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Technical Memorandum | Final

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Subject:	CRWAS Phase I	Tasks 6.6 and 7.11	CDSS Automation, Testing, and Application
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Introduction

This Technical Memorandum summarizes information developed as part of Tasks 6 and 7 of the Colorado River Water Availability Study (CRWAS or Study).

The objectives of CRWAS Tasks 6 and 7 are:

- *Task 6 - Extend historical hydrologic data using currently available tree-ring data and stochastic methods to develop alternate hydrologic traces in formats usable in the CDSS.*
- *Task 7 - Provide agency coordination, literature review, diagnostic analysis, data preparation, and model testing to generate projections for temperature, precipitation, weighted and scaled alternate hydrology, and water use relative to potential changes in forest and climate scenarios.*

Sub-tasks 6.6 and 7.11 involves automation and testing of extended historical hydrology and climate change hydrology traces in Colorado's Decision Support System (CDSS) models StateCU and StateMod for proper and reasonable operation.

This memo describes the methods and results of automating and testing of StateCU and StateMod using CDSS tools. Subsequent sections of this technical memorandum discuss: 1) task objectives, 2) task approach, 3) task results, and 4) task conclusions and recommendations.

Activities

Analyses associated with CRWAS Tasks 6 and 7 requires thousands of model runs to develop results associated with alternate historical hydrology and climate change hydrology and, therefore, requires automation and testing of data-centered models using CDSS tools. The CDSS includes established standard methods for creating input and

output model files using a data-centered approach. The objectives of Task 6.6 and Task 7.11 associated with implementing the established CDSS methods are as follows:

- *Work with the State to identify locations to report model-simulated results for physically available flow, legally available flow, and reservoir storage.*

- *Develop a data-centered automation approach that uses the CDSS Data-Management Interface TSTool to create 100 re-sequenced traces of extended historical hydrology data for the StateMod Historical Baseline dataset for each of the five Colorado River Decision Support System (CRDSS) basins (Yampa, White, Colorado, Gunnison, San Juan / San Miguel / Dolores), resulting in 500 StateMod scenarios. Re-sequencing takes advantage of varying lengths of dry and wet transition periods seen in the paleohydrologic record.*

- *Incorporate projected temperature and precipitation data associated with the climate change scenarios into historical StateCU models and re-run for the ten "as-if" climate scenarios in each of the five CRDSS basins (five "as-if" scenarios for 2040 and five "as-if" scenarios for 2070).*

- *Develop a data-centered automation approach that takes advantage of the CDSS Data-Management Interfaces to create 100 re-sequenced traces for each of the ten climate scenarios for each of the five CRDSS basins (results in 5,000 StateMod scenarios).*

- *Develop a data-centered automation approach to extract information at selected locations for graphing and analysis.*

- *Review the StateCU and StateMod output for proper and reasonable operation. Specifically, graphically review model-simulated physically available flow, and legally available flow, and reservoir storage.*

Approach

A description of the methods and steps used to implement the objectives listed above is provided in the following three sections (*Locations for Results Analysis, Historical Model Simulations, and Alternate Climate Projections*).

Locations for Results Analysis

StateMod results for the five CRDSS basins are extensive and include simulated estimates of physically and legally available flow at more than 1,500 locations. It was necessary to identify a manageable subset of locations to view, analyze, and compare results. The following general criteria were used to select analysis locations:

- Select locations that correspond to USGS stream gages
- Include locations in each of the five CRDSS basins
- Select locations that represent total tributary runoff (locations above river confluences)
- Include locations that represent critical areas (calling rights, for example near Shoshone Power Plant or near Grand Valley Diversions in the Colorado River Basin)
- Consider locations below significant transbasin diversions or reservoirs
- Include locations that overlap with locations selected for presentation in the Front Range Vulnerability Study

Using the criteria, locations were recommended to the State for review. Forty-three (43) final locations were selected as shown in the appendix of this memorandum. In addition, three reservoirs that provide supplemental supplies to meet irrigation demands were selected: Vega Reservoir, Yamcolo Reservoir, and McPhee Reservoir.

