CRWAS Phase I
Overview of the Colorado Decision Support System

1. Introduction

As the State's lead water planning and policy agency, the Colorado Water Conservation Board (CWCB or Board) is responsible for conserving, developing, protecting, and managing Colorado's water for present and future generations. Although not currently authorized to own and operate water supply projects, the Board's inter-state water supply planning responsibilities and its in-state minimum instream flow, flood control, and water project funding programs place the agency in a key position in Colorado's water management activities.

Other agencies in the Department of Natural Resources (DNR), especially the Division of Water Resources (DWR), with its statutory responsibility to administer water rights and enforce interstate river compact compliance; and the Division of Wildlife, with its wildlife and habitat management programs and ownership of reservoirs, fish hatcheries and water rights, are also directly involved in the state's water management activities. All DNR agencies are being affected by increased competition for remaining water supplies.

As a public agency, the CWCB strives for transparency in developing its water management data, tools, and models. Originally developed for the Colorado River and its tributaries in Colorado, the State's computerized water data and modeling system was known as the Colorado River Decision Support System (CRDSS). This integrated system of data and simulation models is now know as the Colorado Decision Support System (CDSS) since it is now being extended to the State's other major rivers. This "data-centered" decision support system allows interested parties to view and to help improve the underlying water use data that supports complex water management computer programs. The CDSS is comprised of the following primary components:

- HydroBase contains historical and current water resources data, including streamflow records, climate data, diversion records, and water rights.

- Spatial data includes GIS layers of diversion locations, irrigated acreage by ditch, stream flow measurement points, rivers, climate station locations, and base coverages including highways and cities.

- StateMod, the State's water allocation simulation program is available on-line with detailed user's manuals (public has direct access to the StateMod programs that the CWCB has developed for each of the main Colorado River tributaries in Colorado).

- StateCU facilitates estimation of water consumed by agriculture. It utilizes climate data (primarily temperature, precipitation, and wind), information on crop types and acreages, and water supply data to generate estimates of consumptive use, diversion requirements and return flows.

Over the past two decades, the CWCB has invested significant resources developing the CDSS. There are no other comparable water management models in Colorado that cover such a broad area or with such transparency. Even with such a large investment of funding and time, the

CWCB continually improves and updates the data and the functionality of the CDSS. The system will continue to evolve as new information comes available, as new water demands emerge, and new agreements are reached on managing, sharing, and utilizing a scarce natural resource for both consumptive and non-consumptive uses.

The State's long history with water management simulation models shows that competing water interests seldom completely endorse a model and all of the data used to prepare publicly-available water management studies. However, competing water interests will often agree that a particular model is the best tool currently available to provide information useful for a specific application. For the Colorado River Water Availability Study (CRWAS), the StateMod/StateCU models are the best available tools.

The CRWAS consulting team will solicit and carefully document input from interested parties on potential modifications and updates to either the underlying data or model functionality. Improvements to the current data and models will be incorporated to the extent that the Study's purpose, needs, budget and schedule allow. Model refinements will focus on modifications that will likely have the biggest impact on the Study's overall purpose of assessing the general magnitude of water availability for Colorado's future consumptive and non-consumptive uses under current (Phase 1) and future conditions (Phase 2).

