CHAPTER 8

SUMMARY AND CONCLUSIONS

River GeoDSS, a spatial-decision support system, is designed and developed to assist in the increasingly difficult task of decision making in river basins when simultaneously considering water quantity and quality, along with legal, operational and administrative aspects. The *River GeoDSS* employs state-of-the-art technology, combining existing models and tools (MODSIM, MODFLOW-MT3DMS, MATLAB, ANN and ArcGIS) and creating modules and interfaces to provide the user with a robust decision support environment. The unique feature of *River GeoDSS* is seamlessly combining its modeling and data subsystems in a powerful and fully-featured GIS interface for water quantity and quality conjunctive surface and groundwater modeling, promoting understanding of water system behavior and facilitating the analysis and comparison of water management alternatives.

River GeoDSS integration with native GIS layers allows use of the USGS National Hydrography Dataset (NHD) networks or existing geo-representations of the system to speed up the construction of the modeling system for the *River GeoDSS*. The capability of the *River GeoDSS* to automate many modeling tasks greatly facilitates system calibration and simulation of complex river basin systems. In addition, implementation of the *River GeoDSS* inside the popular ArcGIS environment avoids the need to learn a new interface to create, manipulate and display the modeling system, making the *River GeoDSS* attractive to new users already familiar with ArcGIS.

River GeoDSS is designed with a core functionality that can be used in any open-channel water system, but with the capability for customization to accommodate particular needs, data sources, analysis, and execution modes (taking advantage of MODSIM customization features). The *River GeoDSS* is a generalized river basin modeling tool, thereby providing a framework with basic tools, modules and methodologies to perform geo-referenced conjunctive surface and groundwater basin modeling. Problem-specific customization allows particular needs, data processing and questions to be addressed for each modeled system. It is believed that the *River GeoDSS* customized applications operating within ArcMap make it appealing, useful and easy to use/adopt by decision makers with a wide range of backgrounds. The *River GeoDSS* main components include Geo-MODSIM, Geo-MODFLOW, an ANN module, the Water Quality Module (WQM), and a set of core interfaces and tools.

Geo-MODSIM extends the MODSIM functionality to ArcGIS by separating the links in streams and canals and implementing gauging station nodes. Use of the ArcGIS geometric network to represent the stream system network allows entering and storing information (e.g., terminal interface characteristics, return flow types and flags, capacities, costs, and priorities) in the GIS objects for robust modeling. This enhanced network representation facilitates network transformations for automatic calibration and simulation operations, as well as special modeling features such as the ANN-based stream-aquifer interaction. Geo-MODSIM provides the core functionality to (1) build any MODSIM network from a functional geometric network, (2) access MODSIM dialogs to enter, edit and visualize model data, and (3) display model output in the GIS interface in an object-oriented and spatially distributed fashion.

Geo-MODFLOW is a *River GeoDSS* tool to manipulate and display MODFLOW-MT3DMS modeling results in ArcGIS. The tool geo-references the model grid and links it with the binary output files, providing spatial-query access of the groundwater flow and water quality modeling results. Geo-MODFLOW allows summarizing and visualizing the groundwater flow budget components and salt loading (concentrations) results for any point, line(s) or polygon(s) in ArcMap, as well as programmatically generating training variables for the ANN Module.

The ANN module uses trained ANNs with different structures to be simulated in the *River GeoDSS* to assist in the modeling of complex phenomena. The ANN module relies on external files containing all the trained ANN information to perform predictions. The ANN module provides a set of MATLAB-based custom interfaces to perform ANN training including: (1) data pre-processing, (2) selection of training options, (3) sequential training for semi-automatic structure and parameter selection, (4) post-processing, (5) training results analysis, and (6) trained ANN export for *River GeoDSS* usage. The ANN module is implemented in the *LAR GeoDSS* for stream-aquifer interaction modeling as an alternative to traditional approaches for basin-scale modeling of conjunctive use of groundwater and surface water modeling. In addition, the ANN module is also applied to reservoir salt transport modeling for predicting the salt load downstream of a reservoir in the evaluation of water management alternatives.

The WQM performs conservative dissolved constituent routing in the *River GeoDSS* modeled system. The module includes (1) general interfaces for data entry, visualization and basic regression functionality to predict concentration as a function of flow, (2) a MODSIM network tracing algorithm to determine the network calculation order from upstream to downstream, (3) the water constituent routing tool that accommodates ANN module predictions and integrates with MODSIM for simultaneous water quantity and quality modeling, and (4) storage and display of the module results. WQM stores data in network-based databases, thereby enhancing data sharing and portability for analysis of improved water management alternatives modeling.

