz and Engman, 2000]. Advances in remote sensing technology and the availability of remotely sensed information are thus the primary drivers of hydrologic modeling research.

3. MANAGEMENT NEEDS

Resource management is the primary objective of government sponsored environmental research and development. To secure funding for software development it is necessary to address specific management needs. Adaptable applications that can be utilized to address and integrate a range of needs are therefore more likely to be funded. The development of customized tools and functionality to address specific needs further strengthens the tool, its user base, and its prospects for continued development. As with any business enterprise, however, projects and partners must be carefully selected to ensure continued relevance.

The approach taken with AGWA has been to establish collaborative partnerships with a variety of governmental agencies and non-governmental organizations. Partnerships were sought to capitalize on the existing strengths of AGWA, while at the same time addressing specific management needs that would improve the overall utility of the tool. Selected examples of such partnerships are presented in Table 1.

Through working directly with resource managers we have gained insight into specific design needs, which are often very different from those of users in the research community. Whereas research users require maximum flexibility to manipulate and calibrate model inputs, managers need user-friendly interfaces, and automated functionality designed to optimize model performance with a minimum of user interaction. This is not to say that users in the management community are less sophisticated than research users, but rather that their training is less likely to have been focused in a particular discipline and that many times they have restricted time requirements for decision analysis. For modeling software to have a

significant environmental outcome it is imperative that these users are accommodated.

In a more general sense, managers need to be able to connect and relate model results to a wide variety of tasks. To address specific objectives it is further necessary to accommodate a range of spatial and temporal scales. Customization of modeling software is often necessary to address particular needs, but careful software design can minimize the effort involved. Modular designs can allow for spatial and/or temporal integration of new information by a variety of models, operating at a range of scales, from a single source. The more models that can access a module, the more powerful it will be.

Table 1. Example partnerships and associated applications/development for AGWA.

Partner	Application(s)
National Weather Service	- Incorporation of radar rainfall data - Real-time flash flood prediction
U.S. Army	- Road removal and rehabilitation - Incorporation of remotely sensed soil-moisture data
U.S. Forest Service	- Post-fire assessment and rehabilitation planning
U.S. EPA Regional & Program Offices	- Environmental review of transportation projects - Alternative future scenario assessment - Riparian characterization and monitoring - Regulatory oversight - BMP placement
State of Arizona	- Training for municipal officials - TMDL assessment and planning
Upper San Pedro Partnership	- Cost-benefit analysis for in-channel recharge of urban runoff

4. DESIGN IMPLICATIONS

Despite the different needs of expert and non-expert users, accommodating them in a software application can work to the benefit of both groups. Automated functionality that lets the software provide data-based estimates of model inputs is tremendously valuable to users who may not be intimately familiar with them. It is also a useful time saver for expert users. The combination of task automation and advanced tools thus represents

a win-win situation for users, and has been a common approach of the software industry.

A potential tradeoff of attempting to accommodate a diverse user audience and their wide range of needs is that a more generic/flexible design can increase the cost of applying the tool in a management setting. This has not been our experience with AGWA because the addition of functionality and tools to accommodate new users and uses has not required the alteration of existing procedures. The core set of functionality needed to model a watershed has been maintained in its original five-step, ordered design: (1) Location identification and watershed delineation; (2) watershed subdivision; (3) land-cover and soils parameterization; (4) preparation of parameter and rainfall input files; and (5) model execution, and visualization and comparison of results. New functionality and tools have provided users with more options within this five-step process, but have not required generalization that would increase the cost of applying the tool.

4.1 Expert Users

Expert users expect a modeling interface to permit manipulation of model parameters, independently and/or as a whole, and implementation of all model features. They further demand tools that assist with the model calibration process, development of alternative scenarios, analysis of results, and integration with other tools/models for decision support. Collectively, these needs align closely with those of research users, and require attention to detail and provision for the maximum amount of flexibility to interact with other applications.

Tools supporting the analysis of model results are another important need of expert users. The design of AGWA includes tools permitting the visualization of distributed outputs, the ability to toggle through output maps for time-specific information, graphing and exporting model outputs, and the calculation and visualization of differences between simulations.

