CRWAS Phase I
Upper Colorado River – StateMod Model Brief

1. Introduction

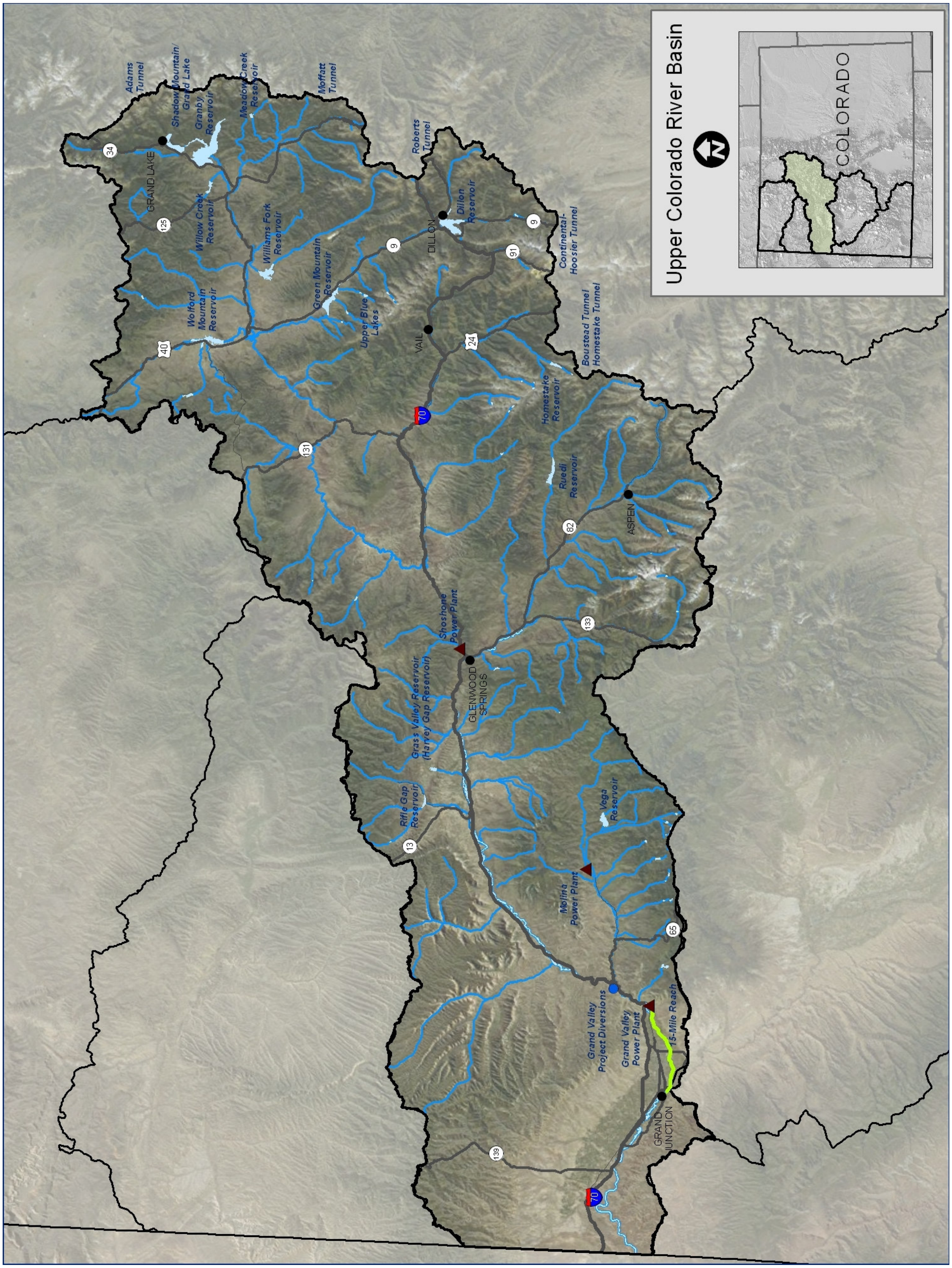
This document provides general descriptions of Upper Colorado River Basin model development, calibration, and potential enhancements. It is a companion document to ***"Overview of the Colorado Decision Support System"***, which summarizes the integrated Colorado Decision Support System (CDSS) and its primary components (including StateMod, StateCU and HydroBase). The following sections describe:

- the four primary aspects of the Upper Colorado River Basin StateMod model: 1) inflow hydrology; 2) physical infrastructure; 3) water demands; and 4) legal and administrative conditions (Section 2); and
- the process used for model calibration (Section 3).

