CHAPTER 3

RIVER GEODSS: COMPONENTS AND MODULES

River GeoDSS is developed to provide the user with a powerful interface and seamless integration of its components for conjunctive use groundwater-surface water quantity and quality river basin modeling. The powerful ESRI®-ArcMap™ spatial interface is selected to provide the framework for the *River GeoDSS* user to enter and manage data, operate the DSS, display results and perform analysis. Most of the existing decision support tools lack geo-referenced integrated interfaces (e.g., AQUATOOL (Andreu et al. 1996), WRAP (Wurbs 2005), RiverWare (Zagona et al. 2001)), giving the *River GeoDSS* design a distinct advantage over these models. Embedding the *River GeoDSS* in a popular and well accepted GIS interface facilitates adoption of the tool since potential users might already be familiar with the interface, and not having to learn a new interface is attractive to the user. In addition, the *River GeoDSS* is packaged with tools and interfaces that allow both experienced and inexperienced users access to the modeling system for performing analysis and answering management and improvement questions with minimal user-required manipulation of data and modeling procedures (e.g., network transformations and calibration/simulation modeling structures). Most of the procedures required to calibrate/simulate a basin in *River GeoDSS* are included in its set of tools, thereby minimizing manual data processing and setup of the system models and modules.

GENERAL *RIVER GEODSS* STRUCTURE

The *River GeoDSS* structure is conceived as centered around a geo-referenced-spatio-temporal database, where river basin data are spatially-managed utilizing GIS capabilities in an object-oriented fashion. The *River GeoDSS* is developed as an integration of graphical components, models, databases, and processing tools with programming code linking all the components together. The *River GeoDSS* contains interfaces to connect models and modules with the database, and graphical user interfaces to facilitate selection of preferences and data manipulation, minimize manual processing tasks and reduce errors when processing large amounts of data. The main components of the *River GeoDSS* are: (1) computer software such as: ArcGIS™, MODSIM, MODFLOW, MT3DMS and MATLAB®, and (2) two modules for water quality modeling and ANN training and integration support. Figure 3.1 shows the *River GeoDSS* components and their interaction within the *River GeoDSS*. The spatial-temporal database contains all the relevant system information and measured data, and he GIS framework displays data, hosts interfaces for data input/output, and delivers a robust spatial processing environment. The MODFLOW-MT3DMS models provide accurate, physically-based groundwater quantity and quality modeling, and ESRI-ArcObjects and SQL encapsulated in VB.NET code customized data processing. Geo-MODSIM, as implemented in the ArcMap interface to ArcGIS, offers the powerful network flow modeling environment which is enhanced with optional (1) ANN stream-aquifer interaction modeling, (2) ANN reservoir water quality transport modeling, and (3) conservative surface water quality routing. The *River GeoDSS* modules are dynamically linked in the Geo-MODSIM modeling environment to provide fully integrated river basin simulation.

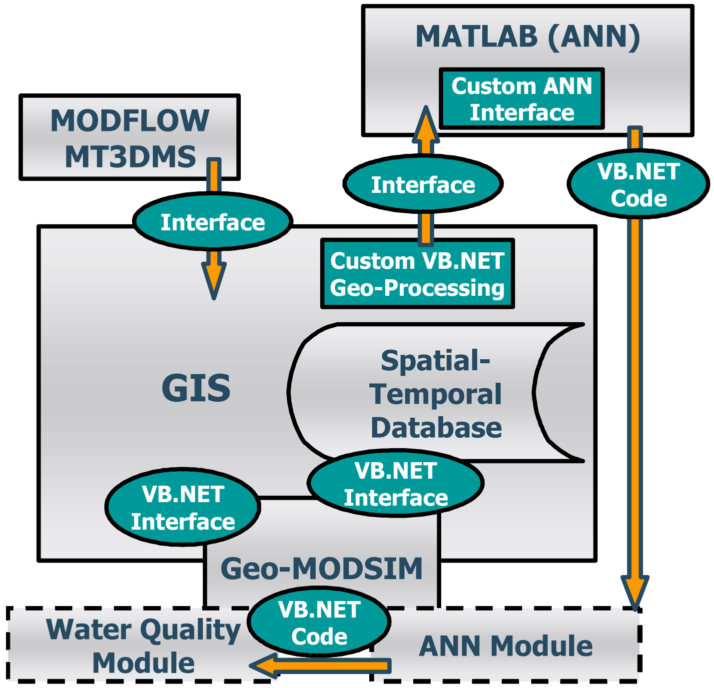


Figure 3.1 – DSS structure diagram

The *River GeoDSS* implements the *Extension* concept to enable/disable optional modules and sets of customized tools that enhance the *River GeoDSS* capabilities in an application-specific fashion. The extensions allow efficient loading of components and data in memory, faster access to data stored in memory, and customized user interfaces that display only active component options and case-specific tools. The extensions are accessed form the main menu under *River GeoDSS Extensions* (Figure 3.2). The Water Quality Module (WQM) and Geo-MODFLOW are available as extensions, with the WQM extension enabling various *River GeoDSS* water quality and file management tools (e.g., loading and saving data within the *River GeoDSS* project). Geo-MODFLOW, as an extension, enables tools for integration of surface water and groundwater modeling. Specialized extensions specifically for the Arkansas River basin provide access to the customized user interfaces and tools that allow case-specific data import and handling, as well as custom run types.

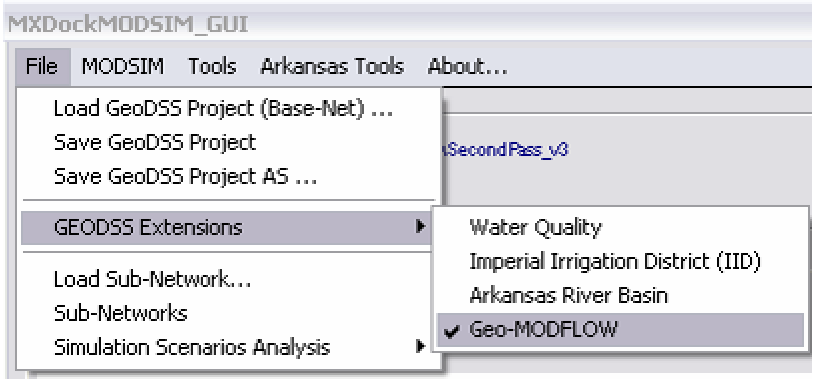


Figure 3.2 – *River GeoDSS* extension menus

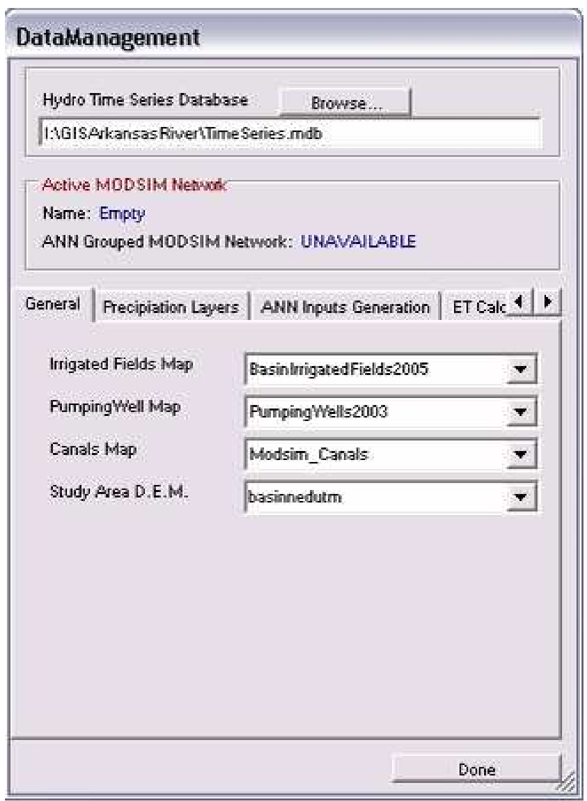


Figure 3.3 – *River GeoDSS* Data Management Interface

A Data Management Interface is implemented in the *River GeoDSS* for organizating layers and files for all components and modules. The *River GeoDSS* Data Management Interface allows setting: (1) the time series database file, (2) water quality database file, (3) precipitation raster map locations, (4) the ANN buffers database file, (5) the ANN training database file, (6) precipitation summary database file, (7) the feature class names for irrigated fields, pumping wells, canals, streams, DEM layer, water bodies, and (8) the MODFLOW finite diference grid, and polygon feature classes representing the extent groundwater modeled area and user defined grouping areas for stream-aquifer modeling using ANNs. Figure 3.3 shows the general tab of the *River GeoDSS* Data Management Interface.