Historical Model Simulations

Figure 1 shows the general steps required to develop and analyze the results for the 100 re-sequenced Historical traces. Each step includes the five CRDSS basin models. As shown, the data management interface TSTool is used create the required revised input files and to extract results for analysis and presentation.

Figure 1
Steps to Develop and Analyze Re-Sequenced Historical Traces
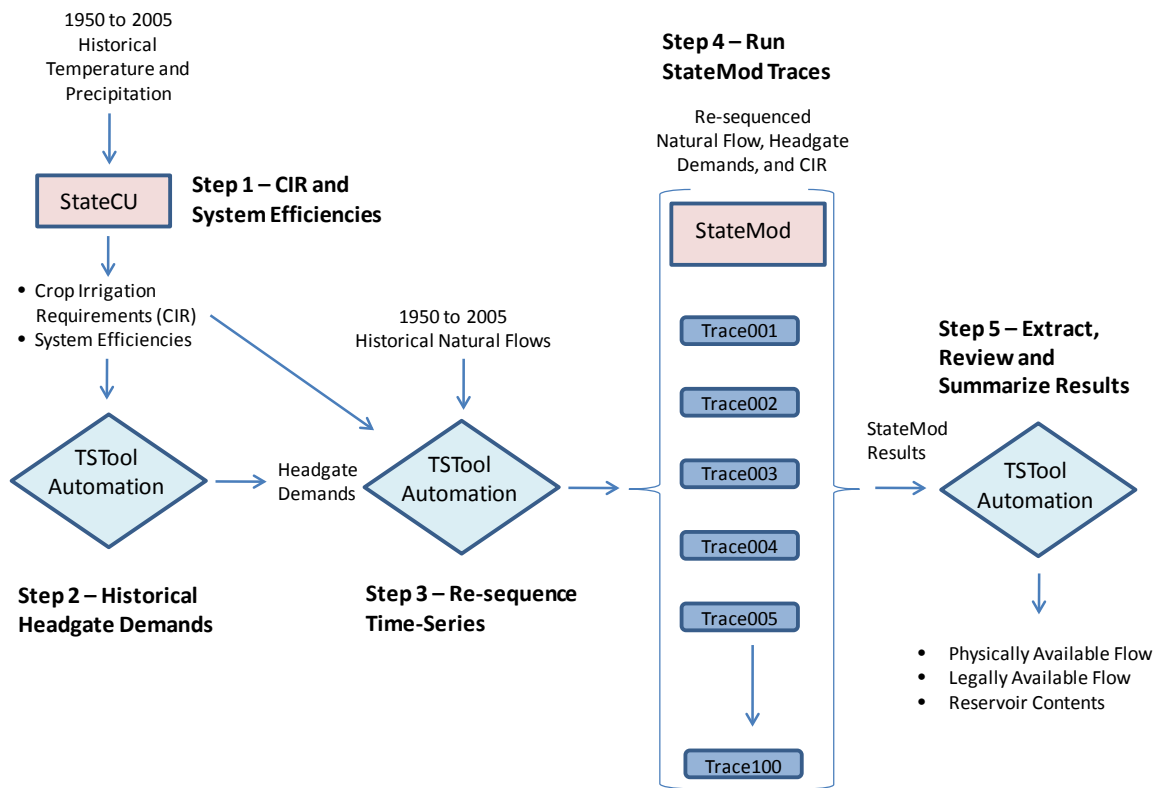
Step 1 – Calculate Crop Irrigation Requirements and Historical System Efficiencies

In CRWAS Phase 1, current levels of demand and current operations are represented. The crop consumptive use analysis was performed using the StateCU model with current levels of irrigated acreage and historical measured temperature and precipitation data. Historical diversions were included to determine actual monthly system efficiencies for the ditch structures included in the analysis. The Historical StateCU input files were developed as part of CRDSS for the period 1950 through 2005 and, for this step, no further revisions for CRWAS were required.