While it has been our experience that expert users are less likely to read and follow directions, they are also more likely to contact developers with questions and problems. Detailed documentation explaining methodologies and assumptions is thus a key need for advanced users, and can minimize the need to address inquiries individually. Listservers or forums can also be a useful means of enabling users to learn from each other once a

critical mass of users is established; the BASINSinfo listserver is a good example (www.epa.gov/waterscience/basins/listserv.htm).

4.2 Non-expert Users

Removing obstacles to the adoption and practical use of AGWA have been the primary objectives of our efforts to facilitate non-expert use. These efforts have focused on two primary themes: design accommodations designed to make the software more easily learned and used, and research and documentation to clearly define how the software can be safely used by non-experts to assist with environmental decision making.

The use of AGWA or any other desktop GIS-based modeling software requires that new users overcome the hurdle of obtaining and using geospatial data in a GIS. When combined with having to use the GIS software itself, the prospect of trying out a new model can be intimidating. For this reason, we have provided potential AGWA users with a wide variety of features that assist novice users without compromising its utility for advanced users. To assist those new to GIS we provide easily followed training/example exercises, including one that walks users through each step in the process of obtaining and using geospatial data in a watershed assessment, and another that provides every detail needed to set up and use AGWA on a personal computer. Detailed user documentation is also available, and describes each task and process in detail.

Developing an Internet-based version of AGWA is another strategy designed to maximize potential users. Serving AGWA via the Internet will ultimately remove the need for users to obtain and prepare geospatial data, and the requirement that they purchase and use GIS software. Although DotAGWA has not yet been implemented nationally, it holds great promise for regional applications requiring the interaction of diverse partnerships working towards a common goal, such as an environmental assessment, from a variety of different scientific, legal, economic and political viewpoints.

Another approach to alleviating the burden of obtaining and preparing input data is to develop a single, Internet-based source and allow modeling tools to access it directly. This approach is presently under development by a workgroup of the Interagency Steering Committee on Multimedia Environmental Models (iscmem.org).

We hope to be able to adopt this resource for use by AGWA in the near future.

The AGWA interface itself is also organized and structured to intuitively lead users through the primary tasks. Menu items are kept to a minimum by grouping tasks into five basic steps, and presented in the order they must be called so that users proceed from top to bottom. Within each step, users are routed automatically through a series of windows in which they are given the option to adjust default values. Wherever possible, default values are derived intelligently from available data, and lists are ordered to reflect the most likely or suitable first choice. This strategy is not novel, but rather designed to work like other software that would seem familiar to first-time users.

It can be argued that non-expert users should not be encouraged to use uncalibrated models to support environmental decisions. Not all groups, however, can afford the luxury of an expert consultant, and not all decisions warrant the expense. For these users it is necessary to establish up front the range of model uncertainty, and define what uses are appropriate. Semmens et al. [2006] have initiated this effort for AGWA by examining the uncertainty associated with forecasting future conditions as part of planning efforts.

4.3 Communication

Marketing our research is not something that is intuitive to most scientists. However, if potential users and collaborators are unaware of a tool, then it will most likely languish in isolation. Scientific publications are an obvious first step and ideal reference, but only a small fraction of potential users will find suitable management tools through a literature search. It is necessary to establish a wide variety of means for potential users to find and use a tool. Examples that have been successful for AGWA include:
- Web sites
- Fact sheets
- Press releases
- Training workshops
- Conference presentations
- Submitting web links and information to agencies and groups who summarize available tools

Two-way communication is also important in software design. In addition to initiating potential users, training workshops offer an ideal means of learning from them as they interact with an application. For AGWA, users have been surveyed following each training workshop to gather suggestions about how the tool could be improved to meet their needs.

A significant concern of environmental model users is whether regulators will accept results derived from a particular model. It thus behooves model developers to communicate with regulatory and other public agencies to establish or demonstrate the validity of modeling software. In cases where model applications are for resource management instead of environmental regulation, it is still important to communicate with governing bodies to establish the merit of an application, and to explore potential integration with existing tools.