GEO-MODSIM

The geo-referenced version of MODSIM called Geo-MODSIM is developed to combine the advantages of spatial distributed information and MODSIM network flow modeling. Geo-MODSIM is implemented as an extension in ArcGIS™ 9 (ESRI®, Inc.) to apply MODSIM to geo-referenced basin models using the ESRI geometric network utilities to create, edit and display the network. The ArcMap™ interface for ArcGIS serves as a geo-referenced user interface for MODSIM, allowing advanced network display and access to network objects. In this way, Geo-MODSIM allows full utilization of the available spatial data processing, display, and analysis tools available in ArcGIS™, in conjunction with the powerful MODSIM model functionality.

A GIS geometric network is a "single dimension non-planar graph with features where edge elements and junction elements are connected by topology" (Borchert 2003) or simply a set of connected edges and junctions for which the GIS knows how things are connected from point A to point B (including flow direction). The MODSIM network is composed of nodes (i.e., reservoirs, demands and non-storage nodes) connected by one-directional links. The similarities between the GIS geometric network and a MODSIM network allow Geo-MODSIM to use the geometric network as the MODSIM network. Using MODSIM v8 .NET integration and ESRI-ArcObjects, Geo-MODSIM packs a set of tools to link geo-referenced system objects in GIS and the model objects. The MODSIM object oriented database is well suited to the linkage structure associated with geo-referenced objects.

Geo-MODSIM Data Model

ESRI geo-database feature classes are used as data sources to define the geometric network. A data-model is developed as template to create the river basin features in ArcGIS and facilitate the building of the MODSIM network in Geo-MODSIM. Figure 3.4 shows the GIS data-model structure; detailed description of the feature classes and fields is found in the *River GeoDSS* User Support (Appendix III).

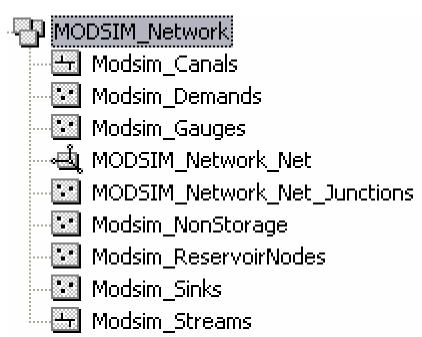


Figure 3.4 - Geo-MODSIM data-model in ArcCatalog™

Geo-MODSIM geometric network

When a geometric network is created, ArcGIS also creates the corresponding logical network, which is used to represent and model connectivity relationships between features.

The logical network is the connectivity graph used for tracing and flow calculations. The MODSIM network topology is constructed directly from the ArcGIS™ logical network. Geometric network nodes are used to create the system nodes and the logical network connectivity is used to create the links between nodes in MODSIM. A set of supporting (synchronization) tables are generated in the geo-database during the MODSIM network creation process. Detailed description of these tables is found in Appendix III.

The geometric network uses six types of nodes: Gauges, Demands, Reservoir, Sinks, Non-storage, and network junctions. In addition, the geometric network implements two types of links: Streams and Canals. These geo-referenced objects are transformed into MODSIM objects while building the MODSIM network. Demands, Reservoirs, Sinks and Non-Storage nodes are common to both the geometric network and the MODSIM network and network junctions are implemented as non-storage nodes. The Gauges nodes are implemented as *flow-through* demand nodes, which are capable of routing non-consumptive water to a downstream node. Base network non-storage nodes defined as interfaces, connecting end of canals with the stream system, are transformed into *flow-through* demands, allowing modeling of operational flow returns to the system.

A common practice is to begin the creation of the geometric network by importing the National Hydrologic Dataset (NHD) stream and canal layers, reservoirs, gauging stations, diversion structures, and wells into the data-model feature classes. Network Utility analyst available in ArcGIS provides tools to test connectivity and adequately implement water movement in the network (e.g., find connected nodes and links, trace up/downstream, find disconnected nodes and links, etc…).

Geo-MODSIM tools in ArcMap

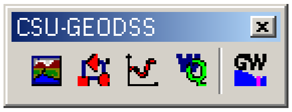


Figure 3.5 – GeoDSS Toolbar in ArcGIS

Geo-MODSIM tools are accessible from the *River GeoDSS* toolbar in ArcGIS (Figure 3.5). The Geo-MODSIM main dialog () gives access to standard MODSIM settings and dialogs (Figure 3.6). The main dialog accesses tools for (1) creating the MODSIM network from the active geometric network in the ArcMap™ project, (2) loading and saving the corresponding MODSIM xy file where the network is stored, (3) accessing MODSIM menu items (Figure 3.6), and (4) invoking basic network synchronization tools. The MODSIM menu items provide access to MODSIM network settings, the water rights dialog, output control, MODSIM extensions, network cost overview and utilities for spatial model output results display. The MODSIM network basic execution is triggered in this dialog.

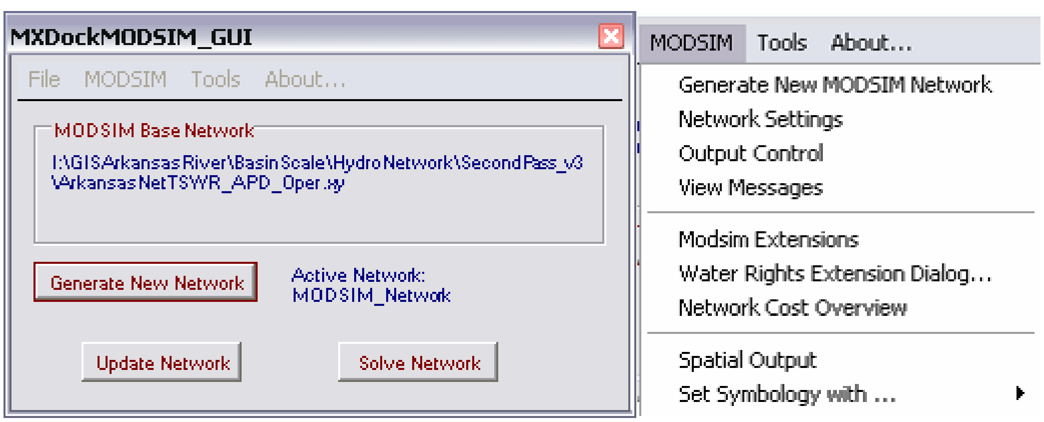
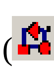
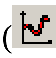


Figure 3.6 – Geo-MODSIM main interface and menu items in ArcMap™

The Geo-MODSIM *Select Feature Tool* () displays the MODSIM database entry dialogs associated with the network objects. Figure 3.7 shows the MODSIM dialog displayed by clicking a system demand node with mouse pointer using the Geo-MODSIM *Select Feature Tool*.

The Geo-MODSIM *Output Tool* () triggers the standard MODSIM output display interface for the selected network object. The output consists of tables and time series plots of the modeled values for all time steps. Figure 3.8 shows an example time series plot for a demand node in the system.

