Jul 1st, 12:00 AM

The AgESGUI Geospatial Simulation System for Environmental Model Application and Evaluation

James C. Ascough II

Olaf David

Shilpa V. Murthy

Follow this and additional works at: https://scholarsarchive.byu.edu/iemssconference

The AgESGUI Geospatial Simulation System for Environmental Model Application and Evaluation

James C. Ascough II[1], **Olaf David**[2], **Shilpa V. Murthy**[3]

[1] USDA-ARS-NPA, Agricultural Systems Research Unit, Fort Collins, CO 80526 USA (jim.ascough@ars.usda.gov)

[2] Colorado State University, Depts. of Civil and Environmental Engineering and Computer Science, Fort Collins, CO 80523 USA (odavid@colostate.edu)

[3] Colorado State University, Dept. of Electrical Engineering, Fort Collins, CO 80523 USA (shilpav@rams.colostate.edu)

Abstract: Practical decision making in spatially-distributed environmental assessment and management is increasingly being based on environmental process-based models linked to geographical information systems (GIS). Furthermore, powerful computers and Internet-accessible assessment tools are providing much greater public access to, and use of, environmental models and geospatial data. This paper provides an overview of the AgESGUI (AgroEcoSystem Graphical User Interface) geospatial simulation system for environmental model application and evaluation. AgESGUI currently provides access to four environmental models: (1) AgroEcoSystem-Watershed (AgES-W), (2) Nitrate Leaching and Economic Analysis Package (NLEAP) GIS/NT, (3) Precipitation-Runoff Modeling System (PRMS), and (4) Soil and Water Assessment Tool (SWAT). AgESGUI data processing and visualization features include: (1) editing and visualization of geospatial model input data; (2) the ability to input measured experimental data for robust statistical model evaluation; and (3) geospatial output visualization across space, time, and modeling scenarios including capabilities for real-time post-processing (e.g., on-the-fly color ramping) and querying. AgESGUI leverages the GeoWind open source GIS platform that integrates Open Geospatial Consortium standards (as implemented in GeoTools) within NASA's World Wind Java SDK. The overall vision of the AgESGUI development effort is the creation of an open geospatial modeling system that enables the scientific modeling process to be closer to a "real world" experience.

Keywords: Graphical user interface, Environmental models; Open source GIS, Geospatial data, NASA WorldWind.

1. INTRODUCTION

Geographical information systems (GIS) software packages have been used for close to three decades as analytical tools in environmental management for geospatial data assembly, processing, storage, and visualization of input data and model output [Burrough 1986]. However, with increasing availability and use of full-featured geospatial data management tools, such as commercial (e.g., ArcGIS and IDRISI) and public domain open source (e.g., GRASS, Quantum GIS, MapWindow) GIS, new issues have arisen regarding application of environmental models to a range of spatial scales and the role of geospatial data tools and analytical techniques in decision making [He 2003]. With increased availability of powerful PCs, cloud computing platforms, and web-based access to geospatial data sets, it is quite common to see hydrologic/water quality (H/WQ) models originally developed for small-scale, site-specific analyses now being applied to new domains/problems, and, through GIS, to very large areas to examine spatial variations in environmental impact assessment [Daniel et al. 2010]. This paper

provides an overview of the AgESGUI (AgroEcoSystem Graphical User Interface) geospatial simulation system for environmental model application and evaluation. The AgESGUI project was initiated after conducting an extensive review of geospatial model interfaces (appropriate for multi-scale H/WQ modeling) and determining that none of the existing GIS tools provided a suitable interface for research/application development. AgESGUI currently provides access to four H/WQ environmental models: (1) AgroEcoSystem-Watershed (AgES-W) [Ascough et al. 2012], (2) Nitrate Leaching and Economic Analysis Package (NLEAP) [Shaffer et al. 2010] GIS/NT, (3) Precipitation-Runoff Modeling System (PRMS) [Leavesley et al. 2006], and (4) Soil and Water Assessment Tool (SWAT) [Arnold et al. 1998]. These models operate at different temporal and spatial scales and may be applied across a range of environmental conditions and scales to evaluate the impacts of management and cropping systems on H/WQ response. Additionally, the models are highly dependent on spatially distributed data; therefore, AgESGUI was equipped with robust data processing and visualization features including: (1) editing and visualization of geospatial model input data; (2) the ability to input measured experimental data for robust statistical model evaluation; and (3) geospatial output visualization across time, space, and modeling scenarios including capabilities for real-time post-processing (e.g., on-the-fly color ramping) and querying. AgESGUI was developed under the following guidelines: (1) the system must be entirely open source, (2) the system must be compatible with commonly available GIS data layers, (3) the system must be useful for assessment and scenario development (alternative futures) at multiple scales, and (4) the system must render geospatial model resources in a contemporary presentation. The overall goal of the AgESGUI development effort is the creation of an open geospatial modeling system that enables the scientific modeling process to be closer to a "real world" experience.

