APPENDIX III

RIVER GEODSS USER SUPPORT

This section provides detailed information of the *River GeoDSS* components and procedures to provide the user with in-deep exposure to details in the *River GeoDSS* implementation and usage.

GEO-MODSIM DATA-MODEL DESCRIPTION

This section describes in detail the Geo-MODSIM data-model components and fields. A Geo-Referenced data-model (see Figure 3.4) was designed and implemented to support the integration of MODSIM and the GIS geometric network. A feature dataset called "*MODSIM_Network*" holds the elements of the geometric network. The geometric network is implemented with Simple Edges - Simple edges are always connected to exactly two junctions, one at each end. Point and line type feature classes hold the elements of the network grouped by the MODSIM object types. The data-model geometric network is created combining these feature classes bringing together all the system elements available in the geo-database. The data-model adopts the ArcHydro (Maidment 2002) *HydroID* concept, which identifies each element in the network with a unique number. All the feature classes' *HydroID* fields are populated with this unique identifier using the ArcHydro tools. This section is focused on the basic fields and the custom field created for the *LAR GeoDSS*. As a rule of thumb, fields prefixed *MOD_* are processed to generate the model input variables. There are common fields for all the feature classes. The following fields are available in all the feature classes:

- *HydroID*: unique identifier for all the objects in the network.
- *MOD_Output*: field used by *River GeoDSS* for spatial output display. This field is populated automatically during the spatial output display feature form the MODSIM output database. It can be used for analysis on a time step basis using the Spatial Output Display tool to populate it for the time step of interest.
- *MOD_Name*: contains the unique name for the MODSIM object. This name can be assigned before creating the network if there are objects that have a pre-defined name; otherwise, it will be automatically assigned during the MODSIM network generation. **It is highly recommended that once the MODSIM network is created the user do not edit this field because can corrupt the *River GeoDSS* project**.
- *MOD_Cost*: this field holds link costs in the data-model. These values can be transferred to the MODSIM objects using the Geo-MODSIM interface menu items (*Tools→Load DataModel Data*).
- *MOD_Number*: This field is populated during the MODSIM network creation in Geo-MODSIM. **This field should not be edited by the user at any time**.

Geometric Network Edges

Two feature classes constitute the geometric network Edges: (1) the Modsim_Canals feature class and (2) the Modsim_Streams feature class. Common fields for the edges feature classes are:

- *FlowDir*: text field indicating the link direction of the flow. This field allows batch-resetting of flow directions in the network using the ArcHydro tools. This field can be populated manually or using the flow direction tools in ArcHydro.

- *Edge Type*: this field is populated with a text to flag artificially created links with the word "*shoreline*". Null values indicate default canal links and "*Flowline*" indicates streams imported from NHD dataset.

- *ANNReturn*: [True/False] field defined for the line type object, indicating if return flow will be calculated at the *to-node* of the link. This is field is commonly empty for canal links.

Modsim_Canals Feature Class

The *River GeoDSS* fields specific for this feature class are:

- *MOD_USG*: [0/1] binary field indicating if the node is active in MODSIM.

DemandID: links populated with this value indicate diversion water conveyance for the entered demand node *HydroID* number.

Modsim_Streams Feature Class

ARK_ReturnType: this field is customized for the Arkansas River modeling. It represents the type of return flow to be calculated on the links flagged to have return flow. The return flow is modeled at the *to-node* of the link. The "*Main_River*" flag triggers the use of the ANN trained for the Arkansas River, the "*Tributary*" flag triggers the usage of the ANN trained for the Arkansas Valley tributaries.

Geometric Network Nodes

Six feature classes are used to represent the geometric network nodes: Modsim_Demands, Modsim_Gauges, Modsim_NonStorage, Modsim_ReservoirNodes, Modsim_Sinks and the automatically created MODSIM_Network_Net_Junctions. The MODSIM_Network_Net_Junctions are usually default nodes in the network (where no other node was defined). The other network nodes usually are manually edited by the user. Common fields to the node feature classes are:

- *BufferID*: text field representing the grouping area (*G*) and the area-buffer number (*B*) where the node falls in. The format is "*G_B*". Null values are allowed for nodes outside of the area-buffers.
- *MOD_Cost*: holds the node priorities for the MODSIM nodes in the data-model. This value is imported to the MODSIM objects using the Geo-MODSIM tools (*Tools→Load DataModel Data*).

The Modsim_Sinks feature class doesn't have additional fields. Specific fields for each of the other MODSIM node feature classes are described next.