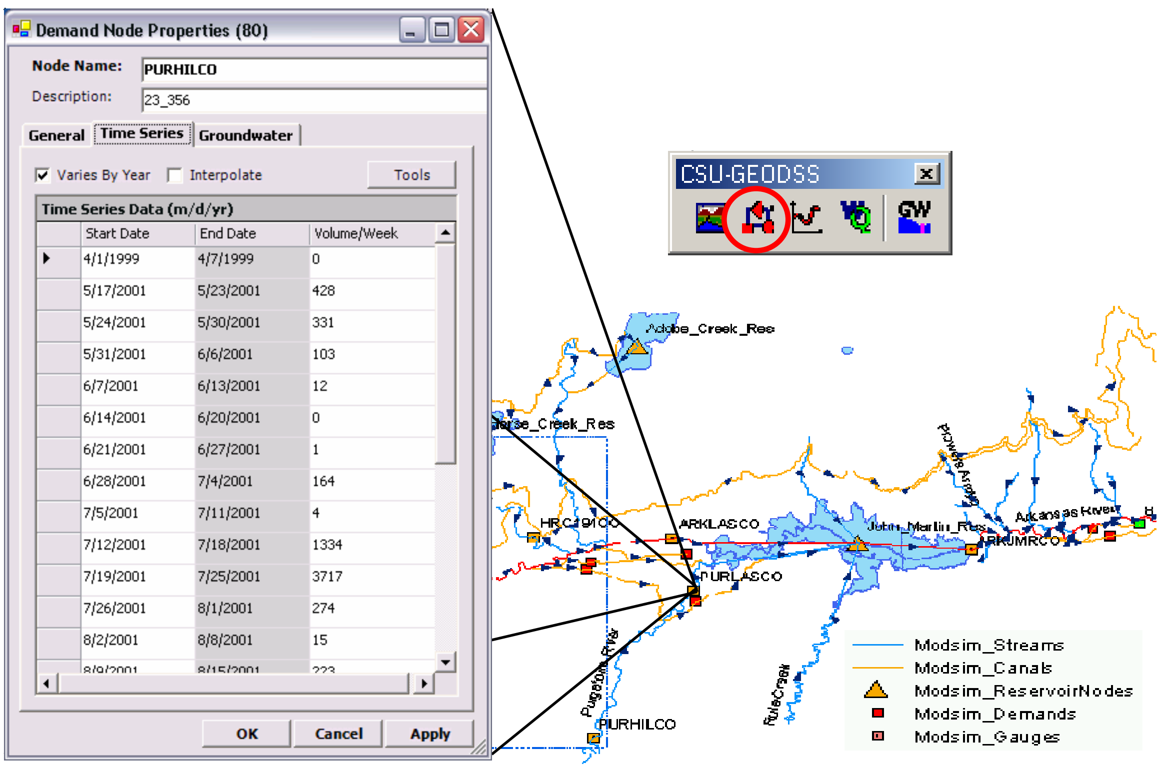


Figure 3.7 – Geo-MODSIM select features tool in ArcMap™

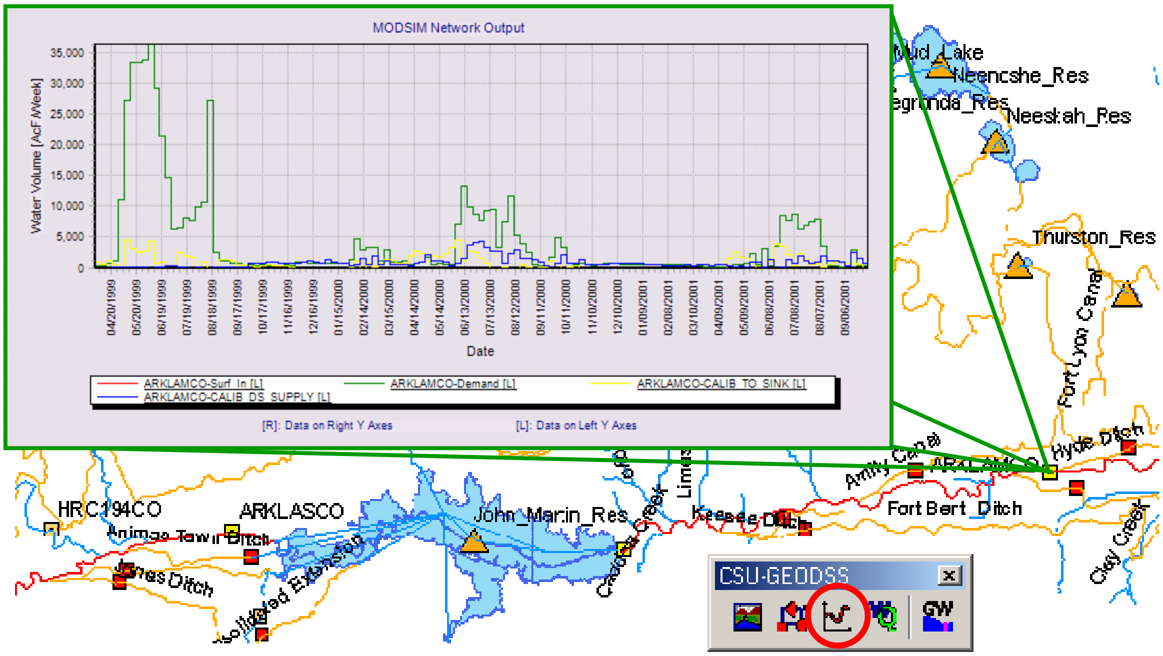


Figure 3.8 – Geo-MODSIM Output Display Tool in ArcMap™

Data-model Data Transfer

System data can be stored directly in the geo-database and loaded into the MODSIM network for model execution without having to maintain the data in both MODSIM and GIS. Data that can be stored in the geo-database include: reservoir capacities, link costs, node priorities, link capacities, and channel loss coefficients.

Network Types in Geo-MODSIM

The MODSIM network created from the geometric network is stored as the Geo-MODSIM *Base-Network*, a MODSIM native xy file. The *Base-Network* is used in Geo-MODSIM to create both calibration and simulation networks. At run time, according to the run type specified (i.e., calibration or simulation), and the active simulation scenario, the network structure is modified, functional structures added and data loaded into another MODSIM file called *Sub-Network*. The Sub-Network MODSIM file is named after the Base-

Network suffixed with the simulation scenario name. Sub-Networks can be turned into an active Geo-MODSIM network (for input/output) using the *File→Sub-Networks* menu item. Sub-Networks generated/executed in *River GeoDSS* are made available to the user for display and comparative analysis under its simulation scenario name. The *River GeoDSS* interface provides tools for comparing side-by-side simulation scenario results under the *Sub-Networks Analysis* menu item by clicking the check boxed next to the available Sub-Networks to be included in the output comparison. The Base-Network and Sub-Networks share the same GIS topology; however, the data can be different (e.g., diversions, channel losses, costs, priorities, etc…). Additional Sub-Networks created in a different *River GeoDSS* project can be loaded into Geo-MODSIM using the menu items. Simulation of changes to the system topology requires generation of a new Base-Network, but the network cannot be categorized as a Sub-Network. Figure 3.9 shows a diagram of the GIS geometric networks and MODSIM Base and Sub-Networks.

The Base-Network can be initially loaded with data that will be used in all Sub-Networks. In some *River GeoDSS* applications, a customized run is implemented to dynamically import time series and other data at run time for each simulation. The latter alternative does not require maintaining the time series in the MODSIM file; rather, the series can be loaded from a central location (e.g., a database). In cases where time series are the same for the simulation scenarios, it is convenient and efficient to store them directly in the MODSIM database.