2. AgESGUI GEOSPATIAL SIMULATION SYSTEM
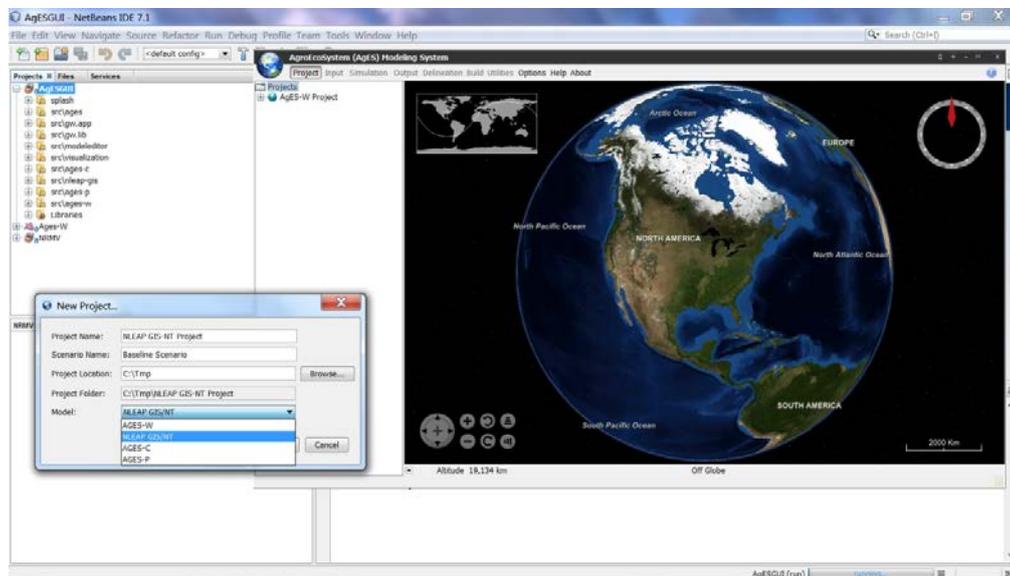
2.1 System overview

Figure 1. AgESGUI NetBeans[TM] development environment.

The AgESGUI geospatial simulation system was developed using the Java programming language and the NetBeans[TM] integrated development environment (Figure 1). The system leverages the GeoWind open source GIS platform (http://geowind.javaforge.com/project/2425) that integrates Open Geospatial Consortium standards (as implemented in GeoTools) within NASA's World Wind Java SDK. In addition, AgESGUI employs nearly 150 Java libraries to provide functionality for various system features including project management, file

handling, spreadsheet operations, Open Source GIS geospatial data management, report writing, graphing/charting, and advanced querying.

2.1 AgESGUI project management

AgESGUI projects are managed using the "Project" button in the AgESGUI menu bar (Figure 1). This button is used to create new projects or open existing projects; the projects are not restricted to a fixed project directory structure, i.e., they can be created (and loaded) from any accessible drive location and directory structure (Figure 1). The New Project window provides access to the integrated AgES-W, NLEAP GIS/NT, PRMS, and SWAT H/WQ environmental models. Once a project has been created, scenarios (e.g., model setups with different management and cropping systems) within the project structure can then be created. Finally, general project management functionality includes saving, copying, closing, renaming, and deleting both projects and scenarios.