Modsim_Demands Feature Class

- *WD*: is the number corresponding to water district assigned to diversion structure by the Colorado Division of Water Resources (CDWR).
- *CODE*: diversion structure identifier assigned by the Colorado Division of Water Resources.

- *TotIrrgArea*: user calculated irrigated area. This value can be populated from the irrigated fields map using the "*Names_*" field to relate the parcels polygons. Its value is in squared meters.
- *TotCanalLength*: user calculated length of the canal downstream of the diversion structure. This value is stored in meters.
- *MOD_SeepCoeff*: contains the assumed baseline average channel loss coefficient ($\bar{s}$) that multiplied times the diversion will approximate the total volume seeped along the length of the canal.
- *MOD_RechRed*: contains the active recharge reduction factor. This field is populated at run time by the management scenario manager with the active scenario values.
- *MOD_AdjSeep*: holds the processed canal seepage coefficient adjusted to the active scenario such that multiplied time the scenario flow results in the targeted baseline seepage reduction.
- *MOD_AddPumping*: Additional pumped value for the active time step and scenario. This field is updated at run time for the active time step.
- *MOD_DiverRed*: holds the calculated diversion reduction for the active time step.
- *MOD_BaseOutput*: Baseline run diversion for the active time step. This field is populated at run time for the active time step.
- *MOD_BaseSeepOut*: baseline run total seepage calculated for the diversion along the conveyance length.

Modsim_Gauges Feature Class

- *HydroCode*: identifier assigned to the station. The field is type text and contains the USGS sequence of numbers that identify the station or the CDWR structure name (letters).

- *GaugeID*: station identifier for the time series database. This value corresponds to the node's *HydroID*. The *GaugeID* field needs to be updated to represent only the stations that contain data. It can be populated copying the HydroIDs for nodes where *Calib_Active="YES"*.

- *Calib_Active*: [Yes/No] field indicating if the node is active during calibration; therefore, a calibration structure will be created around the node.

- *UPS_Source*: [Yes/No] field indicating if the node will be use as a source of the system (the most upstream stations will be flagged with "YES").

- *Ark_CalibRelevance*: relative value used in Geo-MODSIM calibration to set cost on the calibration links, giving priority to provided calibration flows to the nodes assigned with higher relevance.

Modsim_ReservoirNodes Feature Class

- *Capacity_AF*: capacity of the reservoir in acre-ft. This value is imported to the corresponding MODSIM nodes using the Geo-MODSIM data import tools.

- *WD*: is the number corresponding to the water district assigned to a diversion structure by the Colorado Division of Water Resources (CDWR).

- *CODE*: diversion structure identifier assigned by the Colorado Division of Water Resources.

- *MODSIM_Status*: [Active/Inactive] flag that triggers the setting of the targets to enable/disable the storage of water in a reservoir. The *River GeoDSS* populates the reservoir targets time series with zero when the reservoir is *Inactive*.

Modsim_NonStorage Feature Class

- *ARK_Type*: indicates the type of node for network adjustments. This node can be a "*regular node*" in which case the resulting node will be a non-storage node. The "*Terminal Interface*" and "*Reservoir Interface*" nodes will be transformed to a flow-through demand node with the value in the field "*ARK_ReturnFraciton*" specified as the operational flow that flows downstream. Reservoir Interfaces are located at the end of canals where they flow into a reservoir. These nodes allow storing in the reservoir a fraction of the water in the canal.

- *ARK_ReturnFraction*: fraction returned to the system as a result of operational flows at the end of the canals.

GEO-MODSIM SYNCHRONIZATION TABLES

A set of tables are used to synchronize the GIS geometric network and the MODSIM Network. This section describes these table features. Three tables are used to synchronize and support operations that involve linkage between MODSIM and GIS objects.

The first table is named *MODSIMInfo*, it contains information regarding the active network file path, the active scenario, the status of the dialog [open/closed] and a list of network for which alternate points of diversion has been adjusted. The user is discouraged to alter/edit this table at any time; doing so, could end up in malfunctioning of the *River GeoDSS*.