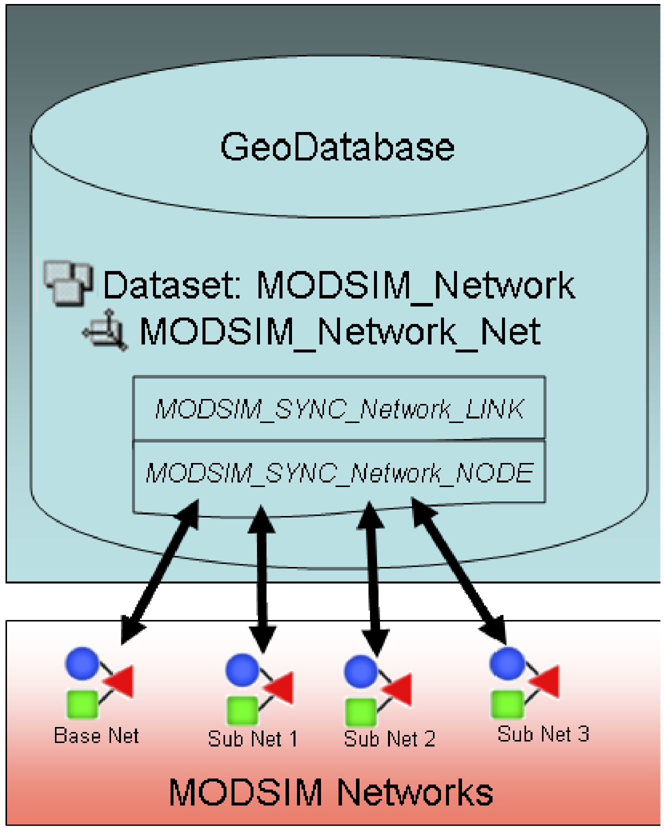


Figure 3.9 – Geometric network and MODSIM network interaction diagram

ANN MODULE IN *RIVER GEODSS*

River GeoDSS ANN module consists of a set of tools to conduct ANN-assisted modeling of river basin systems and integrate the ANN predictions within other components of the decision support tool. The module provides support for neural network training dataset creation and simulation. The module uses ESRI-ArcObjects libraries to build spatially grouped training datasets. The ANN module uses custom MATLAB exported files to load trained neural networks into the *River GeoDSS* to perform simulations, where the export files are generated by the *ANN MATLAB Export Tool*. In simulation, explanatory variables are dynamically generated for each modeling time step. Four types of neural networks are currently supported in the ANN module: Feed forward back propagation (including

Cascade Forward Network), Elman neural network, Radial Basis Neural Net and Generalized Regression neural network.

Special Considerations on the ANN Simulation in River GeoDSS

The ANN simulation dataset needs to be consistent with the training dataset to guarantee accuracy in the predictions; i.e., the basin system states assumed for training based on the groundwater simulations should be dynamically duplicated while simulating them in the *River GeoDSS*. During simulation, the *River GeoDSS* implements the option to generate the ANN simulation datasets from the current MODSIM modeled variables, assuming the explanatory variables are updated each iteration. Although the simulation dataset is generated in a similar fashion to the training dataset, explanatory variables that are functions of the modeling variables might change considerably between simulation and training. It was found in this study that this option creates instability with a slow and inconsistent convergence. In addition, there is a risk of creating an ANN simulation dataset with a different variable space than the dataset used for training, thereby increasing the prediction uncertainty and reducing the overall accuracy of the prediction by accumulation of errors.

An option to support usage of previous runs is implemented by creating a set of explanatory variables that depend on modeling variables from a previous simulation solution. For each time step, the modeled variables, such as river flow, canal diversion, aquifer recharge, and canal seepage, are extracted from the previous simulation results. The advantage of this option is that the previous simulation run is based on a calibrated network that can include complex operations and previously calculated return flows without the need for simplifications. Therefore, the ANN simulation dataset can include complex modeling elements without directly using the current simulation variables that create instability and convergence issues. The previous simulation support option, at the beginning of the simulation, creates a copy of the existing MODSIM output file for the network that is being simulated. This copy of the output file is used to query the system variables in order to build the ANN explanatory variables. An iterative ANN training-simulation process allows refining the ANN performance by reducing the variability of complex explanatory variables such as river flows and diversions resulting from simulation predicated on the ANN predicted flows and water availability.

ANN MATLAB Export Tool

A tool to export the MATLAB trained ANN is implemented for the *River GeoDSS*. The tool extracts required information from the training process and the MATLAB trained ANN for external simulation. The exported text files include input/output scaling parameters, network structure and configuration; and all associated connection weights and biases. Using these exported files, *River GeoDSS* is able to perform ANN predictions when a set of explanatory variables is presented. Detailed descriptions of the files structures and contents are provided in Appendix III – *ANN Modeling Files in River GeoDSS*.

ANN Priming

As found in the literature, and corroborated by earlier experimentation with ANNs, the outputs from previous time steps provide a system "memory" that can significantly improve prediction accuracy. During simulation, the ANN module uses previous predictions to generate the simulation dataset, but for the initial time steps in the simulation, there are no previous predictions to use as explanatory variables. Therefore, the sequential predictions use previous predictions that contain errors. It was observed that the previous output explanatory variables in the first stages of the simulation greatly influence the entire simulation prediction space. That is, when the initial errors are large, the ANN is unable to recover from these errors and the predictions deteriorate over the remainder of the simulation. A priming procedure is implemented in the ANN module to improve selection of the starting explanatory variables. Prediction over initial time steps are iteratively repeated until the prediction converges within a tolerance range. The algorithm predicts the first time step using averages of the explanatory variables in place of use of the previous predictions. The generated prediction then replaces the averages. Since the prediction was calculated using all other actual explanatory variables for the first time step, the process is expected to move the prediction towards a "better" system state at the beginning of the simulation. An iterative process is implemented in which the explanatory variables from previous time steps are replaced with the previous iteration prediction until the prediction converges to a value within 10% of the previous prediction (a maximum of 3000 iteration are allowed). This prediction becomes the output for the first time step, which is then used for the next time step prediction as the *(t-1)* previous output. This process is repeated for all initial time steps where the previous outputs are unknown, where the number time steps to prime depends on the number of previous time steps that the neural network relies on. Figure 3.10 illustrates the most important element of the ANN priming procedure.

ANN Radial Basis Prediction in River GeoDSS

Unrealistic predictions outside the training areas might be possible when explanatory variables found in the variable space differ significantly from those in the training space. The radial basis NN predictions are constrained in the *River GeoDSS* to a range around the maximum and minimum values observed in training, thereby maintaining realism of the predictions. The prediction range is set as a percent of the training range between the maximum and the minimum values, and is calculated as:

$$\begin{aligned} n\_Max_i &= Max_i + d_i \\ n\_Min_i &= Min_i - d_i \end{aligned} \tag{3.1}$$

where Max_i is the maximum training value for output variable i; Min_i is the minimum training value for the output variable i; n_Max_i is the upper bound on the prediction space for output variable i; n_Min_i is the lower bound on the output i prediction space; and d is the deviation above the training maximum and below the training minimum to compute the prediction range, where d is computed as a fraction (F) of the original range.

$$d_i = \frac{F \cdot (Max_i - Min_i)}{2} \tag{3.2}$$

The ANN predictions in the *River GeoDSS* are calculated with a factor of $F=0.25$, allowing a 25% wider prediction range.

Figure 3.10 – Neural network Priming Procedure Diagram

WATER QUALITY MODULE

A Water Quality Module (WQM) is developed to route conservative water quality constituents throughout the system that is coupled with the Geo-MODSIM network flow solution at each time step. The WQM introduces a generalized algorithm to trace the MODSIM network from upstream to downstream in the correct sequence, allowing calculation of concentrations at any point in the network based on previously calculated concentrations on upstream links. The network tracing algorithm is made available through the MODSIM network utility library, as part of the MODSIM version 8 standard package.

For each time step, network concentrations are calculated after the MODSIM network flows have converged to a solution. The MODSIM flow solution is combined with known concentrations to route the resulting constituent mass downstream using the mass conservation principle at the network nodes. The one dimensional mass conservation principle applied to a control volume in the network is expressed as:

$$\frac{\partial \dot{m}}{\partial x} dx \pm R_{source/\sin k} = -\frac{\partial m_{box}}{\partial t} \tag{3.3}$$

where $\dot{m}$ is the flux through the control surfaces; water constituent flux is $\dot{m} = C\,Q$, where C is concentration and the flow rate Q = velocity ($\bar{v}$) in the x direction times the cross sectional area; R = loading rates for sources or sinks; and $m_{box} = VC$ = mass in the control volume, where V= volume of the control volume. Therefore,

$$\frac{\partial\left(C \cdot \bar{v} dydz\right)}{\partial x} dx \pm R_{source/\sin k} = -\frac{\partial\left(C \cdot dxdydz\right)}{\partial t} \tag{3.4}$$

$$\frac{\partial\left(C\bar{v}\right)}{\partial x} \pm \left(R/V\right)_{source/\sin k} = -\frac{\partial C}{\partial t} \tag{3.5}$$