2.2 AgESGUI input file management

Model input files (and associated parameters) for the four environmental models implemented in the AgESGUI may be accessed through the "Input" button in the main menu bar. All model implementations require GIS input layers (i.e., ESRI shape files) for geospatial land unit visualization. For example, the AgES-W model requires GIS input layers for watershed hydrologic response units (HRUs) and stream reaches (Figure 2). For the NLEAP GIS/NT model that operates on a plot to field scale, only a single GIS land unit layer is required. AGESGUI requires data input files to be in comma separated value (i.e., csv) format. In addition, some input files have visualization capabilities directly attached to them, e.g., selecting the check box for the AgES-W topology input file displays topological linkages between HRUs and stream reaches in a watershed. Special utility code was also developed to facilitate incorporation of model input files into AgESGUI. This "input file tree builder" code reads in a directory listing that is then used to create a file tree structure as shown in both Figure 2 (AgES-W) and Figure 3a (NLEAP GIS/NT). All .csv files located within the directory tree structure are then automatically imported into AgESGIU input spreadsheets with full editing (row and column insert/delete etc.) capabilities (Figure 3a). Blank file templates are also provided for all AgESGUI model input files in the case the user wishes to create a new input file from scratch. Finally, selected input file parameters can be viewed graphically (e.g., rainfall time series, Figure 3a) or geospatially using GIS (e.g., watershed elevation color ramping, Figure 3b).
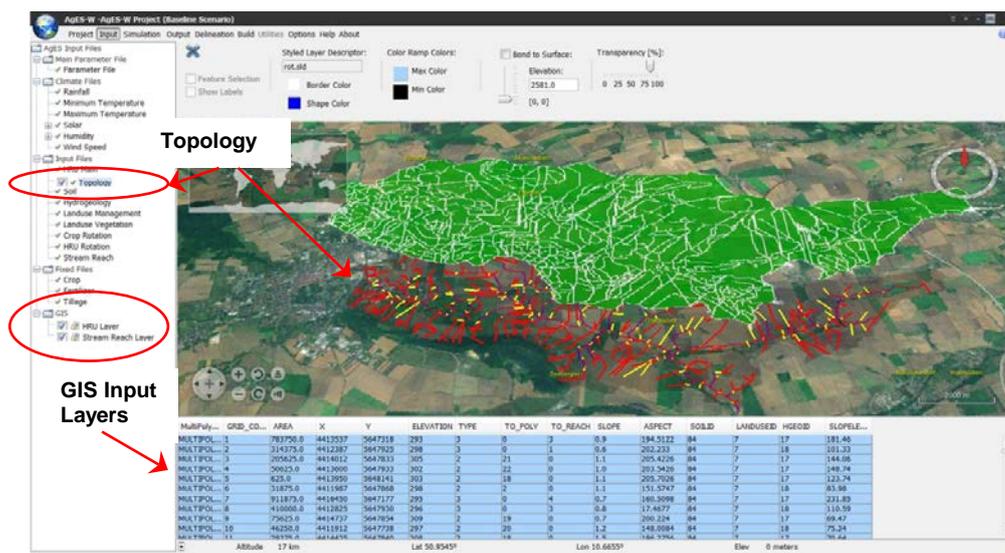