The second table contains relational information between nodes in the MODSIM network and the geometric network. This table is named *MODSIM_SYNC_Network_NODE*. The table fields are:

- *NodeNo*: MODSIM node number.
- *NodeName*: MODSIM node name
- *ClassID*: internal identifier of the feature classes the ArcMap project. This number is assumed does not change during the live of the project; however, layer manipulation in ArcMap might result in changes of this identifier.
- *OID*: internal number that identifies the object in a feature class.
- *NodeType*: MODSIM node type. It can be *Demand*, *Non-Storage*, *Reservoir* or *Sink*.
- *X*: x axis coordinate (longitude) from the geo-referenced object. This value is used to resolve inconsistencies in the sync process.
- Y: y axis coordinate (latitude) from the geo-referenced object. This value is used to resolve inconsistencies in the sync process.
- *WD*: is the number corresponding to water district of a diversion structure assigned by the Colorado Division of Water Resources (CDWR). Used for demand nodes with diversion records.
- *StructureID*: diversion structure identifier assigned by the Colorado Division of Water Resources. Used for demand nodes with diversion records.

- *GaugeID*: HydroID value for demand nodes that play the role of gauging stations, all other nodes will have a null value.

- *Calib_Structure*: text combining the *Calib_Active*: and *UPS_Source* flags for gauging stations.

- *BufferID*: text field representing the grouping area (G) and the area-buffer number (*B*) where the node falls in. The format is "*G_B*". Null values are allowed for nodes outside of the area-buffers.

- *HydroID*: shallow copy of the node object's *HydroID.*

The following fields are used to create multi-links and bypass links in the MODSIM network.

Orig_DSNode: Name of the original (geometric network) downstream node. It is populated, during the creation of the MODSIM network, only when a single node is located upstream.

Orig_UPNode: Name of the original (geometric network) upstream node. It is populated, during the creation of the MODSIM network, only when a single node is found downstream.

The third table contains relational information between links in the MODSIM network and the geometric network. This table is named *MODSIM_SYNC_Network_LINK*. The table fields are:

- *LinkNo*: MODSIM link number.

- *Name*: MODSIM link name.
- *ClassID*: internal identifier of the feature class in the ArcMap project.
- *OID*: internal number that identifies the object in a feature class.
- *FromNode*: name of the MODSIM node upstream of the link.
- *ToNode*: name of the MODSIM node downstream of the link.
- *NetEID*: geometric network unique identifier for the link.
- *ANNReturn*: copy of the ANNReturn flag in the base feature class.
- *ARK_ReturnType*: copy of the *ARK_ReturnType* flag in the base feature class.

GEOMETRIC NETWORK PROCESSING

Imported networks usually need processing to move water correctly and become functional in GIS. A functional geometric network is required to generate the MODSIM network. Few tips are described herein.

Flow Directions

ArcHydro tools provide the initial assignment of flows using the digitized direction. The NHD network is usually accurate on the flow directions according to the digitized direction for stream. In canal lines, fine tuning of the direction is usually needed. An ESRI support page downloaded tool is useful to assign individual links flow direction based on the digitized direction. Alternatively, the field *FlowDir* in the data-model combined with the assign ArcHydro flow direction tool (from field) can be used to change individual links flow direction. The edited direction can be saved to the geodatabase using the ArcHydro tool. Flow direction is reset every time a new network is generated. The edited flow directions can be loaded later on using the data-model saved values.

Simple Edges and Water Movement

All points in the network should be connected to successfully build the MODSIM network. The nodes connection to the network process can be done using the "connect" tool. It is advised to store the flow direction using ArcHydro tools in advance to facilitate restoring the flow direction after the nodes are connected to the network.

MODSIM NETWORK EXECUTION PRE-PROCESSING

The standard Geo-MODSIM run performs transformations to the Base-Network to accommodate the *River GeoDSS* features. The following operations are carried out before the network is solved:

It creates a copy of the MODSIM Base-Network using the Base-Network name and the simulation scenario name. If the WQM is active, it stores the water quality data to the *River GeoDSS* project Water Quality Database, using the same MODSIM basename and "*TS.mdb*". Finally, the current preferences (active network and *River GeoDSS* interface status) are stored in the data-model database.

If the WQM is active, the module initializes the water quality variables in the nodes and links *TAG* objects.

Network flow is blocked downstream of the Geo-MODSIM demand nodes (gauging stations are not included in this group).

Adjust the system interfaces, converting them to *flow-through* nodes and assigning the corresponding data-model return flow fraction. The interfaces priorities are set sequentially, starting at 4800 and subtracting a unit for each subsequent interface.

It creates the *flow-through* demand structure at the Geo-MODSIM demand nodes, allowing diverted water to flow to the terminal interfaces. The demand node downstream link is closed to flow.

A system sink is attached to the most downstream end of the network (*ARKCOOKS* station) to capture excess water created during the simulation scenarios by rejection of historical diversions. In calibration mode, the sink node is assigned with a priority of 4850; otherwise, its priority is 2000 (value related with reservoir layer priorities in simulation).