The general advection-diffusion transport equation may be written as:

$$C\frac{\partial \bar{v}}{\partial x}+\bar{v}\frac{\partial C}{\partial x}\pm C_{source/\sin k}=-\frac{\partial C}{\partial t} \tag{3.6}$$

Neglecting diffusion and assuming a conservative constituent, i.e., assuming no change in concentration in the *x* direction and no change in concentration over time:

$$\dot{m}_{out}-\dot{m}_{in}\pm R_{source/\sin k}=0 \tag{3.7}$$

where $\dot{m}_{out}$ = mass rate out of the control volume and $\dot{m}_{in}$ = mass rate entering the control volume. Equation 3.7 can be written for any node in the network as:

$$\sum C_{out}Q_{out}-\sum C_{in}Q_{in}=0 \tag{3.8}$$

Equation 3.7 implies complete mixing at the system nodes to model the water constituents. Since only network nodes, and not network link elements, are assumed to have external sources or sinks, the rate of mass entering a link upstream is equal to the rate of mass leaving the link downstream. Concentration calculations at the nodes are performed sequentially, starting at the most upstream nodes in the system, in the order dictated by the network tracing algorithm. The sequential calculation computes outflow link concentrations at each node as a function of the inflow links.

$$C_{out}=\frac{\sum_{in} C_i Q_i}{\sum_{out} Q_i} \tag{3.9}$$

Figure 3.11 shows a basic diagram of the WQM and MODSIM coupling. The WQM implements an MS-Access database to store the module parameters and data for each *River GeoDSS* project. During simulation, the module reads the network node inflow concentrations and calibration tolerances from the MS-Access database. When the MODSIM network is initialized, the network is traced and the node order from upstream to downstream is established. Once a solution for a time step is achieved in MODSIM, the module calculates water constituent concentrations throughout the network. The concentration of water flowing out of a node is a function of the concentration of all sources of water flowing into that node. The WQM is integrated with the *River GeoDSS* ANN module to include ANN prediction in the computations (e.g., groundwater-surface water quality integration and reservoir water quality transport). When a trained ANN is available, the WQM uses the ANN groundwater constituent load predictions as external contributions to the nodes.

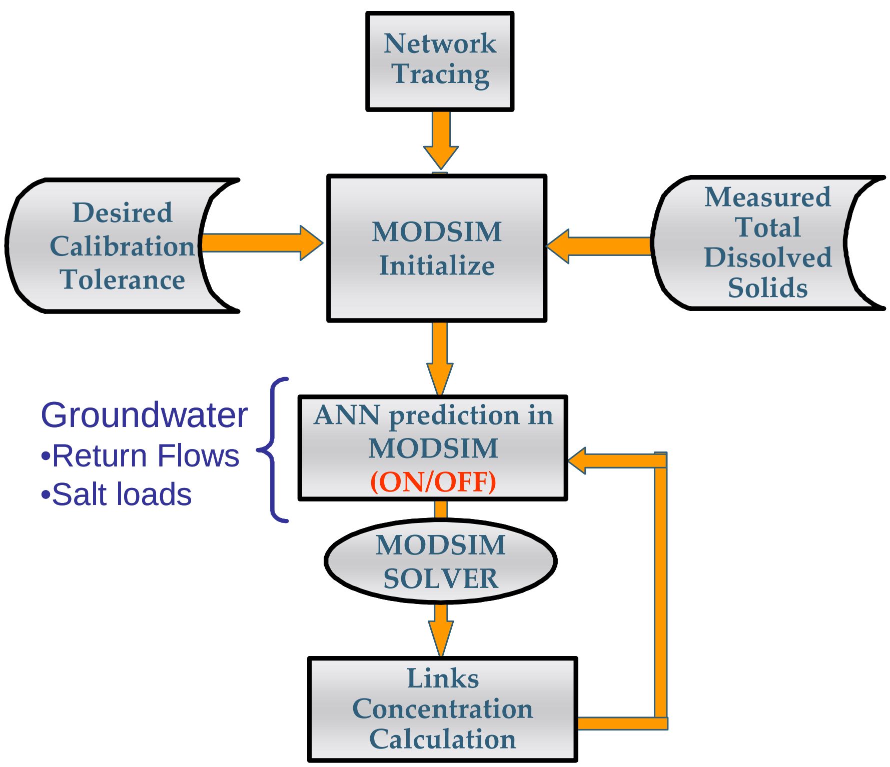


Figure 3.11 – Water Quality Module and MODSIM coupling diagram

Water Quality Module User Interfaces

A set of interfaces are implemented in the WQM to interact with the user. The interfaces allow (1) entering, editing and visualizing water quality input data (Figure 3.12), (2) developing and incorporating in the modeling the concentration vs. flow relationship (Figure 3.13), (3) the setting upper and lower bounds for water quality model calibration based on historical measured values (Figure 3.14-A) and (4) import of time series data from the water quality database for the WQM (Figure 3.14-B).