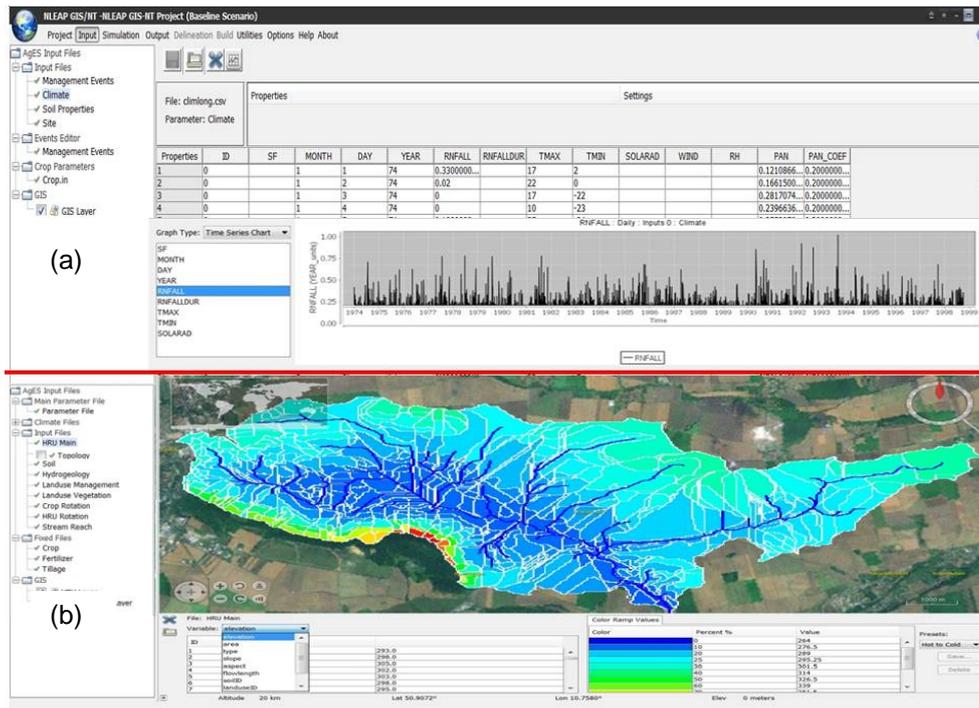**Figure 2.** AgESGUI input screen – GIS layer input and display.

Figure 3. AgESGUI input screen – (a) spreadsheet editing and input parameter time series visualization, and (b) input parameter geospatial color ramping visualization.

2.3 AgESGUI model execution

Once the input file building process is complete, the "Simulation" button in the main menu bar may be used to display the model simulation screen (Figure 4). This screen contains simulation start and end dates, plus additional Java Virtual Machine (JVM) run-time memory options for the AgESGUI Java-based simulation models (i.e., AgES-W and PRMS).
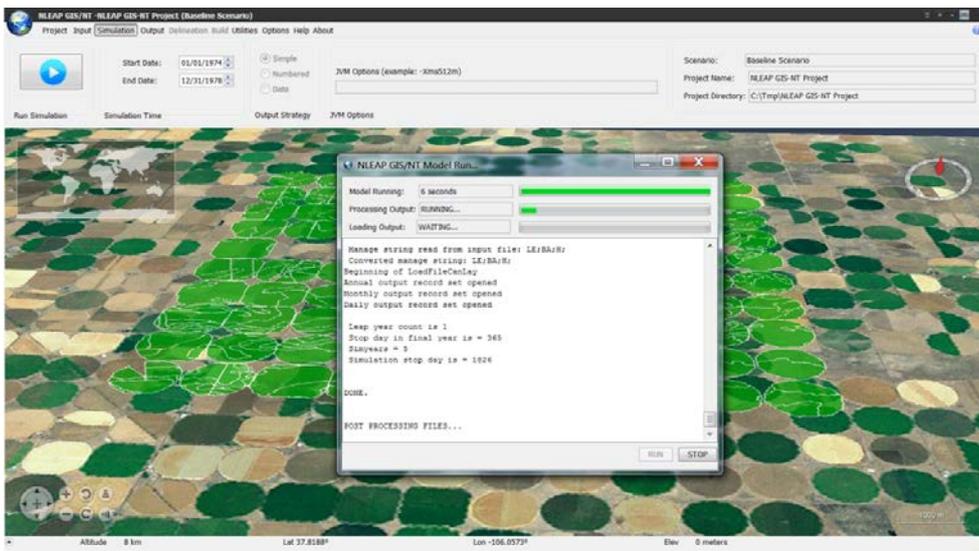

Figure 4. AgESGUI simulation screen with example runtime dialog for the NLEAP GIS/NT model.