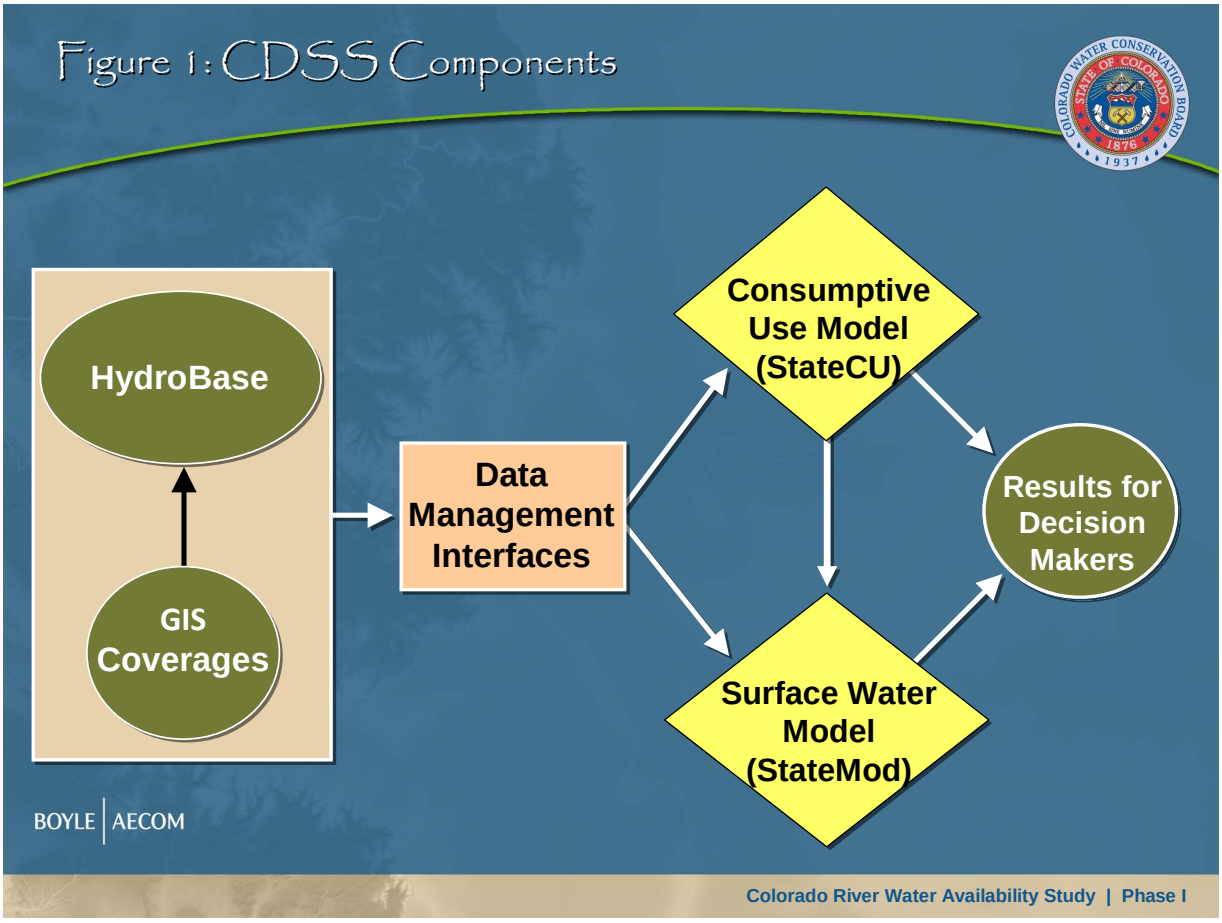
The hydrologic conditions of the past several years highlight the need for the State to further understand opportunities for enhanced water management for consumptive and non-consumptive water uses. There is increasing attention in the Upper Basin States to future Colorado River Compact administration and to future climate conditions. The State legislature adopted a very transparent approach in authorizing this study as a public process. The public will have direct access to the data, methods, and conclusions of the CRWAS and the input of the Basin Round Tables will be fully considered in conducting this important Study.

Task 4.1 of the Consultant's Phase I scope of work dictates the preparation of brief summaries of the primary operating criteria, calibration methodology and results associated with the State modeling of current water supplies and demand for each of the four major Colorado River Subbasins. This document has been prepared to provide an overview of the CDSS and its primary components including: StateMod; StateCU; and HydroBase (with the Data Management Interfaces). This document will serve as an introduction to the basin-specific descriptions of model operations.

2. CDSS Components

The Colorado Decision Support System (CDSS) consists of several components including: 1) a database of hydrologic and administrative information related to water use in Colorado; 2) a variety of tools for reviewing, reporting, and analyzing the data and 3) models to simulate water consumption and the operation of water diversions, storage, use and return flows. Under the CDSS umbrella, there is a Water Resources Planning Model (StateMod) for each of the five river basins (White, Yampa, Upper Colorado, Gunnison, and combined Dolores/San Juan/San Miguel) comprising the Colorado River Basin within the State of Colorado. These water allocation models can be used to estimate availability of water to individual users and projects based on alternative hydrologic scenarios, the State's administration of water rights, and operating rules and practices.