The *River GeoDSS* Simulation Scenarios Manager provides files management capabilities and handling of the graphical/tabular comparison of results between the various simulated scenarios. In addition, customized application of the scenario manager allows setting network preferences and operational characteristics to simulate “what if” water management simulation scenarios (e.g., those examined with the *LAR GeoDSS*). The *River GeoDSS* modeling tools simplify the water quantity and quality network calibration, as well as the simulation processes making use of the calibration results.

The seamless integration of the *River GeoDSS* components in both calibration and simulation modes allows state-of-the-art modeling of conjunctive use of groundwater and surface water quantity and quality. The *River GeoDSS* is demonstrated by application to the LARV in Colorado with focus on screening of improved water management alternatives. The *LAR GeoDSS* provides a set of custom tools to build the modeling system from the available data, calibrate the water quantity and quality modules, and simulate "what if" simulation scenarios for evaluation of improved water management alternatives in the LARV. The network calibration automatically computes local gains and losses representing unmeasured components of the river system. These gains and losses are incorporated into the simulation by assuming the same underlying hydrological conditions to evaluate system response to changes in operational rules, agricultural practices, and infrastructure improvements. The water quality calibration enables computation of unknown salt concentrations to match as closely as possible the measured concentrations at selected control points. The unknown concentrations are constrained to maximum and minimum field-observed values in the monitored regions, and the ANN is used to predict salt loading to the river from the aquifer as a known water quality component. Unfortunately, assigning TDS concentrations within the allowed range to inflows lacking measured concentrations limits the ability to control the downstream reach concentration and to match measured concentrations at several control points in the system. The baseline simulation is used to compare relative changes in concentrations during simulation of the water management alternatives, which reduces the impact of the constrained water quality calibration.

The comparative analysis of regional-scale-developed water management alternatives implemented at a basin scale was performed for the LARV using two river system operational modes. The results show that small adjustments and flexibility in the reservoir operation policy are required for implementation of most of the alternatives. In addition, the ability to control the storage and release of additional flows generated by the improved water management alternatives provides noticeable improvement in the overall water quality of the system. This is particularly true when additional water is stored in the reservoirs at the end of the simulation period, since this represents water that could be used during the year to further improve water quality in the system by diluting flows released for beneficial uses. In this ideal operation, impacts on the reservoir operation policy could be less than those presented herein, since water will be released during the year when needed, rather than stored over the length of the simulation period. Further investigation is required to determine if it would be possible to amend the Arkansas River Compact allowing a new account to be created in John Martin reservoir to store water generated by the improvement alternatives implementation, regulate it to improve the water quality in the entire system, and indirectly increase flows at the state line.

The ANN used in the *LAR GeoDSS* for stream-aquifer interaction modeling is trained on a regional-scale groundwater flow and salt transport numerical model to recognize patterns between system state changes (i.e., stresses) in the surrounding areas to the modeled interface and the stream-aquifer interaction. The extracted relationships are applied to predict interactions at the stream-aquifer interface in neighboring non-modeled areas. This ANN modeling approach indirectly captures all aspects modeled in the finite difference groundwater model, including detailed non-saturated zone water and salt transport modeling. In this sense, the introduced methodology does not require simplified assumptions or lumped parameters that are required within many basin-scale return flow prediction methods. In addition, the ANN is trained based on historical stress combinations (i.e., weekly pumping combined with canal seepage and areal recharge) and calibrated aquifer responses. Therefore, the system states used for ANN training are realistic and physically based. The ANN training includes simulated responses from the management alternative groundwater simulations that enhance its ability to predict stream-aquifer interactions resulting from changes to the historical stresses.

ANN prediction from two different system operations showed good agreement between the prediction and the MODFLOW-MT3DMS modeled net return flow and salt loadings for several grouping areas and scenarios. The small ratio between the number of cases used in training and those used in testing indicates that the ANN has developed strong relationships between the explanatory variables and the predicted variables by predicting with good accuracy a larger number of cases outside of the training datasets. The *LAR GeoDSS* stream-aquifer interface modeling at the basin scale approximates “reasonable” return flow and salt load values according to historical surface system observable characteristics. Evaluation and analysis of flow predictions over the improved water management scenarios indicate their consistency with respect to the baseline conditions. Although the predicted TDS concentrations show discrepancies between the baseline as modeled in MODFLOW-MT3DMS and the *LAR GeoDSS*, the small magnitude of the percent error is not expected to be significant in the overall process of screening alternatives. The stream-aquifer modeling approach introduced herein reveals a promising alternative path for basin scale conjunctive surface groundwater modeling, especially in the evaluation of “what if” scenarios.