Step 2 – TSTool Automation to Develop Irrigation Headgate Demands

Monthly system efficiencies from the historical data set, per structure, were grouped using TSTool then averaged to determine wet, dry, and average monthly efficiencies. Based on the hydrologic year type, crop irrigation requirements from Step 1 were divided by the corresponding monthly efficiencies to determine headgate demands. Headgate demands for municipal structures and transbasin diversions were set to current demands, as described in Section 5 (Baseline Dataset) of each basin's Water Resources Planning Model Final Report.

Step 3 – TSTool Automation to Re-sequence Time-Series Data

TSTool has the capability to re-sequence time-series data based on a sequenced list of years. There are three time-series input files to each basin StateMod model that were re-sequenced based on the extended historical hydrology sequences developed and documented in CRWAS *Task 6.4 Methods for Alternate Hydrology and Water Use*. These time-series included natural flow, crop irrigation requirements, and headgate demands. In addition, several reservoirs operate based on filling and releasing patterns driven by wet, dry, and average year forecasts. The StateMod time-series target files for Green Mountain, Ruedi, Lemon, and Vallecito reservoirs were re-sequenced. Finally, there are three agreements between Colorado and the United States to maintain minimum river flows for fish and other piscatorial purposes that are based on hydrologic year type. The Colorado 15-mile reach fish flows, Taylor Park Reservoir minimum bypass flows, and Black Canyon of the Gunnison National Park minimum flows were also re-sequenced.

TSTool was used to read in the new sequence of years for the 100 traces; read in the original historical time-series files; perform the re-sequencing on the required files; then save the new time-series input files to new directories named trace001 through trace100.

Step 4 – Run StateMod Traces

StateMod was simulated for the five CRDSS basins for each of the 100 traces. Only the re-sequenced time-series input files, described in Step 3, differed between the 100 simulations (natural flows, headgate demands, crop irrigation requirements, plus certain reservoir targets and minimum flows demands as discussed). Other StateMod input files that define current physical characteristics of diversions and reservoirs, current water rights files, and current operational rules were used in each trace simulation without revisions.

Execution of the 500 model runs (100 traces x five basin models) was automated using a simple DOS "batch file" approach. The first line of the batch file starts StateMod in the Trace001 subdirectory and executes each of the five CRDSS basin models. The batch file then changes directories to Trace002 and, again, starts StateMod and executes each of the five CRDSS basins. The batch file automatically steps through each of the 100 traces in this fashion.

Step 5 – Extract, Review, and Summarize StateMod Results

For each simulation, StateMod saves output parameters into a binary file. More than 20 parameters are saved for every node represented in the model. TSTool was used to read each binary file and extract and save physically available flow and legally available flow for the 43 selected locations and storage content for the three selected reservoirs. The extracted data was saved to a file that can be read directly by TSTool for quick viewing and analysis, and by Excel for final presentation. As with Step 4, a batch file was created to

execute TSTool to extract and save the data from the Trace001 subdirectory. The batch file then changes directories to Trace002 and, again, executes TSTool to extract and save the data.

TSTool graphing capabilities were used to format charts of the data for visual review of the results from each of the 100 scenarios to assure that the model executed fully and that the results appeared reasonable. Review of the model simulation output files showed that the StateMod code simulated correctly. The 100 model simulations for each CRDSS basin ran successfully through the full 56 year period. Review of the model results proved that each model maintained mass balance. In addition, review of reservoir operations indicated that current operations represented in each of the models are appropriate for Phase I.

Alternate Climate Projections

Figure 2 shows the general steps required to develop and analyze the results for the 100 re-sequenced StateMod traces associated with each of the ten alternate climate projections. Each step is performed for the five CRDSS basin models (5,000 total StateMod simulations = 5 basins x 10 climate projections x 100 traces). The automation flow chart for alternative hydrology of climate change is the same as for the historical simulations except historical temperature, precipitation, and natural flows are replaced with temperature, precipitation, and natural flows representative of an alternate climate for the ten scenarios chosen and described in CRWAS Task 7.8 Climate Projection Selection (documented in CRWAS Technical Memorandum *Task 7.5 Climate Change Approach*). As with the historical automation, the data management interface TSTool is used create the required revised input files and to extract results for analysis and presentation.