Figure 1: CDSS Components



The models utilize StateMod, the CWCB's generic water allocation and accounting model developed to make comparative analyses of various historical and future water management policies in a river basin. StateMod operations, like Colorado's rivers, are governed by hydrology, water demands, and legal conditions (water rights and operational policies). The model's simulation algorithm follows Colorado's unique application and enforcement of the Prior Appropriation Doctrine used in the Western U.S. CDSS and its component databases and

models is the only comprehensive model currently available with the detail needed within Colorado for conducting the Colorado River Water Availability Study (CRWAS).

Baseline data sets for each of the five river basins (White, Yampa, Upper Colorado, Gunnison, and combined Dolores/San Juan/San Miguel) extend from the most currently available hydrologic year back to 1909. These datasets include representations of current water demands, current infrastructure, and current administrative policies and regulations as though they were all in place throughout the modeled period (1909 to most recent available year). The Baseline data sets were developed as the basis to compare the impacts of alternative future water demands, reservoirs, water rights and/or changes in operations and management procedures and strategies. The data sets can be modified to simulate potential changes in physical water supplies at specific points throughout the river basins. In addition, the data sets can be modified to assess changes in water demands resulting from potential changes in temperature and precipitation that might result under a range of potential future climatic conditions.

Though the baseline data sets for the CDSS models begin in 1909, the study period selected for CRWAS is a subset from 1950 to 2005. The principal reasons for adopting this study period include the following:

- CDSS natural flows are based on historical measured data, including stream flows, diversions, reservoir contents, and climate data. The availability and reliability of these data sources increased greatly between 1909 and 1950, providing more confidence in natural flows for the 1950 to 2005 subset period.
- The subset period includes extended wet, dry, and average periods, plus both extreme drought and high runoff years in each of the five basins. Therefore this period provides the wide variation in hydrology desirable to use as the basis for re-sequencing to represent alternative tree-ring hydrology.
- CDSS natural flows will be used to calibrate the climate change hydrology. The gridded climate data set chosen to disaggregate climate change hydrology to local drainages has a period of record from 1949 through 2005.

3. StateMod Overview

StateMod is a linked-node model. Nodes are located where information currently exists or where information is desired. Nodes can be located at the following types of locations:

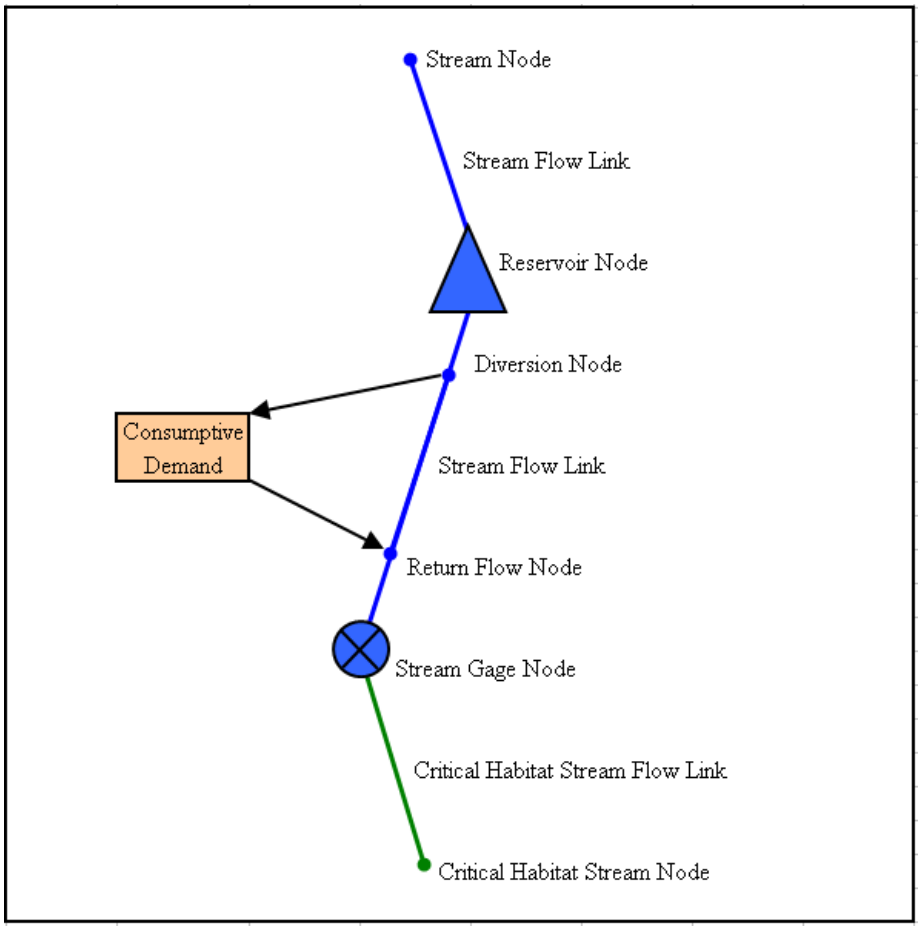
- Stream gages
- Diversion locations
- Reservoirs
- Beginning/ending of instream flow reaches
- Return flow/discharge locations
- Important habitat reaches