As found in the literature reviewed, the ANN is positively influenced by the “memory” provided by the usage of previous observations as explanatory variables. The *LAR GeoDSS* stream-aquifer interaction modeling using the ANN is tested though simulation, where the ANN predictions are used as previous observation explanatory variables in the prediction. In this situation, there is the possibility of jeopardizing the prediction by sequential accumulation of prediction errors. The ANN priming to find a good starting prediction point seems to be a key instrument in developing stable ANN predictions. Even though larger errors are observed during simulation than during the ANN testing, the overall predictions in the simulation seem to be in agreement with the order of magnitude and distribution of the MODFLOW-MT3DMS modeled data. Comparison of the aquifer net return flows and the total net gains from surface water measurements suggests an over-prediction tendency in the *LAR GeoDSS* ANN predictions. Finally, embedding the ANN within the basin scale decision tool eliminates the computational burden of directly incorporating realistic finite-difference models such as MODFLOW-MT3DMS over the entire basin.

The screening of water management alternatives using the *LAR GeoDSS* leads to identification of infeasible management alternatives based on exhaustion of water in the reservoirs at the end of the simulation, significant water shortages, and Arkansas River Compact violation. Feasible water management alternatives with the larger reduction in areal recharge and canal seepage in the operational mode B, such as *Rech80Seep90*, *Rech80Seep90Drain50* and *Rech90*, showed the largest potential to improve conditions in the basin. The improvement potential is evaluated based on amount of water stored above historical levels in the reservoirs, and in reduction in TDS concentrations at diversions and at the Kansas-Colorado state line.

In summary, the *LAR GeoDSS* is a unique decision support tool for evaluating the benefits and feasibility of regional-scale improved water management alternatives, in which the scenario approach applied here provides a solid framework for comparison of water management alternatives, thereby reducing the effects of calibration and simulation errors in the analysis. The *LAR GeoDSS* is a prototype system that could provide the basis for the proposed State of Colorado Arkansas River basin decision support system.

FUTURE IMPROVEMENTS AND RESEARCH IDEAS

RIVER GEODSS ENVIRONMENT

Implementation of the *River GeoDSS* in Other GIS Environments

Although, ArcGIS™ is the most widely used GIS package in the world, the need to acquire expensive licenses is still an obstacle for targeted *River GeoDSS* users with little experience in GIS. The cost of the ArcView™ as a minimum requirement for GIS functionality in the *River GeoDSS* may also be too high for many users. In these cases, it would be ideal to support the *River GeoDSS* under different GIS platforms with low cost licensing requirements. A strong candidate is *MapWindow*™, an open source programmable GIS system (http://www.mapwindow.com/) which has an actively growing user community. The implementation can be designed to use the underlying files and modules currently utilized in the *River GeoDSS*, allowing a *River GeoDSS* project to be used across GIS platforms. The *MapWindow* GIS environment does not require a purchased license as the ESRI products do.

River GeoDSS Online Interface

An online version of the *River GeoDSS* would facilitate its accessibility for a larger group of interested users. A *River GeoDSS* viewer can be designed to provide decision making support, information, and enhanced understanding of a river basin. In addition, feedback from a larger group of beta users could provide a substantial contribution in guiding future enhancements and tool developments.

Water Quality Module Expansion

The current *River GeoDSS* Water Quality Module only deals with routing of conservative solutes, and is specifically designed for salt transport modeling only. Future work should expand the water quality modeling capabilities, building on the current structure and tracing utilities, to implement chemical reactions and other processes throughout the network for potentially non-conservative constituents. Complex water quality modeling could also be accomplished by coupling the *River GeoDSS* with link-based water quality models such as QUAL2E.