2.4 AgESGUI output visualization

Output response visualization for all models implemented in AgESGUI may be accessed through the "Output" button in the main menu bar. Figure 5 shows AgESGUI basic graphing/charting functionality. AgESGUI utilizes a "quasi-4D" graphing approach where: 1) model output response variables (one or more); 2) temporal resolution (daily, monthly, yearly, or summary over a specified date range); 3) spatial extent (one or more land units); and 4) management scenarios (one or more) may be selected together. AgESGUI contains a heuristic rule-base (similar to an expert-system) in the output visualization component to ensure that the appropriate type of graphs are displayed (e.g., time series chart, bar graph, scatter plot, etc.) depending on the variable, space, time, and scenario input selections. In addition, basic statistics (e.g., mean, standard deviation, variance, median, etc.) can be calculated and displayed for the selected graph data.
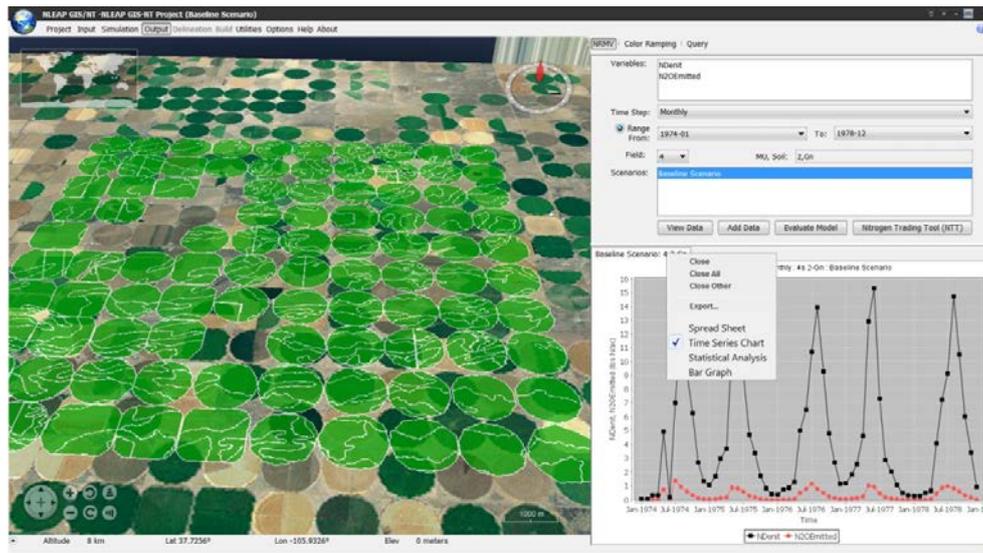

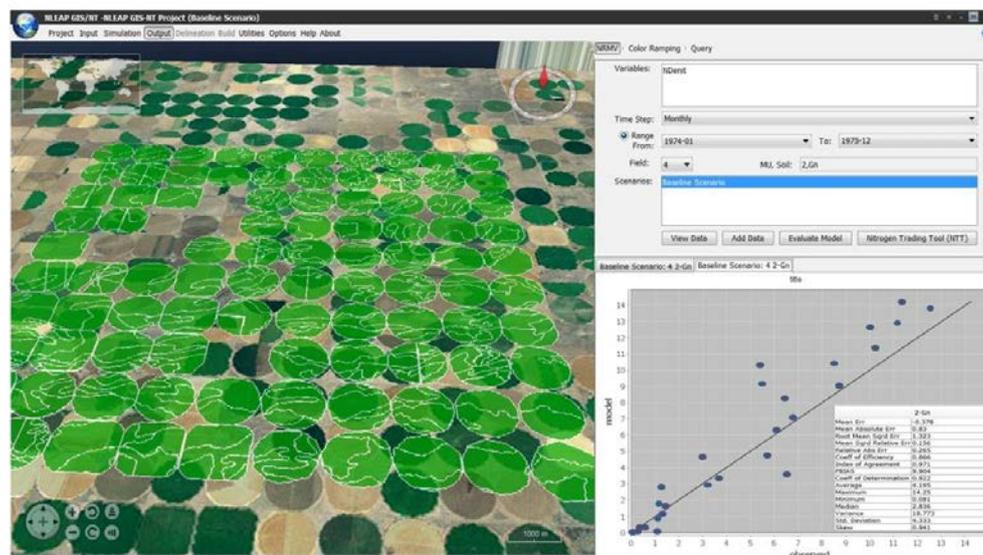**Figure 5.** AgESGUI basic graphing/charting functionality.