Links move water from node to node and represent:

- Rivers
- Canals
- Pipelines

Figure 2 is a generic example of StateMod linked-node connectivity.

Figure 2: Example StateMod Linked-Node Connectivity



The StateMod water allocation models are driven by natural flow hydrology. In previous CDSS documentation, natural flows are generally referred to as "baseflows". Natural flows represent natural streamflow, absent human effects that include agricultural, municipal, domestic, and industrial water uses. Nodes and links tie the natural systems to physical systems developed to support these human uses. StateMod simulates water use restricted by physical properties such as headgate and ditch capacities and by reservoir storage and outlet capacities. Finally, legal and administrative conditions are represented in the models, including water rights and operational policies.

StateMod simulates the flow of water through a river system for each time step in the modeling period. For example, if a 1909 through 2007 period and a monthly time step is selected by the user, there would be 99 years times 12 months, or 1,188 time steps in a single model run. If, in a selected river basin, there are 100 nodes (stream gages, reservoirs, diversion points, return flow points, etc), the model would generate 118,800 output sets of values such as average monthly flow, reservoir contents, etc. Furthermore, there may be more than one path (or link in modeling terms) for water to flow from one node to another node and the model must select which flowpath to use in each of the 1,188 time steps according to the legal conditions defined by the water rights and operating procedures of the water conveyance and storage systems.

StateMod operates each time-step based on the Modified Direct Solution Algorithm. At each modeled time-step, StateMod allocates available stream flow based on the following general steps.

1. Physical water availability is determined at each river node to include both native inflows and return flows accruing from a prior time step.
2. The most senior direct, instream, storage, or operational water right is identified.
3. Diversions are estimated to be the minimum of the decreed water right, structure capacity, demand, and available flow in the river. For a direct flow or reservoir right, the available flow in the river is the minimum of available flow at the diverting node and at all downstream nodes. By considering flow at downstream nodes, the model preserves the correct supply for downstream senior water rights when calculating the diversion for an upstream junior right. For an instream right, the available flow in the river is the flow at each river node within the instream reach.
4. Downstream flows are adjusted to reflect the senior diversion and its return flows.
5. Return flows for future time periods are determined and stored.
6. The process is repeated in order of priority for each successive direct, instream, storage, and operational water right.
7. If new water is introduced to the system from a reservoir's operation or return flows accrue to a non-downstream node, the process is repeated beginning with the most senior direct, instream, storage or operational right.

StateMod currently includes nearly 50 different types of operating rules that allow representation of administrative policies in Colorado. Operating rules are not required if water demands are met from a river using direct-flow water rights, or if on-channel reservoirs store water using storage rights. They are required, for instance, if a river diversion structure operates as a carrier to store water in an off-channel reservoir or if a demand is met from a reservoir release. Each

implementation of an operating rule; that is, each operational right in the Baseline Model data set for each of the five river basins (White, Yampa, Upper Colorado, Gunnison, and combined Dolores/San Juan/San Miguel), is assigned a priority, such that it operates in correct order with respect to other water rights following the Modified Direct Solution Algorithm.

Where to find more detailed information:

- Section 7.8 and 7.9 of the State of Colorado's Water Resources Model (StateMod) Documentation, available on the CDSS website (http://cdss.state.co.us/), provides detailed examples of the Direct Solution and Modified Direct Solution Algorithms.