River GeoDSS Data-Management Tool Improvement and Time Series Database Improvement

Improvements to the core *River GeoDSS* functionality can include a data import tool that implements the most common sources of data, e.g., USGS and CDWR. The *River GeoDSS* data could be updated using data available on USGS web links and CDWR databases. Dynamic linkage with data sources could automate the population of time series, water rights, and even system characteristics. This automation would not require local management of data and could facilitate *River GeoDSS* usage in the future. The structure of the time series database can be revisited to make its implementation easier and dynamic for future *River GeoDSS*s. Use of HydroIDs is cumbersome, and better results could be obtained using the native HydroCode that is used in the downloaded data. New technologies such as the Network Common Data Form (*NetCDF*) supported in ArcGIS 9.2

should be explored as alternatives to efficiently managing time series data in GIS-based systems.

Implementation of Time-Variant Water Rights Tool

Water rights change over time due to abandonment, transfers, sales, exchanges, etc. The current water rights utility processes the transactions to bring them up to date transactions in the river basin simulation. A time-variant water rights analysis tool is proposed for accurately performing long-term historical simulations where water rights might have been active at some point but are currently inactive. The tool would require the use of water rights time series data, which are not currently handled by the MODSIM water rights utility.

Improvement in the *River GeoDSS* Network Update

At this stage, the *River GeoDSS* includes an inadequate algorithm for capturing changes in network topology in the geometric network and translating those changes into the MODSIM network. It is proposed that the algorithm be updated to allow capturing changes in the system topology and accommodating these changes in the MODSIM modeling system without the need to regenerate the network.

LOWER ARKANSAS RIVER GEODSS

Stream-Aquifer Interaction Modeling Enhancement

Additional passes of the simulation-training procedure could be implemented to refine the simulation-dependent explanatory variables such as canal diversions and river flows, as well as including surface water quality related explanatory variables that indirectly provide information about salt loadings to the soil from irrigation activities. Location of the prediction within the basin should be accounted for since noticeable salt concentration changes are registered from upstream to downstream. Additional explanatory variables can be introduced that directly account for relative changes in the original explanatory variables between previous and current time steps, providing additional "memory" to the prediction process; however, difficulties related to the initial conditions for simulation are anticipated. Incorporation of other variables related to alluvial aquifer properties, such as hydraulic conductivity and aquifer thickness, should be considered.

Improvement of performance in predicting return flow and TDS concentration in the tributaries should be explored in future improvements of the *LAR GeoDSS*. Better performance could be achieved by incorporating additional or new explanatory variables that could capture system stress changes in area-buffers around the tributaries, building area-buffers for tributaries in a fashion similar to that for the main stem in the current explanatory variables processing. In addition, defining individual grouping areas around each tributary might improve the resolution of the tributaries predictions, especially for current cases where different size tributaries are located in the same grouping area.

Introducing system stresses from upstream of the grouping area could provide additional information to explain return flows. This could be achieved by using the already calculated explanatory variables or defining new buffers that partially cover the neighboring region of the upstream grouping area. Additional improvements to the stream-aquifer interaction could be achieved by developing additional explanatory variables to capture quality aspects of the basin and the aquifer.

It is believed that additional MODFLOW-MT3DMS modeled areas (downstream of John Martin Reservoir regional model) will greatly enhance the ANN training dataset by providing a wider range of geometries and therefore historical conditions and aquifer responses. Another enrichment of the training dataset can be achieved by extending the modeled time period of the current MODFLOW-MT3DMS modeled area by providing responses under different hydrologic and climatic regimes. Tributary return flow and salt load predictions could be improved by adding explanatory variables that provide information regarding the size of the tributary and frequency of flows.

Since the ANN is duplicating the MODFLOW-MT3DMS response, improvements in groundwater model calibration, especially improvements in the surface flow calibration, should consequentially reduce the uncertainty in the evaluation of water management alternatives. Improvements to the MODFLOW-MT3DMS model such as the use of NEXRAD spatial precipitation estimates can greatly enhance the information provided to the ANN by these precipitation explanatory variables. Currently, there is only one available pumping scenario modeled in MODFLOW-MT3DMS. Additional modeling of vertical drainage scenarios should provide the ANN with better foundation to make consistent predictions of this scenario type.

Groundwater Modeling Improvement Using Surface Water Modeling

A dynamic interaction between the MODFLOW-MT3DMS models and *LAR GeoDSS* could be implemented to provide the modeler with tools to check modeled return flows against the unmeasured gains and losses computed in the surface system water balance between gauging stations, allowing a more refined MODFLOW-MT3DMS flow calibration. In addition, *LAR GeoDSS* simulated TDS concentration at water diversion points can be used to improve the MODFLOW-MT3DMS simulation, providing more realistic estimates of the salt applied to the soils by irrigation within the water management alternatives.