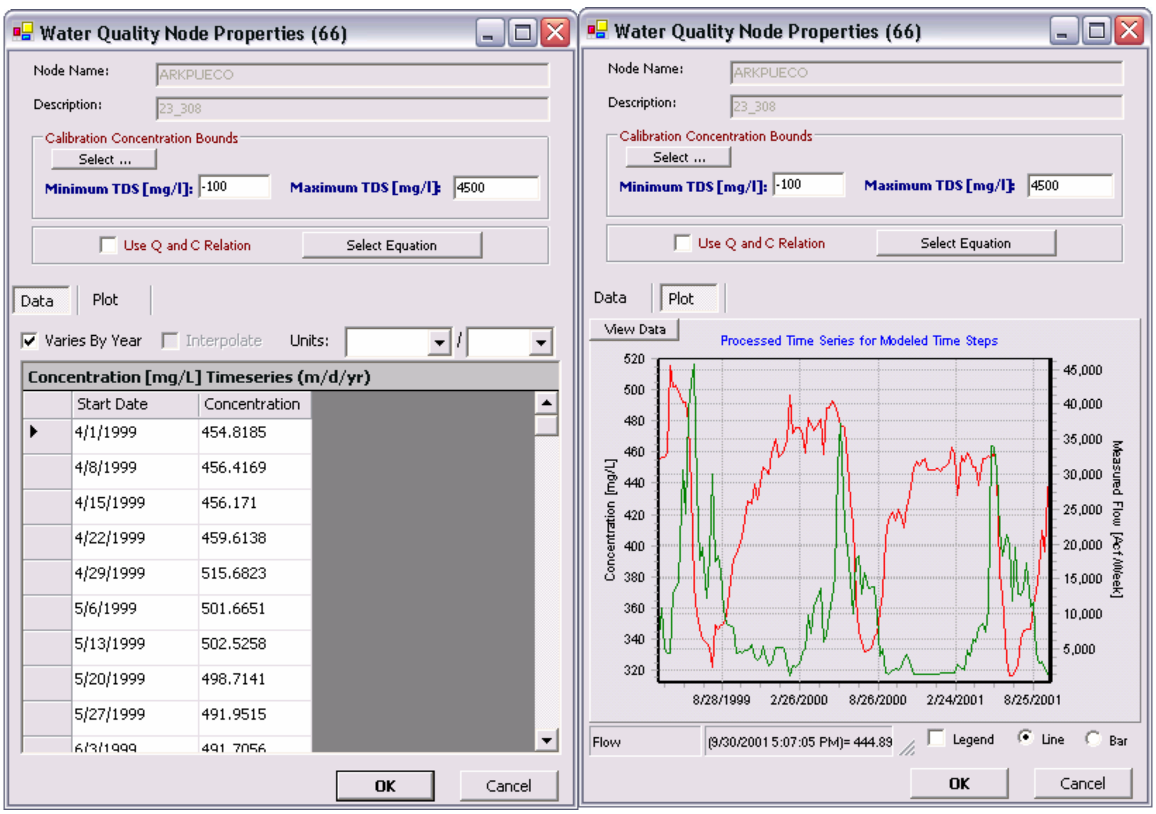


Figure 3.12 – WQM network node user input dialog sample

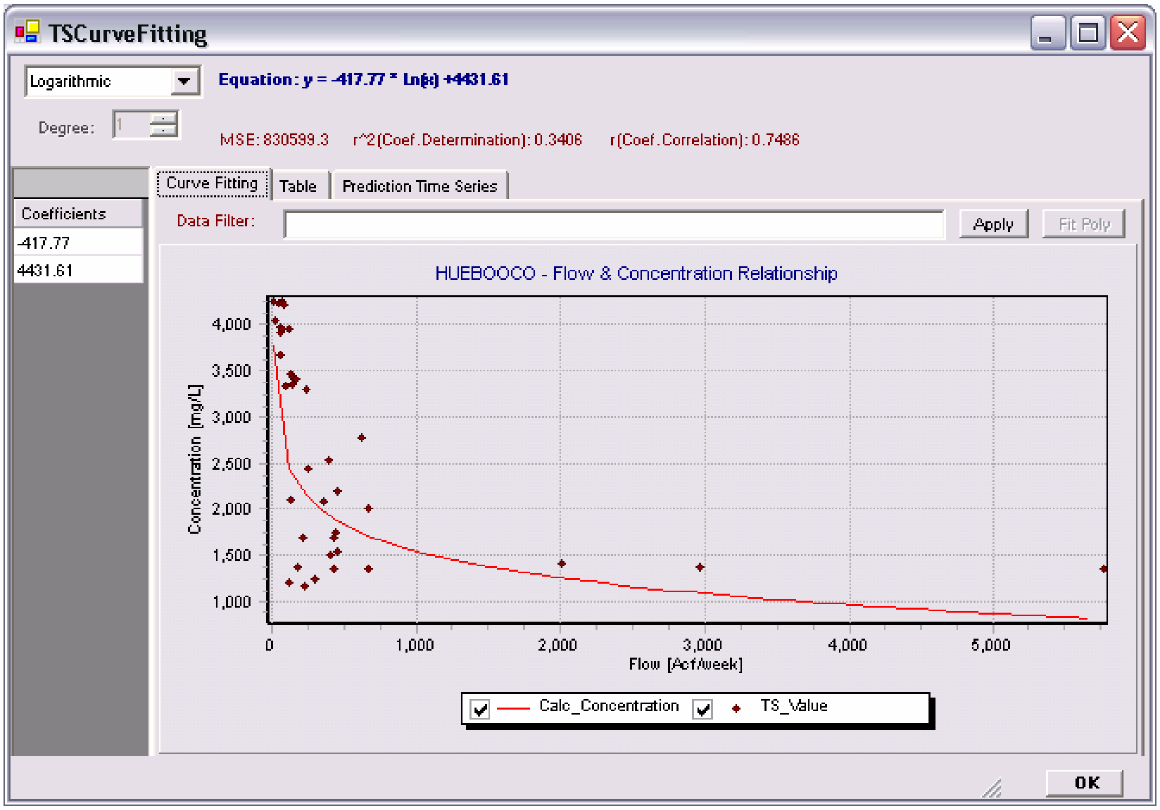


Figure 3.13 – WQM Flow-Concentration relationship user dialog sample

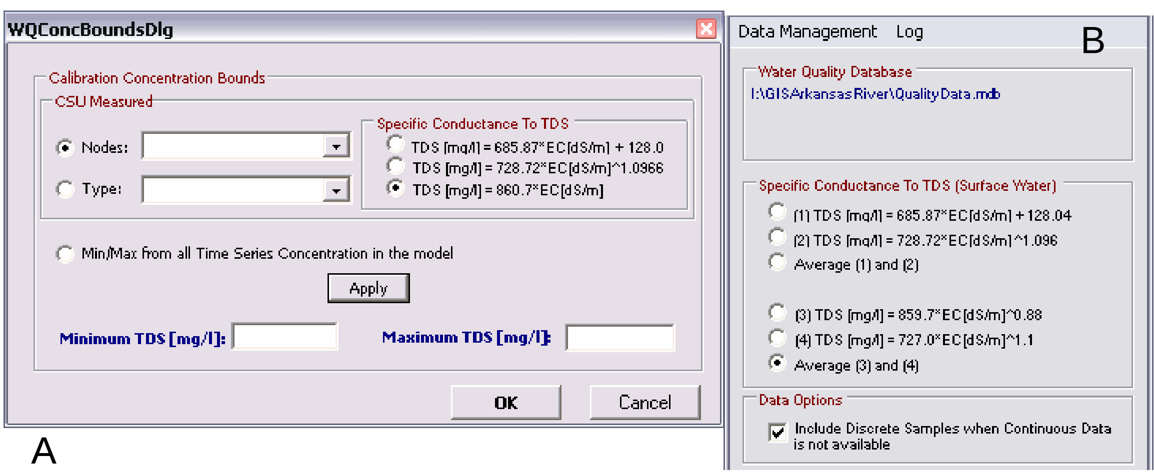


Figure 3.14 – Water Quality modeling preferences and WQ data import user dialog samples

Water Quality Data in WQM

Measured concentrations are imported and processed to be consistent with the simulation time step. Data are usually made available as daily mean concentration, use of larger simulation time steps requires processing of the concentration data. Processed data are stored in a customized MS-Access database associated with the Base-Network name. The imported data are represented in the *River GeoDSS* as a MODSIM style time series (Figure 3.12), where the missing data are filled with the available previous value. Additionally, the available data can be used to fit a regression equation to the available points (Figure 3.13). Basic functionality for polynomial equation regression is provided in the interface, where user defined equations of other types (e.g., exponential, power, logarithmic) can be externally processed and entered using the equation coefficients spreadsheet. When using a regression equation at a gauging station, the equation is used in the WQM to represent the water quality constituent for all time steps as a function of flow. The interface shown in Figure 3.13 allows filtering of the data and provides plots of measured and calculated concentrations and flows. The regression equation preferences are stored in the *River GeoDSS* project Water Quality Database. Description of the data import tool is found in Appendix III – *RIVER GEODSS Water Quality Import Tool*, and details of the structure and characteristics of the WMQ database are found in Appendix IV – *Water Quality Database*.

Network Tracing

The WQM features an efficient network flow tracing algorithm that allows navigating throughout the fully circulating MODSIM network from the physical upstream nodes to the downstream nodes. The network tracing algorithm creates a logical order to calculate mass balance at the system nodes. Details on the tracing algorithm are given in Appendix IV – *Network Tracing Algorithm*.

Water Quality Module Results in River GeoDSS

Combined with the simulated flow results, the user is able, at any location in the system (e.g., river, canals and network nodes), to monitor constituent concentrations. A MODSIM user-defined output is implemented to graphically display concentrations at links and nodes. For nodes, graphs are provided for (1) the concentration at that point in the system as result of the combined concentrations and flows of links flowing into that node and (2) the measured concentration at the system nodes. The WQM output is then embedded in the MODSIM output database and made available to the user through the standard MODSIM output tools. Figure 3.15 shows a sample of the modeled/measured concentration results as displayed in ArcMap™ using the Geo-MODSIM output display tool for a station in the Arkansas River.