- Section 4.13 of the State of Colorado's Water Resources Model (StateMod) Documentation provides available operating rules, guidelines for selecting the appropriate rules based on water source and destination, and examples of how each operating rule has been applied to represent real Colorado operations.

4. StateCU Overview

The State of Colorado's Consumptive Use Model (StateCU) was developed to estimate and report crop consumptive use within the state. The following consumptive use methods are incorporated in the program: Modified Blaney-Criddle; Original Blaney-Criddle, and the Pochop (for bluegrass only) methods for calculations on a monthly basis and the ASCE Standardized Penman-Monteith method for calculations on a daily basis. StateCU is used to develop crop irrigation water requirements for the diversion structures serving the irrigated areas. Because of the large amount of water consumed by agriculture in Colorado, including the West Slope, these requirements are key inputs to all five Baseline Models. The StateMod model's calculation of crop consumptive use and associated return flows is based on this information. In addition, as described below, irrigation water requirements are used to estimate irrigation diversion demands, another input to the models.

For the StateCU Model for each of the five river basins (White, Yampa, Upper Colorado, Gunnison, and combined Dolores/San Juan/San Miguel), the Modified Blaney-Criddle method using crop coefficients provided in the SCS Technical Release 21 (TR21) is used to estimate potential crop consumptive use at lower elevations (generally below 6500 feet). The Original Blaney-Criddle method using Denver Water South Park Study calibrated coefficients for pasture grass is used to estimate potential crop consumptive use at higher elevations. The TR21 method for estimating effective precipitation is used throughout the basins to estimate crop irrigation water requirements – the maximum amount of water that crops require from an irrigation source. StateCU has been used to develop the five-year Consumptive Uses and Losses Report as a check for the USBR report required by the Colorado River Basin Project Act of 1968.

The StateCU Baseline Model data set for each of the five river basins (White, Yampa, Upper Colorado, Gunnison, and combined Dolores/San Juan/San Miguel) includes 100 percent of irrigated acreage determined for the year 2000, by ditch, for the entire model study period. Climate station data from 55 stations in the five basins (4 in the White, 9 in the Yampa, 12 in the Upper Colorado, 12 in the Gunnison, and 18 in the combined Dolores/San Juan/San Miguel subbasins) are used in the analysis.

Where to find more detailed information:

- Section 4 of the StateCU Documentation available, on the CDSS website, describes the Blaney-Criddle and effective precipitation algorithms.
- SPDSS Task 59.1 – Develop Locally Calibrated Blaney-Criddle Crop Coefficients, available on the CDSS website, describes the review of high-altitude coefficients and recommendation for the use of the Denver Water South Park Study calibrated coefficients.
- "Evapotranspiration and Agronomic Responses in Formerly Irrigated Mountain Meadows, South Park, Colorado", Report for the Board of Water Commissioners,

City and County of Denver, CO. March 1, 1990 (Walter, I.A., Siemer, J.P., Quinlan and Burman, R.D.) describes the development of the Denver Water calibrated coefficients.

5. HydroBase / DMI Overview (CDSS Data Centered Approach)

Baseline Model data sets exist for each of the five river basins (White, Yampa, Upper Colorado, Gunnison, and combined Dolores/San Juan/San Miguel), which rely on a significant amount of data stored in the State of Colorado's relational database (HydroBase). HydroBase contains historical, real-time, and administrative water resources data, including streamflow records, climate data, diversion records, and water rights. Like the development of all CDSS products including StateCU, the data is extracted and additional data included using a data centered approach that allows the input files to be readily modified and extended through the use of Data Management Interfaces (DMIs). Time-series data, such as diversion records and streamflow measurements, are extracted and formatted for modeling efforts using the TSTool DMI. Physical data and water rights information are extracted and formatted for modeling efforts using StateDMI. This command-driven approach to input file development helps assure that results are reproducible; provides a means to revise complex input files easily; and provides self-documenting input files that include data sources and filling techniques in the file header. The command files created to develop the StateMod and StateCU Baseline data sets allow automation of changing input files to include new hydrology and climate data, and corresponding demands associated with climate variability.