Management Alternatives Modeling Improvements

Modeling the management alternatives could be improved for more accurate evaluation of the alternatives in the following aspects.

Refined Description of Areal Aquifer Recharge as Affected by Irrigation Application Efficiency

Application efficiency could be represented as a function of the canal command area, location, time or available flow. A more flexible and varied application efficiency is proposed to be implemented in the *LAR GeoDSS*, where the efficiency term could be associated with each canal command area, thereby affecting refined reduction in areal recharge to the aquifer.

Reservoir Layer Balancing Improvements

The reservoir layers used to model system storage should be improved for more realistic simulations. The current storage zones or layers defined for John Martin Reservoir and Pueblo reservoir result in operations with extremely low volumes to be stored in John Martin Reservoir due to the layers design to store water as high in the system as possible. More realistic reservoir operational policies can be custom-coded into MODSIM to handle this situation. Interviewing the reservoir operators could guide improved representation of the operating rules towards more realistic simulations.

Refinement of Sub-Surface Drainage Alternative Modeling

The sub-surface drainage alternative modeling should be improved for better prediction of drainage water back to the river system. The drained volume is returned to the surface water system more rapidly than if it travels through the aquifer porous media. The improved prediction of drainage water will allow better evaluation of the performance and feasibility of these alternatives. The existing stream-aquifer interaction ANN could be enhanced, or a similar modeling approach used, to predict drainage water for the groundwater grouping areas. The drainage water can be distributed among the river nodes in the grouping areas in a similar fashion to the vertical drainage scenario.

ANN Improved management alternative modeling

ANNs can be used to improve predictions of modeling components that directly affect system water availability in the basin scale modeling such as canal seepage estimation and actual irrigation induced aquifer recharge.

Improved Estimation of Areal Aquifer Recharge

Estimation of areal aquifer recharge from overirrigation could be refined by using the MODFLOW-MT3DMS output to train an ANN that predicts aquifer recharge based on the system state and the management scenario characteristics, enabling the ability to predict more accurately the areal aquifer recharge volume, that is currently calculated as a function of the canal diversion.

Improved Seepage Prediction

Indirect changes in canal seepage caused by other management alternative components can be captured from the MODFLOW-MT3DMS output. An ANN-based method is proposed to model the changes in seepage during the detailed MODFLOW-MT3DMS modeling. The ANN could predict canal losses for simulation of both the baseline and those management alternatives that do not include explicit calculation of seepage reduction.

Diversion Reduction Algorithm Improvement

Improvement in the *Simulation Scenario Manager* tool that adjusts system water demands is proposed. Since some of the improved water management scenarios specify increased efficiency in water usage, it is likely that less water will be needed from storage contracts before direct flow diversions are reduced. Since the storage contracts are modeled as high priority links, historical diversions from storage contracts should be reduced at the same time that node water demands are reduced.

Time Series Improvements

An improvement in the Geo-MODSIM time series management module would involve moving MODSIM time series data to a database management system that provides more flexibility, control, and tools to analyze and enter data into the MODSIM objects. The time series database implemented for the water quality module could be expanded to achieve this goal. In addition, linkage or usage of third party time series managers should be explored to enhance flexibility and attract more users. Some available time series managers that could be considered include: the DHI Temporal Analyst (http://www.dhigroup.com/Software/WaterResources/TemporalAnalyst.aspx) and the U.S. Army Corps of Engineers (HEC-DSS) time series database management systems.

Finally, time series processing tools should be implemented in the *LAR GeoDSS* for filling gaps in data, providing statistical and forecasting information. This functionality could be added by linking *LAR GeoDSS* with existing tools such as CSU-SAMS (Sveinsson et al. 2003).

Improved Modeling of Water Carrier Structures

An additional implementation is required to discourage usage of canal diverted flows by in-canal demands, forcing the in-canal demands to fully utilize the diversion structure bypass link (described in Chapter 6) as their water supply. This implementation will require changes to the network cost structure and a custom code to transform the terminal interface modeling from low priority sinks to high priority demands so that they are able to retain the diverted flows in the canal links until the end of the canal.