Figure 2
Steps to Develop and Analyze Climate Projection Traces
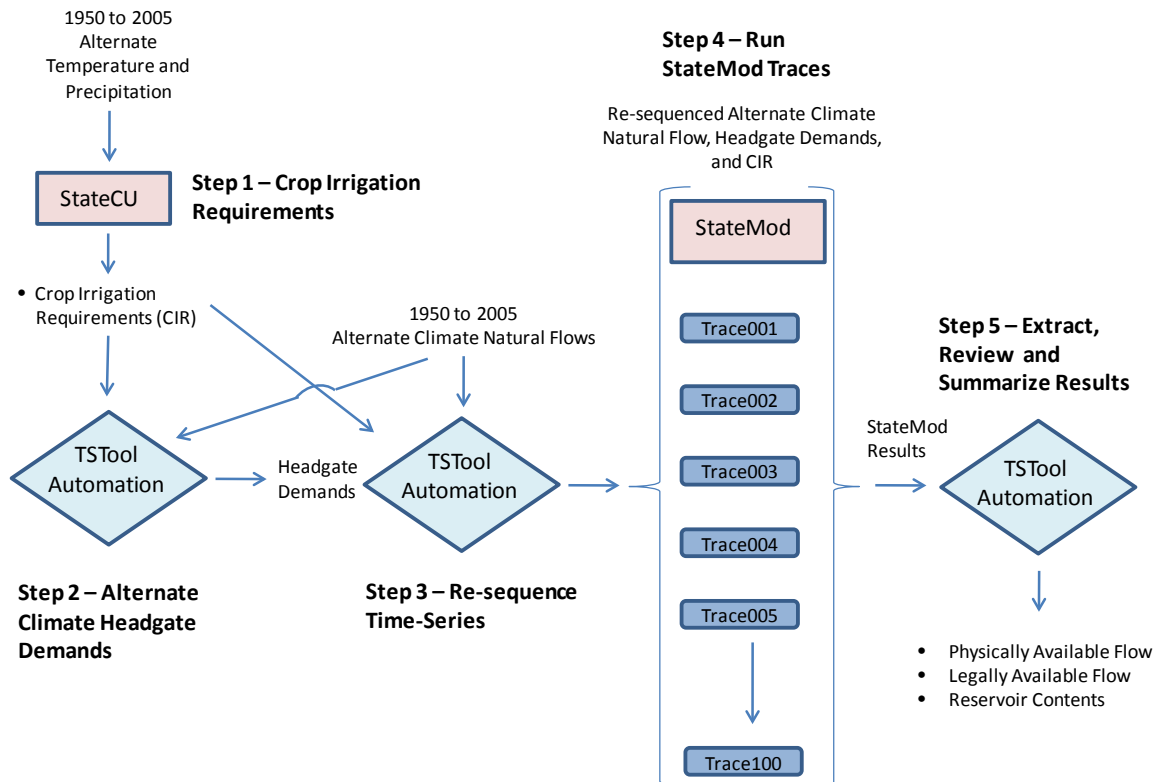
Step 1 – Calculate Crop Irrigation Requirements

CRWAS Phase I includes representation of current levels of demand and current operations. Alternate temperature and precipitation associated with each climate projection replace historical temperature and precipitation to determine crop irrigation requirements. The crop consumptive use analysis was performed using the StateCU.

Step 2 –TSTool Automation to Develop Irrigation Headgate Demands

Monthly system efficiencies, per structure, were estimated based on historical demands and historical diversions, as described in Historical Model Simulations Approach Step 1. These efficiencies represent current irrigation practice under wet, dry, and average hydrologic conditions. TSTool was used to read Alternate Natural Flow for each of the climate projects and re-categorize hydrologic year type by Water District. This procedure is described in detail in the CRWAS Supporting Technical Memorandum *Headgate Irrigation Demands Associated with Alternate Climate Scenarios.*

As expected, in most climate projections, more years were categorized as dry and average, and fewer years were categorized as wet. Because there are more dry and average years, individual irrigation ditch systems are generally more efficient. Based on the hydrologic year type, crop irrigation requirements from Step 1 were divided by the corresponding monthly efficiencies to determine headgate demands. Headgate demands for municipal structures and transbasin diversions were set to current demands, as described in each basin's Water Resources Planning Model Final Report, under Section 5, Baseline Dataset.