5. DISCUSSION

The success of AGWA as an application for management and planning is owed largely to the collective contributions from individual partners with specific management goals. Investments from partners have come in the form of funding for continued research and development, direction to meet specific objectives and needs, and training employees to effectively implement and use the tool. Cumulatively, they have resulted in the development and integration of numerous additional tools and data sources supporting a range of objectives. Successful applications have included managing urban growth and associated water resources impacts, watershed-scale hydraulic design, TMDL planning, post-fire assessment and rehabilitation planning, range management, and real time flash flood warning. The primary role of research and development has thus become to create and maintain accessible and adaptable modeling platforms, from which customized management applications can grow, and to design and conduct research in support of model usage for specific management applications.

Efforts to accommodate and promote use by resource managers (expert and non-expert) have proceeded on many fronts, all with the aim of improving practical usability. Complex processes associated with model parameterization have been automated to the greatest extent possible to minimize both the number of steps and the required user input. Tools have been developed to assist with the interpretation of model results through visualization of distributed, time-series outputs. Multiple versions of the interface for ArcView 3.X, ArcGIS 9.X and the Internet have been developed to accommodate users with

variable GIS skills and software, and to facilitate integration with additional models and tools. Detailed user documentation and a range of training exercises have been made available via the Internet, and training workshops have been hosted around the country and abroad.

Management needs are dynamic and widely varied. We believe that the success of AGWA in management applications is a direct result of its adaptability to a range of tasks, its ability to incorporate evolving sources of information, and its potential for integration with other software for decision support. Together with a design intended to facilitate users with a range of expertise, AGWA has bridged the gap between research and management by utilizing management needs as a source of inspiration for research.

6. REFERENCES

Cate, A.J., D.J. Semmens, I.S. Burns, D.C. Goodrich, and W.G. Kepner, AGWA Design Documentation: Migrating to ArcGIS and the Internet, U.S. EPA Report EPA/600/R-05/056, 2005.

Goodrich, D.C., S. Scott, M. Hernandez, I.S. Burns, L. Levick, A. Cate, W.G. Kepner, D.J. Semmens, S.N. Miller, and D.P. Guertin, Automated Geospatial Watershed Assessment (AGWA): A GIS-based hydrologic modeling tool for watershed management and landscape assessments, Proceedings of the 3rd Federal Interagency Hydrologic Modeling Conference, Reno, NV, April 3-6, 2006.

Goodrich, D.C., Kepner, W.G, M. Hernandez, S. Miller, B. Goff, B. Jones, C. Edmonds, T. Wade, D. Ebert, and D. Heggem, Landscape Indicator Interface with Hydrologic Models, U.S. EPA Report EPA/600/R-00/042, 2000.

Lahlou, M., L. Shoemaker, S. Choudry, R. Elmer, A. Hu, H. Manguerra, and A. Parker, Better assessment science integrating point and nonpoint sources: BASINS 2.0 User's Manual, U.S. EPA Report EPA-823-B-98-006, 1998.

Maidment, D., and D. Djokic, Hydrologic and Hydraulic Modeling Support with Geographic Information Systems, ESRI Press, Redlands, CA, 2000.

Miller, R.C., D.P. Guertin, and P. Heilman, Information technology in watershed management decision-making, *Journal of the American Water Resources Association*, 40(2), 347-357, 2004.

Miller, S.N., D.J. Semmens, D.C. Goodrich, M. Hernandez, R.C. Miller, W.G. Kepner, and D.P. Guertin, The Automated Geospatial Watershed Assessment tool, *Environmental Modeling and Software*, In press.

Miller, S.N., D.J. Semmens, R.C. Miller, M. Hernandez, W.P. Miller, D.C. Goodrich, W.G. Kepner, and D. Ebert, GIS-based hydrologic modeling: The Automated Geospatial Watershed Assessment Tool, Proceedings of the 2nd Federal Interagency Hydrologic Modeling Conference, Las Vegas, NV, July 29-August 1, 2002.

National Research Council (NRC), Committee on Watershed Management, New Strategies for America's Watersheds, National Academy Press, Washington, D.C., 1999.

Schultz, G.A., and E.T. Engman, Introduction to *Remote Sensing in Hydrology and Water Management*, Schultz, G.A., and E.T. Engman (eds.), Springer, 483 pp., New York, 2000.

Semmens, D.J., M. Hernandez, D.C. Goodrich, and W.G. Kepner, Hydrologic model uncertainty associated with simulating future land-use/cover scenarios, Proceedings of the Second International Conference on Research in the Watersheds, Otto, NC, May 16-18, 2006.