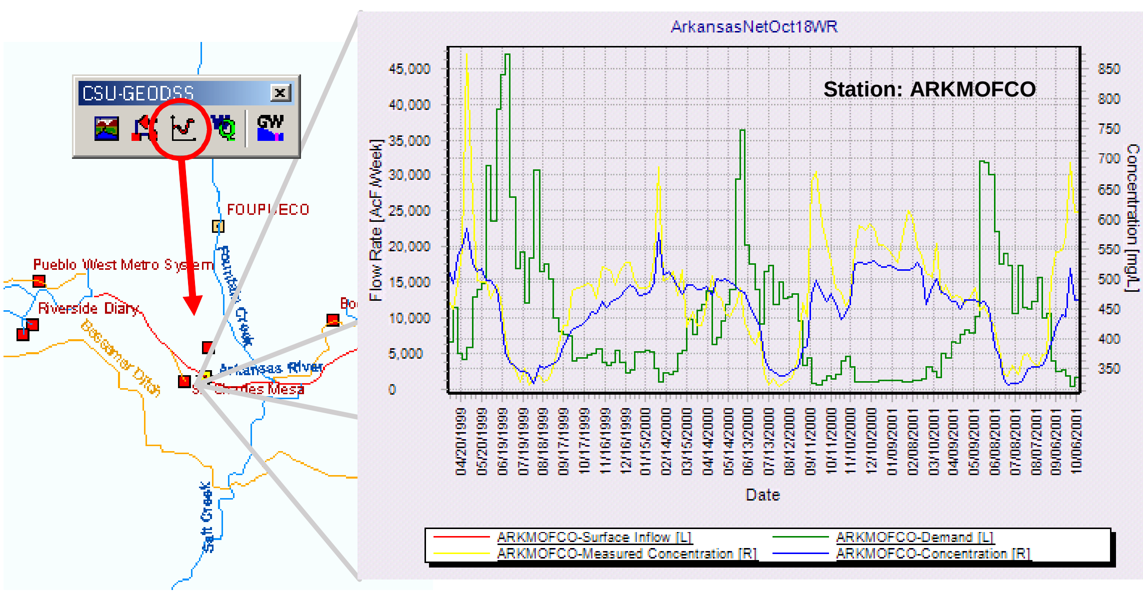


Figure 3.15 – Water Quality results display in *River GeoDSS* example

SIMULATION SCENARIOS MANAGER

This tool allows the user to create, edit and delete simulation scenarios in the *River GeoDSS*; and to select the active scenario for *River GeoDSS* modeling. Each simulation scenario network is constructed from the Base-Network, with containing modeling options such as: (1) quality module activation, (2) stream-aquifer interaction module activation and preferences, (3) run types, and (4) calibration options. Sub-Networks created in this manager are automatically made available in the scenarios analysis module when the *River GeoDSS* project is loaded. Simulation scenario information is then stored in the geometric network geo-database so as to be available as part of the *River GeoDSS* project.

GEO-MODFLOW

River GeoDSS features the Geo-MODFLOW extension as a set of tools that allow querying of the MODFLOW-MT3DMS binary output files based on the geo-referenced model grid in ArcGIS. An ArcMap VBA macro is implemented to create the geo-referenced MODFLOW grid layer in ArcMap. The macro uses the GMS file **.2dg* to extract the cell coordinates and creates polygons to represent the model cells. The field *CellNumber* is populated with the MODFLOW first layer cell number providing linkage between the output files and the geo-referenced cell object. The MODFLOW-MT3DMS output is processed using spatial relationships between the grid cells and other features in the GIS (e.g., MODSIM nodes or links, groundwater modeling grouping areas, and area-buffers). The tool allows summarizing, by geographic features, the elements of the MODFLOW flow budget (Sources and Sinks - Figure 3.16) and MT3DMS concentrations.

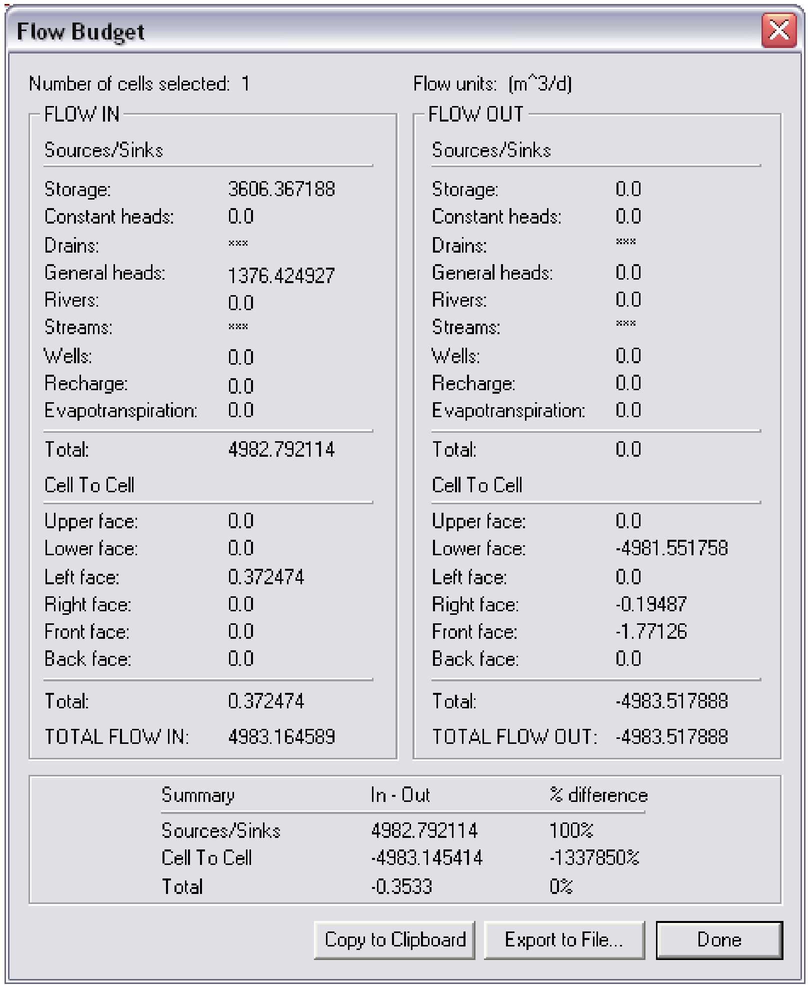


Figure 3.16 – MODFLOW Flow budget in GMS (Environmental Modeling Systems, Inc)

The Geo-MODFLOW *Select Tool* () is available from the *River GeoDSS* tool bar, allowing selection of any single feature in GIS for which Geo-MODFLOW processes and summarizes the MODFLOW-MT3DMS output. In addition, Geo-MODFLOW provides a user interface (Figure 3.17) that allows (1) selecting the component of the flow budget (Figure 3.16) to be summarized, (2) generating combined flow budget summaries for feature(s) currently selected in ArcMap, and (3) specifying the type of spatial relationship between the selected feature(s) and the groundwater model grid. The interface implements six spatial relations between the grid and the GIS features: intersects, overlaps, touches, contains, crosses and within. The user interface is displayed during the loading of the active scenario MODFLOW output files in memory or when the *select tool* is activated.

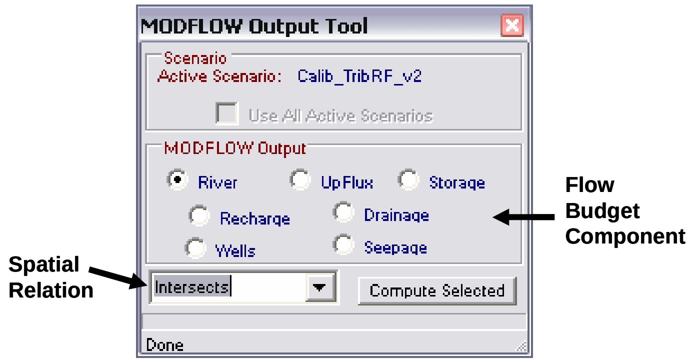


Figure 3.17 – Geo-MODFLOW user interface as displayed in ArcMap™

This tool generates a summary that contains a plot and a table with all summations for all modeled time steps of the selected flow budget component for all the cells that meet the specified spatial relation (e.g., intersect, overlap or touch) with the feature(s) selected in GIS. The output values are grouped in positive and negative values to separate aquifer sources from sinks. The summary includes: (1) Sources and Sinks Flux, (2) Mass, and (3) Concentration. Appendix III – *Geo-MODFLOW Summary Calculation Details* contains the detail descriptions of the generated summary calculations. Figure 3.18 shows the Geo-MODFLOW summary for the aquifer recharge of the selected area in ArcMap.

Geo-MODFLOW implements parallel processing technology to load and process large amounts of data, allowing the user to continue working in ArcMap while the groundwater data are processed or loaded.