Step 3 – TSTool Automation to Re-sequence Time-Series Data

The re-sequencing of projected climate time-series data was the same as described above under the section "Historical Model Simulations" Step 3. TSTool was used to read in the new sequence of years for the 100 traces; read in the new climate projection time-series files; perform the re-sequencing on the required files; then save the new time-series input files to new directories named Trace001 through Trace100. This step was repeated ten times, for each of the climate projections.

Step 4 – Run StateMod Traces

StateMod was simulated for the five CRDSS basins for each of the 100 traces associated with each of the ten climate projections. Only the re-sequenced time-series input files described in the section "Historical Model Simulations" Step 3 differed between the traces (natural flows, headgate demands, crop irrigation requirements plus certain reservoir targets and minimum flow demands as discussed). The other StateMod input files that define current physical characteristics of diversions and reservoirs, current water rights files, and current operational rules were used in each trace simulation without revisions.

Execution of the 5,000 model runs (10 climate projections x 100 traces x 5 models) was automated using a simple DOS batch file approach initiated on 10 separate computers – one computer to run simulations for each of the ten climate projections. The first line of the batch file changes to subdirectory Trace001 containing time-series input files for the first of the 100 data sets reflecting the climate projection to be simulated on the particular computer. StateMod is started in the Trace001 subdirectory and executes each of the five CRDSS basin models. The batch file then changes directories to Trace002 and, again,

starts StateMod and executes each of the five CRDSS basins. The batch file automatically steps through each of the 100 traces in this fashion.

StateMod executed successfully for each of the 5,000 model runs; therefore, no adjustments to current operations were necessary.

Step 5 – Extract and Summarize StateMod Results

For each simulation, StateMod saves output parameters into a binary file. More than 20 parameters are saved for every node represented in the model. Parameters include input information such as headgate demand and crop irrigation requirement; streamflow information such as node inflow, outflow, and legally available flow; and node-specific information such as diversions to demand from direct flow, diversions to demand from reservoir storage, diversions to off-stream storage, etc.

TSTool was used to read each binary file and extract and save physically available flow and legally available flow for the 45 selected locations and storage content for the three selected reservoirs. The extracted data was saved to a file that can be read directly by TSTool for quick viewing and analysis, and by Excel for final presentation. As with Step 4, a batch file was created to execute TSTool to extract and save the data from the Trace001 subdirectory. The batch file then changes directories to Trace002 and, again, executes TSTool to extract and save the data.

TSTool graphing capabilities were used to review time-series of physically available flow, legally available flow, and reservoir storage contents from each of the 100 scenarios for each of the ten climate projections to assure that the model executed fully and that the results appeared reasonable.

TSTool graphing capabilities were used to format charts of the data for visual review of the results from each of the 100 scenarios to assure that the model executed fully and that the results appeared reasonable. Review of the model simulation output files showed that the StateMod code simulated correctly. The 1,000 model simulations for each CRDSS basin ran successfully through the full 56 year period. Review of the model results proved that each model maintained mass balance. In addition, review of reservoir operations indicated that current operations represented in each of the models are appropriate for Phase I.

Results

The 500 Historical StateMod scenarios (100 re-sequenced traces x 5 basins) executed completely through the 56-year periods and the graphically reviewed results appeared reasonable. The 5,000 Climate Projection StateMod scenarios (10 Climate Projections x 100 re-sequenced traces x 5 basins) also executed completely and the graphically reviewed results appeared reasonable. Output was saved in the format required for further analysis and presentation. The automation approach, and the use of multiple computers, allowed for the scenarios to be completed in about 170 hours (24 hours a day for 7 days) without the need for more sophisticated hardware.