In calibration mode, the calibration structure is created. The system source node is named *CALIB_SOURCE* and the system sink in named *CALIB_SINK*. Links downstream of the gauging stations are closed for calibration. In simulation, these links are open and acts as the station bypass credit link (for output purposes). In simulation, the gauging stations are set to an incremental priority starting at 5100 (to remove the gauging station from the water rights allocation system). The link from the source to the station's downstream node is created and named with the station name suffixed with *_CALIB_DS_SUPPLY*. The *Ark_Calib_Relevance* data-model field value (*Rel*) is used to assign the link cost using the formula: $\cos t = -5 + \mathrm{Re}\, l$. The system inflow links created for the most upstream gauging stations are called after the station name suffixed with *_CALIB_SOURCE*. The cost on the system inflow links is -7. The *_CALIB_SOURCE* link creation is triggered by the data-model field *UPS_Source* set to "YES". The excess flow link, from the station to the system sink node, is created and named with the station name and the suffix *_CALIB_SINK*.

1. In simulation mode, the calibration network results are used to set to the maximum bounds on the calibration links (suffixed with *_CALIB_DS_SUPPLY*, *_CALIB_SOURCE* and *_CALIB_SINK*). For each gauging station node, the cost of the calibration links is set to -51000 minus a node counter.

2. Diversions are updated for management alternatives simulation. The demands are reduced according with the amounts specified for canal seepage reduction, aquifer recharge reduction and vertical drainage pumping.

3. Create the Sub-Network and save the *River GeoDSS* project, including the changes to the MODSIM network and the water quality database.

4. When using the ANN module, the module is initialized and a copy of the previous simulation scenario network results is generated. When the module is initialized, the MATLAB export files for the active trained ANN are loaded and the ANN support network structures are created.

STREAM-AQUIFER INTERACTION GROUPING AREAS

Grouping areas for the Neural Net-based stream-aquifer interaction modeling are a key component in the successful application of the learned relationships outside the detailed groundwater modeled area. The areas should have similar areal characteristics for the expected predictions per unit length to be in the same order of magnitude. A suggested procedure to create these areas is outlined in this section. A USGS Digital Elevation Model (DEM) is used as input for ArcHydro. The ArcHydro terrain processing steps are followed to generate catchments, drainage areas, lines and points. The grouping areas are build isolating the Main River lines from all other stream lines in the system. Points at 15-km apart are created to split the stream-aquifer interaction calculations in similar size reaches. ArcHydro Watershed Processing tool is used to define sub-watersheds for the 15-km-spaced points on the Arkansas River. Each sub-watershed is the base for the grouping polygons (adjacent areas). The grouping areas boundaries, for the most part, follow the angles of the sub-watershed delineation lines except in sub-watersheds with very narrow sections where the division lines are modified to end up with more similar-sized areas. Figure III-1 shows the grouping areas created with this procedure for the *LAR GeoDSS*. The adjacent areas of the river sections are extended on both sides of the main river to approximately the alluvial aquifer. The most far north-south irrigation canal around of the river is a good approximation to delimit the alluvial aquifer.

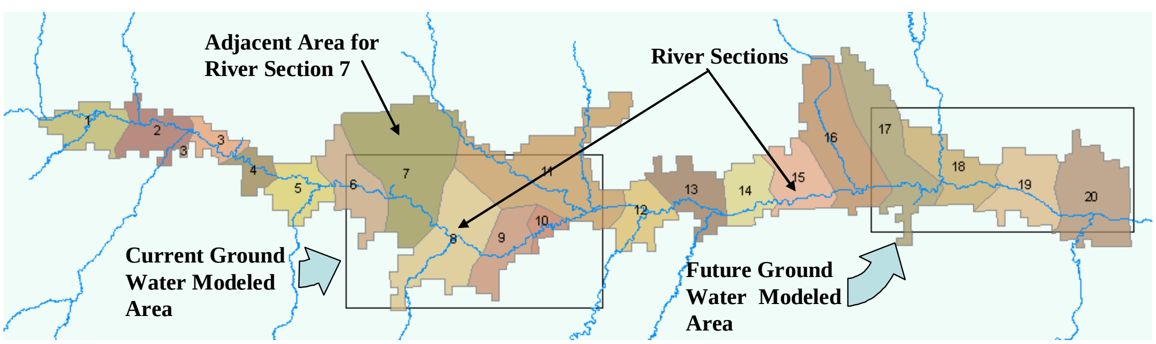


Figure III-1 – Grouping-areas for ANN stream-aquifer interaction modeling in the Lower Arkansas River

ANN Modeling Files in *LAR GeoDSS*

The MATLAB trained ANN is exported into two text files for *LAR GeoDSS* simulation. These files include all information about the training parameters that allows implementing predictions in the *LAR GeoDSS*-ANN module. The exported text files are named with the

ANN corresponding basename and the suffixes ***ANNInputs.csv*** and ***ANNWeights.csv***. The files are stored in the MATLAB workspace.