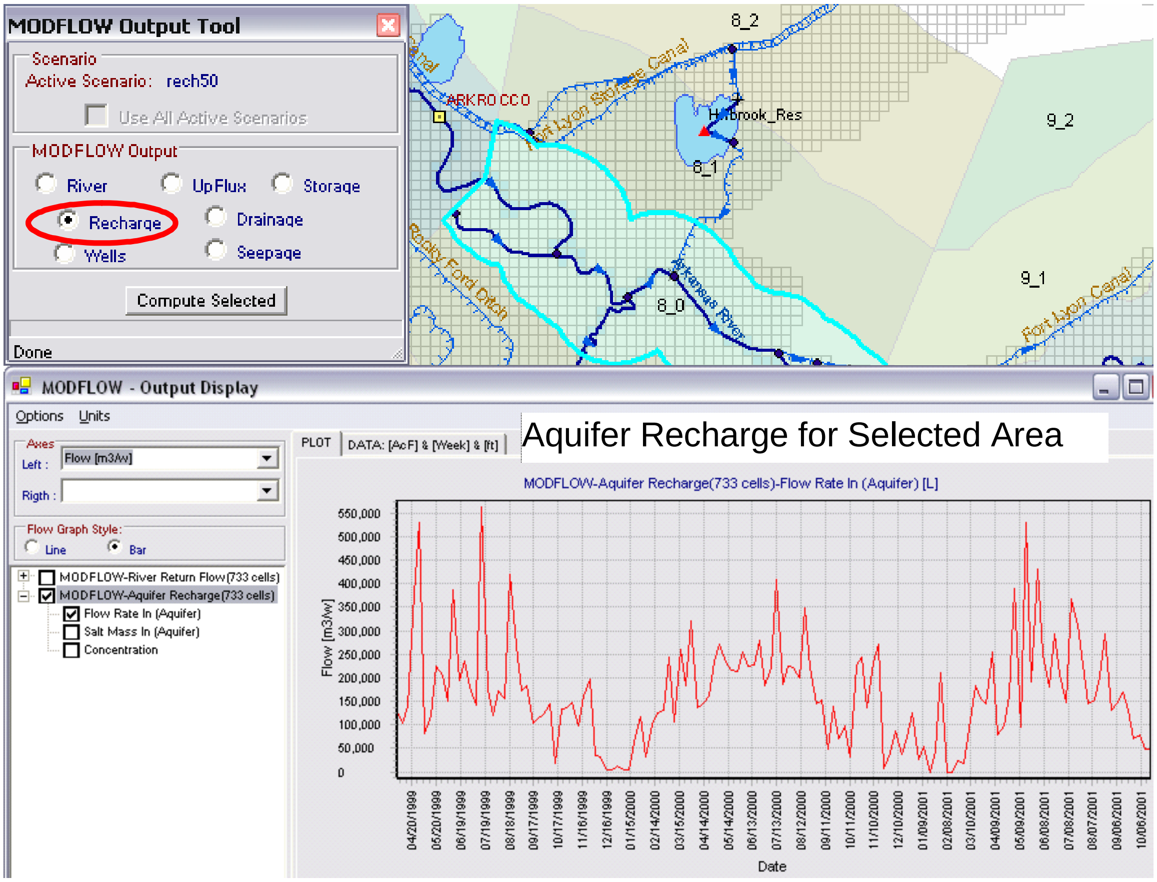


Figure 3.18 – Geo-MODFLOW summary display in ArcMap™

CUSTOMIZABLE INTERFACES AND TOOLS

Customized interfaces and tools have been implemented in the *River GeoDSS* for the Lower Arkansas River basin that illustrate the customization environments embodied in the *River GeoDSS* that accommodate the particular needs of the modeled system. The customized *River GeoDSS* uses the core underlying tools and modules but implementing custom data import and processing tools, network pre-processing and executions. Additions to the user interfaces are easily handled using .NET inheritance, with the *River GeoDSS* base-user interface inherited and enhanced for custom applications.

A custom interface is implemented for the Arkansas River basin modeling. These interface and tools are developed for evaluating and analyzing "what if" management alternatives for salinity and waterlogging remediation. The *LAR GeoDSS* provides a set of tools to import time series and water rights, and handle storage water operations and alternate points of diversion. The *LAR GeoDSS* features a Simulation Scenario Analysis Tool, which builds overall simulation-summaries of the system water quantity and quality for quick management alternative comparison. Detailed description of these custom features, and their application to the Arkansas River basin, is provided in Chapter 6.

SPATIAL OUTPUT DISPLAY

River GeoDSS enhances the standard MODSIM result display/analysis tools with a spatial visualization the modeling results in ArcMap. This tool allows simultaneous display of any MODSIM variable at all the network elements; the results can be animated to observe spatial system changes in the modeled values through the simulated period. The results are color or size coded for each of the objects in the system, so they are spatially displayed for each time step. The spatial representation of the output is a great tool for problem identification and analytical analysis of system operations and can provide information for management improvement. Figure 3.19 shows an example of the spatial result visualization in ArcMap of the Imperial Irrigation District network; where the surface inflow to demand and sink nodes is size coded, and the percent full of canal links is color coded. The *River GeoDSS* interface to control the display options and results animation is also shown in Figure 3.19; in addition, the interface displays the currently displayed time step and date.

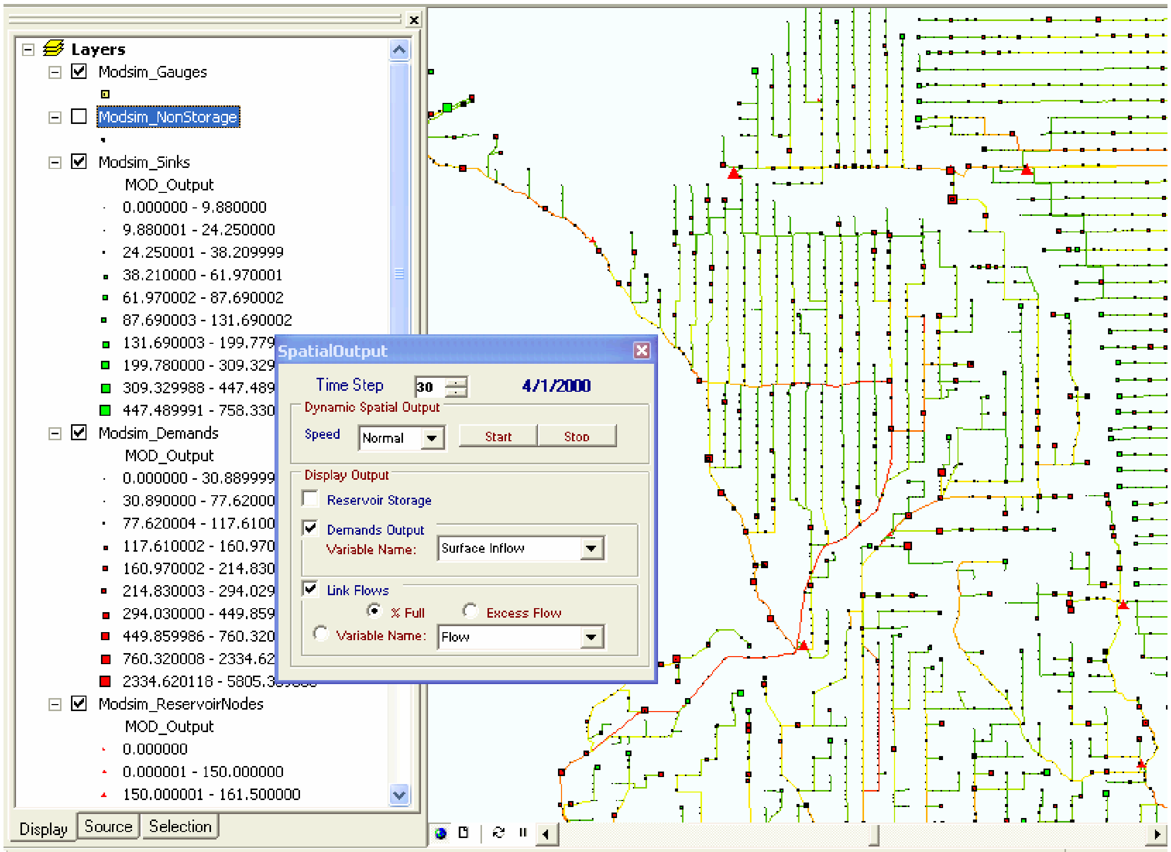


Figure 3.19 - *River GeoDSS* spatial results visualization example in ArcMap™