Conclusion and Recommendations

The data-centered automation approach developed will facilitate the execution and analysis of future condition scenarios in Phase II.

Appendix

Locations for Results Analysis

CRDSS Basin	Location Description	USGS Gage ID
UPPER COLORADO	COLORADO RIVER NEAR GRANBY	09011000
UPPER COLORADO	MUDDY CREEK AT KREMMLING	09041500
UPPER COLORADO	BLUE RIVER BELOW DILLON	09050700
UPPER COLORADO	BLUE RIVER BELOW GREEN MOUNTAIN RES	09057500
UPPER COLORADO	EAGLE RIVER BELOW GYPSUM	09070000
UPPER COLORADO	COLORADO RIVER AT DOTSERO	09070500
UPPER COLORADO	ROARING FORK RIVER NEAR ASPEN	09073400
UPPER COLORADO	ROARING FORK RIVER AT GLENWOOD	09085000
UPPER COLORADO	COLORADO RIVER NEAR CAMEO	09095500
UPPER COLORADO	PLATEAU CREEK NEAR CAMEO	09105000
UPPER COLORADO	COLORADO RIVER NEAR CO-UT STATE LINE	09163500
GUNNISON	EAST RIVER AT ALMONT	09112500
GUNNISON	TAYLOR RIVER AT ALMONT	09110000
GUNNISON	TOMICHI CREEK AT GUNNISON	09119000
GUNNISON	GUNNISON RIVER NEAR GUNNISON	09114500
GUNNISON	CIMARRON RIVER AT CIMARRON	09126500
GUNNISON	GUNNISON RIVER BELOW GUNNISON TUNNEL	09128000
GUNNISON	GUNNISON RIVER NEAR LAZEAR	09136200
GUNNISON	UNCOMPAHGRE RIVER AT DELTA	09149500
GUNNISON	GUNNISON RIVER NEAR GRAND JUNCTION	09152500
SAN JUAN/DOLORES	SAN JUAN RIVER NEAR CARRACAS	09346400
SAN JUAN/DOLORES	PIEDRA RIVER NEAR ARBOLES	09349800

SAN JUAN/DOLORES	LOS PINOS RIVER AT LA BOCA	09354500
SAN JUAN/DOLORES	FLORIDA RIVER AT BONDAD	09363200
SAN JUAN/DOLORES	ANIMAS RIVER NEAR CEDAR HILL, NM	09363500
SAN JUAN/DOLORES	LA PLATA RIVER AT HESPERUS	09365500
SAN JUAN/DOLORES	LA PLATA RIVER AT CO-NM STATE LINE	09366500
SAN JUAN/DOLORES	MANCOS RIVER NEAR TOWAOC	09371000
SAN JUAN/DOLORES	MCELMO CREEK NEAR CO-UT STATE LINE	09372000
SAN JUAN/DOLORES	DOLORES RIVER NEAR BEDROCK	09171100
SAN JUAN/DOLORES	SAN MIGUEL RIVER AT NATURITA	09175500
YAMPA	YAMPA RIVER BELOW STAGECOACH RES	09237500
YAMPA	ELK RIVER AT CLARK	09241000
YAMPA	ELKHEAD CREEK NEAR ELKHEAD	09245000
YAMPA	WILLIAMS FORK AT MOUTH, NEAR HAMILTON	09249750
YAMPA	YAMPA RIVER NEAR MAYBELL	09251000
YAMPA	LITTLE SNAKE RIVER NEAR LILY	09260000
YAMPA	YAMPA RIVER AT DEERLODGE PARK	09260050
WHITE	NORTH FORK WHITE RIVER AT BUFORD, CO	09303000
WHITE	SOUTH FORK WHITE RIVER AT BUFORD	09304000
WHITE	WHITE RIVER BELOW MEEKER	09304800
WHITE	PICEANCE CREEK AT WHITE RIVER	09306222
WHITE	WHITE RIVER NEAR CO-UT STATE LINE	09306395