The *ANNInputs.csv* file contains the number of input variables, followed by the list of variables with the type of pre-processing function [MnMx/Std], the minimum, maximum and a sample value of the input variable in the training dataset. The file is a comma separated (csv) text file. Figure III-2 shows a sample of this file structure (as seen in Excel).

	A	B	Min	Max	Sample	F
1	ANNInputs					
2	25					
3	StreamLength	std	1.51E+01	2.28E+00	1.00E+01	
4	RiverFlow	std	4.50E+06	6.84E+06	3.61E+06	
5	BufArea_0	MnMx	3.77E+01	9.21E+01	4.38E+01	
6	AvePumped_0	std	9.58E+04	1.20E+05	9.08E+01	
7	AveDiversion_0	std	1.63E+05	1.61E+05	1.94E+05	
8	Canals_0	MnMx	0.00E+00	4.26E+04	1.93E+04	
9	AveElev_0	MnMx	-1.39E+03	-1.03E+03	-1.20E+03	
10	BCanalsElev_0	std	-1.12E+03	3.40E+02	-1.20E+03	

Figure III-2 – ANNInputs.csv file layout example

The *ANNWeights.csv* file contains information about the network, including user comments about the network and summary of the preferences used in the training. The second row includes the number of neurons in the first layer, the number of inputs, and the number of outputs. The following rows include the list of output variables and their scaling parameters, including the post processing type and the maximum and minimum values. The rest of the file includes the hidden layers' weights and biases calculated during the training. The structure of the file changes slightly depending on the type of Neural Net used for the training. Figure III-3 shows a diagram of the file structure including type-specific weights for the different types of networks. The red colored letters are labels inserted in the file to assist its reading of the different data types. The blue labels indicate the size of the block in the file. *FFBias* block is used by Feed Forward NNs, Elman and Radial Basis Networks. A sample of the file is shown in the following Figure III-4.

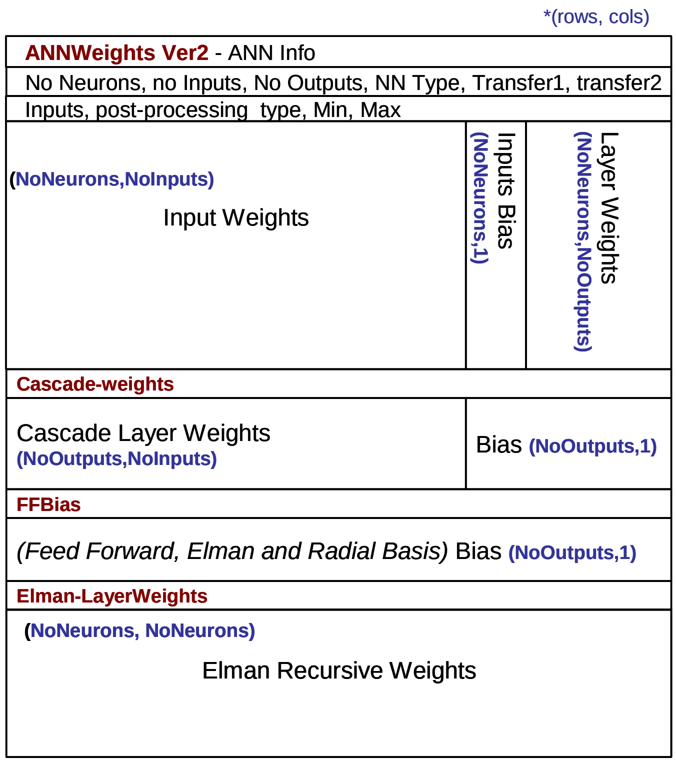
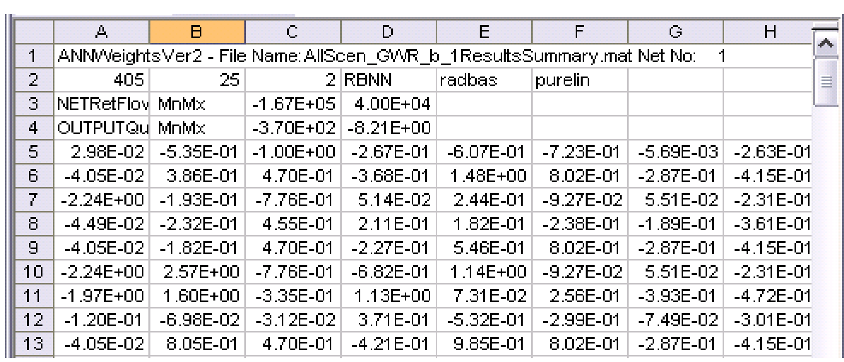