Figure 6. AgESGUI model evaluation functionality.

Figure 6 shows AgESGUI model evaluation functionality. Using the "Evaluate Model" button, observed experimental data may be pasted into an embedded spreadsheet editor and then compared to simulated model output response. Currently, ten commonly accepted model statistical evaluation criteria (e.g., coefficient of correlation/determination, root mean square error, Nash-Sutcliffe model efficiency, Wilmot index of agreement d) are available for observed data vs. model predicted comparison purposes.
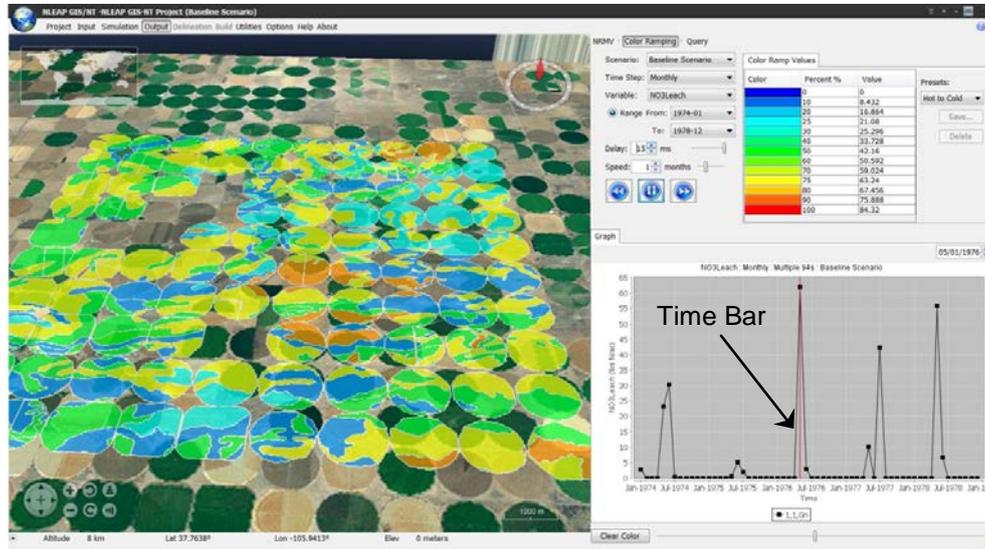

Figure 7. AgESGUI geospatial color ramping visualization capabilities.

AgESGUI geospatial color ramping visualization capabilities are shown in Figure 7. Similar to the basic graphing/charting selection requirements, a scenario, time step, output response variable, and date range must be selected for color ramping visualization. In addition, up to three spatial units may be selected for standard graphing (Figure 7, lower right). Once the "play" (▶▶) button is selected, a "time bar" scrolls across the time series graph, moving at the selected time step "speed" (e.g., daily, monthly, or yearly). The time bar may be speeded up or slowed down depending on user preference.
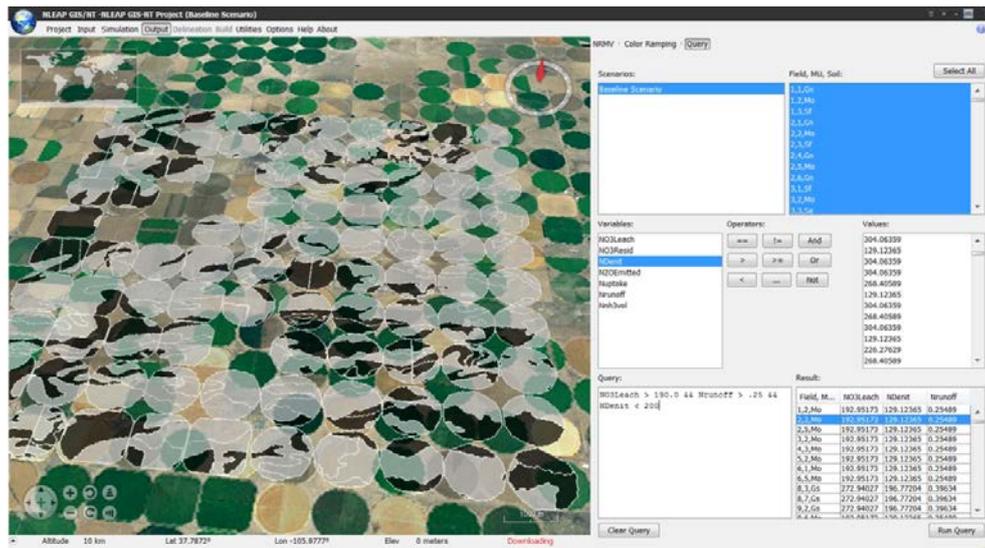