Canal Seepage Losses Simulation Improvements

The original assumption of a basin-wide seepage loss reduction coefficient should be relaxed by including detailed data from the canal seepage loss field studies, where available. This process might require including more complex seepage functions that are conditioned on canal flow rates, pre-existing conditions, and soil profile characteristics. The *LAR GeoDSS* data-model and spatial representation of the system will be extremely useful for this implementation. Canal seepage characteristics could be defined at high resolution (by link) and combined to be included in the basin water demand calculations. These algorithmic improvements can lead to better model alternatives for simulating the impacts of lining sections of canal systems. Since the return flows are spatially affected by the lined sections, the data-model could be updated to hold seepage loss reduction coefficients for each link in the system where changes in seepage characteristics are introduced. The algorithm to capture seepage-related explanatory variables will have to be improved in order to accommodate the link-based seepage characteristics.

Unmeasured Tributary Flow Estimation

It is believed that unmeasured tributary flows are a large fraction of the total unknown gains to the system. Estimation of tributary flows requires a robust predictor since the phenomenon is intermittent and depends upon surface runoff as well as upon groundwater contributions. An ANN-based model using NEXRAD spatial precipitation, other system stresses and physical characteristics of the sub-watershed as explanatory variables could provide valuable predictions reducing the unknown gains in calibration. Tributaries with measured flows can be used for training and testing to develop predicting models for other tributaries. Tributaries could be grouped by size and similar characteristics to guide the flow predictions. Challenges are expected for modeling small tributaries, usually with sparsely-measured data, that will not have a rich training and testing dataset.

Optimal System Operation to Meet Water Quality Goals

Reservoir operations could be optimized to meet water demands and to minimize deviations from water quality targets. Using an iterative approach, the system could be modeled by the *LAR GeoDSS* and optimized with the CSUDP dynamic programming algorithm until convergence to a solution. The optimization results would take into account the conjunctive use of water in the basin, as currently modeled in *LAR GeoDSS*. Successful linkage of MODSIM and CSUDP for including dynamic programming in optimal reservoir operation design (Triana and Labadie 2000; Uematsu 2007) can be used as platform for this improvement.

System Operation under Restricted Operational Policies

Additional simulations of the system assuming restricted usage of a particular in-stream reservoir could be useful in negotiation of a win-win situation for all parties involved in the

Arkansas River Valley operation. For example, assuming that the Arkansas River Compact cannot be modified, a system simulation that maintains historical volumes to the compact accounts provides information about the feasibility and expected improvements if only Pueblo Reservoir is available for regulating water generated by the management alternatives implementation.

Detailed Modeling of Complex Water Storage Operations

Initially, a custom tool can be implemented to summarize storage water use for reservoir water accounting. This interface would be based on information stored in the *F* field of the CDWR diversion records database, which indicates the source of the storage account. The MODSIM output can be combined with the storage owner modeling links to generate reports of storage water use per owner.

The modeling of storage accounts can be implemented to allocate supplemental water for users holding both natural flow water rights and storage account ownerships. It is recommended that improved diversion modeling be implemented whereby diversion nodes could be bypassed to enable storage of water in the off-stream reservoirs. Initially, the carrier links could be set with upper bounds corresponding to the historical diversions. Stored water should be allocated to the storage ownerships using storage accounting mechanisms available in MODSIM.

Refining Water Quality Modeling

It is highly desired to improve the TDS concentration predictions for those periods where there is a lack of measured concentration data. A more robust method should be implemented to improve the prediction performance by regionalizing the water quality regression equations to predict concentrations at stations with limited numbers of observations. Alternatively, an ANN could be trained with sets of explanatory variables that capture more conditions for predicting concentrations. This implementation could be investigated by basin, region, or individual stations.

Use of equations for converting EC to TDS can be improved by implementing the use of zonal equations to import the water quality data. New relationships could be derived for specific points in the basin where more accurate TDS values are needed (e.g., water quality at the Colorado-Kansas state line).

Efforts should be made to incorporate other solutes of interest into the model, such as Se and U. This will require the inclusion of these constituents in the MODFLOW-MT3DMS model and associated ANN.

Extending the Modeling to the Arkansas River Head Waters

The current extent of the *LAR GeoDSS* could be expanded to include the portion of the Arkansas River Basin in Colorado upstream of Pueblo Reservoir. This process will require development of additional groundwater models or methodologies to implement conjunctive use modeling in areas with significant change in system characteristics. This improvement will allow a comprehensive basin-wide management analysis with improved conditions upstream directly influencing the initial environmental conditions downstream and also comprehensive analysis of the water rights in the basin for development of operational strategies aimed toward implementation of the water management alternatives.