Figure III-3 – ANNWeights.csv file structure diagram



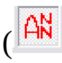
	A	B	C	D	E	F	G	H
1	ANNWeightsVer2 - File Name:AllScen_GWR_b_1ResultsSummary.mat Net No:							1
2	405	25	2	RBNN	radbas	purelin		
3	NETRetFlov	MnMx	-1.67E+05	4.00E+04				
4	OUTPUTQu	MnMx	-3.70E+02	-8.21E+00				
5	2.98E-02	-5.35E-01	-1.00E+00	-2.67E-01	-6.07E-01	-7.23E-01	-5.69E-03	-2.63E-01
6	-4.05E-02	3.86E-01	4.70E-01	-3.68E-01	1.48E+00	8.02E-01	-2.87E-01	-4.15E-01
7	-2.24E+00	-1.93E-01	-7.76E-01	5.14E-02	2.44E-01	-9.27E-02	5.51E-02	-2.31E-01
8	-4.49E-02	-2.32E-01	4.55E-01	2.11E-01	1.82E-01	-2.38E-01	-1.89E-01	-3.61E-01
9	-4.05E-02	-1.82E-01	4.70E-01	-2.27E-01	5.46E-01	8.02E-01	-2.87E-01	-4.15E-01
10	-2.24E+00	2.57E+00	-7.76E-01	-6.82E-01	1.14E+00	-9.27E-02	5.51E-02	-2.31E-01
11	-1.97E+00	1.60E+00	-3.35E-01	1.13E+00	7.31E-02	2.56E-01	-3.93E-01	-4.72E-01
12	-1.20E-01	-6.98E-02	-3.12E-02	3.71E-01	-5.32E-01	-2.99E-01	-7.49E-02	-3.01E-01
13	-4.05E-02	8.05E-01	4.70E-01	-4.21E-01	9.85E-01	8.02E-01	-2.87E-01	-4.15E-01

Figure III-4 – ANNWeights.csv file structure example

ANN PREDICTIONS IN GEO-MODSIM

The trained Neural Net requires assembling the simulation explanatory variables sets in the same way that the training dataset were constructed. The *LAR GeoDSS* tools allow creating basin-wide spatial processed explanatory variables when creating the training dataset. The variables are carried and processed through the training process and made available for *LAR GeoDSS* simulation.

When the MODSIM model is initialized the *LAR GeoDSS* ANN module is initialized. The ANN module uses the preferences in the *LAR GeoDSS Simulation Scenario Manager* to load MATLAB trained Neural Nets from the MATLAB exported files. In addition, the basin-wide GIS-generated ANN inputs tables are loaded to the module in memory. These tables are created during the ANN training dataset generation by the *ANN Database Management Tool* based on GIS spatio-processed ANN training dataset. The ANN Module models only the links flagged with *ANN_Return* in the GIS feature class. Using this flag, the link's downstream node is marked for return flow modeling. At the beginning of each modeled time step, the ANN Module computes the ANN explanatory variables that are constant for the simulated time steps, e.g., areas, elevations, lengths, pumping, precipitation. During the MODSIM iterative process, the module computes the explanatory variables that are a function of the MODSIM-modeled variables, e.g., diversions, canal seepage, aquifer recharge. Each MODSIM iteration, the ANN module calculates stream returns/depletions per grouping area and adjusts the ANN simulation structure links flow bounds (Figure 6.10), activating the ANN predictions in the MODSIM water allocation solver. If the Water Quality Module is active, the predicted concentration is assigned to each ANN modeling support links to be part of the salt routing calculation.