Figure 8. AgESGUI geospatial querying and visualization capabilities.

AgESGUI geospatial querying and visualization capabilities are displayed in Figure 8. Average output response values (from the summary output file) for the entire simulation are used for querying purposes. In order to perform a query, the scenario and land units must first be selected (geospatial queries across multiple scenarios are currently not permitted). A query string can be constructed by clicking on the (model output response) variables, operators (e.g., <, >, =, AND, OR) and numerical values which are imported (for each output response variable) from the summary output file. Thus, extremely complex queries can be constructed and displayed. The land units for which the query was satisfied are both highlighted in black and listed in the result box with the matching numerical values (Figure 8). The "Clear Query" button resets both the query box and the geospatial visualization.
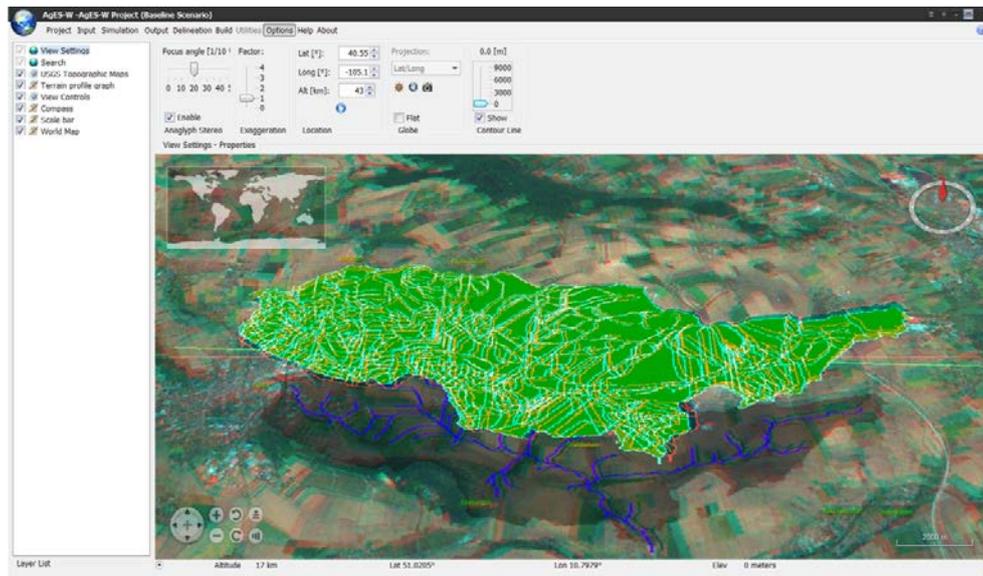

Figure 9. Additional AgESGUI display features and options.

2.5 Additional AgESGUI features

Figure 9 shows additional display features and options in AgESGUI. The user may display United States Geological Survey (USGS) topographic maps, cross-section elevation graphs of the land surface terrain, and 3D anaglyph stereoscopic views of the land surface and GIS input layers (Figure 9). All the above features are directly provided via the underlying NASA World Wind library.