The ANN-based aquifer stream interaction modeling requires assigning each node and each pumping well with the corresponding groundwater modeling grouping area ID. A preprocessor is implemented in *LAR GeoDSS* for this purpose. The tools update the *GridID* field in the *LAR GeoDSS* data-model nodes and the used-specified pumping wells feature class. Figure III-5 shows the tab in the ANN user interface () to access these ANN preprocessing tools.

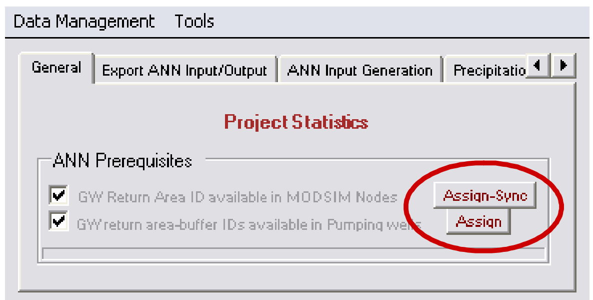


Figure III-5 – ANN preprocessing tools user interface

River GeoDSS Water Quality Import Tool

A tool is developed to import specific conductance data into the WQM. The tool processes data stored in the *River GeoDSS* water quality database and populates the time series object class in the module with the total dissolved solids (TDS). The *River GeoDSS* water quality database contains concentrations in microsiemens per centimeter (µS/cm). The import tool's GUI (Figure 3.14-B) provides access to a set of equations that can be used to convert the measured specific conductance (µS/cm) to TDS (mg/L). Two relationships were implemented using the equation from a regression analysis of the surface water field-collected EC and samples analyzed in the laboratory in the Arkansas Valley between 1999 and 2005 (Mueller and Gates 2006):

- ✓ Upstream of John Martin Reservoir

$$TDS\,[mg/l] = 685.87 * EC[dS/m] + 128.04 \qquad \text{(III-1)}$$

- ✓ Downstream of John Martin Reservoir

$$TDS\,[mg/l] = 728.72 * EC[dS/m]^{1.0966} \qquad \text{(III-2)}$$

Gates et al. 2006 reported similar relationship between field-measured EC and samples analyzed in the laboratory using the surface water sampling in the LARV. These surface water relationships are:

- ✓ Upstream of John Martin Reservoir

$$TDS\,[mg/l] = 859.7 * EC\,[dS/m]^{\,0.88} \qquad \text{(III-3)}$$

- ✓ Downstream of John Martin Reservoir

$$TDS\,[mg/l] = 727.7 * EC\,[dS/m]^{\,1.1} \qquad \text{(III-4)}$$

Figure III-6 shows a comparison of the weekly average TDS (mg/L) calculated with the different equations, using the USGS measured EC (μS/cm) at Coolidge, KS, gauging station (ARKCOOKS). Using the upstream equation to represent the downstream TDS will introduce a small error. For equations III-1 and III-2, it was found to under predict the TDS up to 14% and for low concentrations over predicts up to 20%. For equations III-3 and III-4, the upstream equation under predicts the downstream TDS up to and 15% and over predicts the lower concentrations up to 16%.

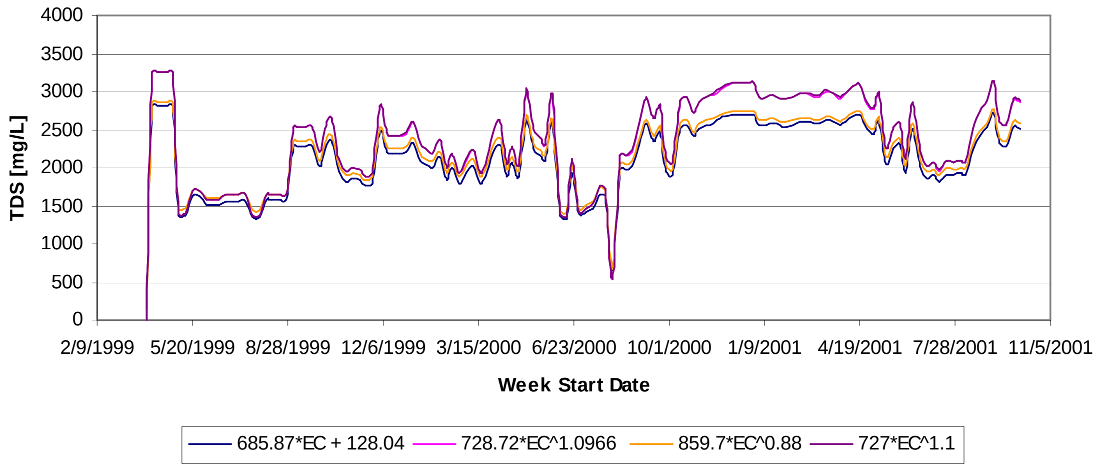


Figure III-6 – EC to TDS equations performance example

For the Arkansas River basin-wide modeling the import option that uses the average TDS of the upstream-downstream equations is utilized (Figure 3.14-B). In addition, the import tool allows using both regularly measured and sporadic (grab samples) data. A checkbox allows the user to use the available sporadic specific conductance measurements when there are no available regular records. The tool queries the main water quality database for the average of both sporadic (type = 9) and continuous (type = 2) for each MODSIM time step. The query results are analyzed and placed in the concentration time series according to the user import preferences. If available, the continuous data are used in first place. If there are less regular records than sporadic samples a weighted average is used to represent the average EC. If there is not available regular data for the time step, the average of the available sporadic samples in the time step is used. The time series object requires to have the first modeled time step date in the first row of the time series table, therefore when no data is available a 0 mg/L will be assigned. When sporadic measurements are used, the missing periods are skipped from the time series allowing the MODSIM time series logic to fill missing values with the previous available concentration value until a new concentration value is found. On the other hand, when sporadic values are not used the missing values will be assumed as 0 mg/L.

GEO-MODFLOW SUMMARY CALCULATION DETAILS

Geo-MODFLOW relies on the cell numbers field in the Geo-referenced MODFLOW-MT3DMS grid in ArcGIS. The cell numbers in the grid feature class correspond to the cell numbers in the first layer of the MODFLOW-MT3DMS grid. These first layer cell numbers are used in Geo-MODFLOW to find cell numbers in other layers (MODFLOW-MT3DMS uses a different cell number for each layer). The cell number (*Cell*) of the first layer is calculated as:

$$\mathrm{Cell} = (\mathrm{Row} - 1) * \mathrm{Ncols} + \mathrm{Col} \tag{III-5}$$

where, *Row* = the current row number from the upper left corner, *Col* = the current column number from the upper left corner and *Ncols* = the number of columns of the MODFLOW-MT3DMS grid.

The MODFLOW binary file is sequentially read, storing in memory arrays the cells values for each layer of the data under the following headings: *WELLS*, *RIVER LEAKAGE*, *ET*, *DRAINS*, *RECHARGE*, *HEAD DEP BOUNDS* and *STORAGE*. The MT3DMS concentration output file is also read to memory storing the cell-concentration for each layer using the first layer cell number as identifier. Utility functions are implemented in Geo-MODFLOW to query the Aquifer object for incoming and outgoing water using: the time step, the cell ID and the layer as an optional parameter (if no layer is specified, all layers are combined). The water constituent mass flowing out of each aquifer layer (Sink case only) is computed using the individual layer data (multiplying the volume times the concentration). The mass is totalized adding the mass for all layers. Mass sources have specified concentrations that are usually different from the aquifer concentration (MT3DMS output). Multi-layer combined concentration (*C*) in Geo-MODFLOW is computed using ***only the outgoing mass***. *C* is computed as the sum of the outgoing mass (negative sign in MODFLOW-MT3DMS output) divided by the volume of water flowing out of the aquifer.

$$C = \frac{\sum_{i=1}^{Cells}\sum_{l=1}^{NL} Vo_{i,l} * C_{i,l}}{\sum_{i=1}^{Cells}\sum_{l=1}^{NL} Vo_{i,l}} \qquad \text{(III-6)}$$

where, *Cells* = the set of cells to be queried, *NL* = the number of MODFLOW-MT3DMS grid layers, $Vo_{i,l}$ = the volume of water flowing out the aquifer at cell *i* and layer *l*, $C_{i,l}$ is the concentration for the cell *i* layer *l*. When no layer parameter is specified in the Geo-MODFLOW Select Tool summary, the summary corresponds to total water in/out the Aquifer.

Aquifer return mass to the River is computed using the aggregated value for all MODFLOW-MT3DMS layers. The value for river return flow will be zero for cells not marked as river cells; therefore, the aggregated value will correspond to river cells mass moving from the aquifer to the river. Notice that the storage term in the MODFLOW flow budget refers to the amount of aquifer storage that becomes a Source or Sink. Water entering to the aquifer storage is considered as a flow budget outflow while water released from storage is considered as a flow budget inflow. In the GMS flow budget dialog shown in the Figure 3.16, the positive storage value (source column) represents water flowing out of the aquifer storage; therefore, the net change in the cell water storage is a net reduction (lowering the water table).