3. CONCLUSIONS AND FUTURE WORK

The utilization of GIS technology in environmental modeling has brought great value and presents future potential benefits for natural resource managers. The literature on this topic shows that the capabilities for applying GIS in environmental modeling are growing among stakeholders [Martin et al. 2005]. This is evident by the efforts of various government agencies to disseminate spatial information to stakeholders and an overall commitment to improving GIS-based environmental modeling tools, particularly at the watershed scale. The success of these efforts is heavily dependent on the effectiveness of GIS-environmental model interface developers in producing user-friendly systems. To this end, a GIS-based geospatial simulation system called the AgroEcoSystem Graphical User Interface (AgESGUI) has been developed to facilitate H/WQ analysis. This tool has been developed as open-source, is fully modular and customizable, and provides access to the AgES-W, NLEAP GIS/NT, PRMS, and SWAT environmental models. AgESGUI is equipped with wide-ranging data processing and visualization features including: (1) editing and visualization of geospatial model input data; (2) the ability to input measured experimental data for robust statistical model evaluation; and (3) geospatial output visualization across time, space, and modeling scenarios including capabilities for real-time post-processing (e.g., on-the-fly color ramping)

and querying. Initial application and evaluation of AgESGUI by environmental modelers indicates that it is practical, comprehensive, and has the potential to improve the efficiency and efficacy of the H/WQ modeling process.

With the AgESGUI interface, land use change scenarios can be readily explored with the implemented environmental models to help resource planners and decision makers develop water quantity/quality management plans. Future AgESGUI enhancements include the addition of a standalone watershed delineation tool (currently being developed separately) and integration of tools for model autocalibration and sensitivity/uncertainty analyses. Supplementary benefits of using modeling systems such as AgESGUI include the ability to conduct a variety of applications such as assessment of sediment and nitrogen loading dynamics, evaluation and development of Total Maximum Daily Loads (TMDLs), and peak discharge computation. Major advances in environmental modeling characteristically rely on geospatial data (e.g., DEMs), commercial and open source GIS software, and remote sensing technologies (e.g., NEXRAD, LiDAR) to understand and represent natural resource processes. Future trends suggest that GIS will continue to influence environmental modeling by providing flexible platforms to support more rapid model development, real-time data collection, and deployment of web-based environmental modeling applications. Finally, open-source GIS software tools such as AgESGUI appear to have a prominent role in the environmental modeling arena, and show great potential as cost-effective alternatives to their proprietary GIS counterparts.

ACKNOWLEDGMENTS

REFERENCES

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams, Large-area hydrologic modeling and assessment: Part I. Model development, *J. American Water Res. Assoc.*, *34(1),* 73-89, 1998.

Ascough II, J.C., O. David, P. Krause, G.C. Heathman, S. Kralisch, M. Larose, L.R. Ahuja, L.R., and H. Kipka, Development and application of a modular watershed-scale hydrologic model using the Object Modeling System: Runoff response evaluation, *Transactions of the ASABE, 55(1)*, 117-135, 2012.

Burrough, P.A, *Principles of Geographical Information Systems for Land Resources Assessment,* Oxford, Oxford University Press, 1986.

Daniel, E.B., J.V. Camp, E.J. LeBoeuf, J.R. Penrod, M.D. Abkowitz, and J.P. Dobbins, Watershed modeling using GIS technology: A critical review, *Journal of Spatial Hydrology*, 10(2), 13-28, 2010.

He, C., Integration of geographic information systems and simulation model for watershed management, *Environmental Modelling & Software*, 18 (2003), 809-813, 2003.

Leavesley, G.H., S.L. Markstrom, and R.J. Viger, USGS modular modeling system (MMS) - precipitation-runoff modeling system (PRMS). In: Singh, V.P., Frevert, D.K. (Eds.), Watershed Models, CRC Press, Boca Raton, FL, pp. 159-177, 2006.

Martin, P.H., E.J. LeBoeuf, J.P. Dobbins, E.B., Daniel, and M.D. Abkowitz, Interfacing GIS with water resource models: A state-of-the-art review, J*ournal American Water Resources Association*, 41(6), 1471-1487, 2005.

Shaffer, M.J., J.A. Delgado, C. Gross, R.F. Follet, and P. Gagliardi, Simulation Processes for the Nitrogen Loss and Environmental Assessment Package (NLEAP). In: J.A. Delgado and R.F. Follett, eds., *Advances in Nitrogen Management for Water Quality*. Ankeny, IA: Soil and Water Conservation Society, 2010.