Each section concludes with cross-references (denoted in gray boxes entitled "Where to find more detailed information:") that guide the reader to specific sections of existing CDSS documentation for further reading (e.g., Model User's Manual, Information Reports, and other CDSS documents). An Appendix describes primary water supply project operations.

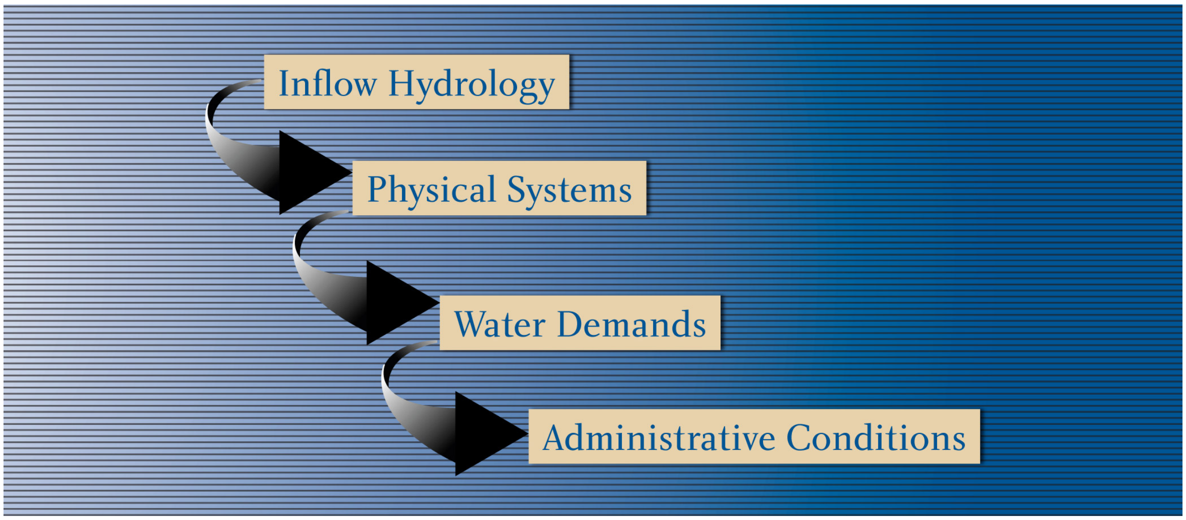
Figure 1 highlights the extent of the Upper Colorado Basin Model and key rivers, streams, towns and water storage facilities.

Figure 1: Upper Colorado River Basin Key Hydrography and Facilities



2. Model Components

The major components of the Upper Colorado Model are input files representing the basin's unique hydrology, diversions, water demands, and legal and administrative conditions affecting project operations. The model consists of the following four major components:

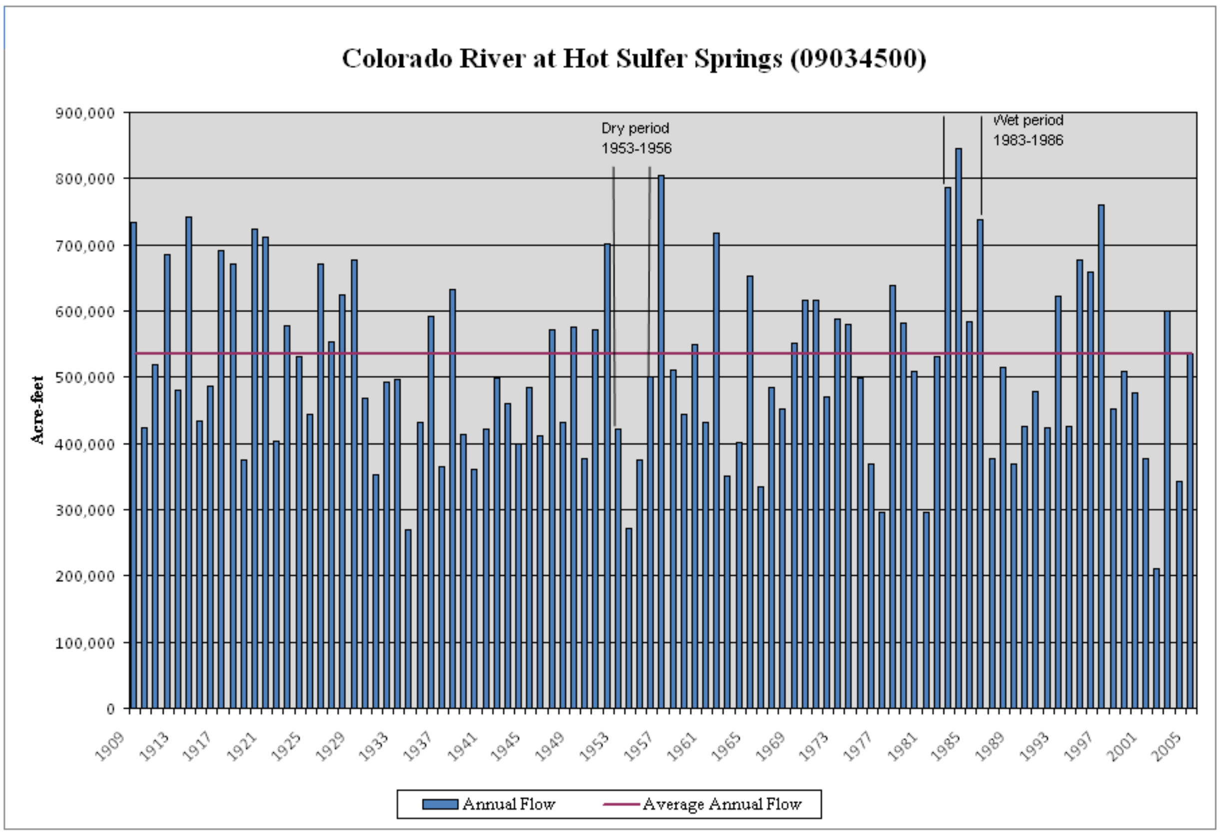


2.1 Inflow Hydrology

In order to simulate river basin operations, the model starts with the amount of water that would have been in the stream if none of the operations being modeled had taken place. These undepleted flows are called natural flows. Note that "baseflow" is synonymous with natural flow, and is the term used the Upper Colorado River Basin Water Resources Planning Model User's Manual. Natural flows represent the conditions upon which simulated diversion, reservoir, and minimum streamflow demands were superimposed. StateMod estimates natural flows at stream gages during the gage's period of record from historical streamflows, diversions, end-of-month contents of modeled reservoirs, and estimated consumption and return flow patterns. It then distributes natural flow at gage sites to ungaged locations using proration factors representing the fraction of the reach gain estimated to be tributary to a natural flow point.

Given data on historical diversions; estimated timing and location of return flows; and reservoir operations; StateMod can estimate natural flow time series at specified discrete inflow nodes. Upper Colorado River basin natural flows were estimated in three steps: 1) remove affects of man at USGS stream gage flows using historical records of operations to get natural flow time series for the gage period of record; 2) fill the gage location natural flow time series by regression against other natural flow time series; 3) distribute natural flow gains above and between gages to user-specified, ungaged inflow nodes.

Monthly natural flows for the USGS water year period 1909 through 2005 were developed to allow a long hydrologic period to "drive" the model. Because measured data was limited in the early period, and the development of natural flows required significant data-filling, the period 1950 through 2005 was chosen as the model period for the purposes of the Colorado River Water Availability Study (CRWAS). Detailed discussion on this chosen model period is provided in this Model Brief's companion document entitled "Overview of the Colorado Decision Support System". This period includes extended wet, dry, and average periods plus both extreme drought and high runoff years. The wide variation in hydrology provides the ability to check that the model adequately represents historical river administration and operations under differing flow regimes. The following natural flow graph, representing the Colorado River at Hot Sulphur Springs gage, illustrates that wet, dry, and average years are all represented in the modeling period. Successive years with annual flows below the average (e.g.,1953-1956) constitute extended dry periods; conversely, successive years with flows above the average (e.g., 1983-1986) constitute extended wet periods.



Natural flows are introduced to the Upper Colorado Model at 214 gaged and headwater locations on more than 100 Colorado River tributaries. Extended hydrology based on tree-ring data and alternate hydrology based on climate change and forest modification scenarios will replace the natural flows at the 82 USGS stream gage locations, and the automated process developed as part of CDSS will allow the distribution of these new natural flows to the remaining ungaged inflow nodes. In addition to the main stem Colorado River, main tributaries represented include:

- Fraser River
- Williams Fork River
- Blue River
- Eagle River
- Roaring Fork River
- Plateau Creek

In addition, nearly 100 other sub-tributaries are included. The decision on which streams to include in the model was generally based on the extent of acreage irrigated served by diversions or the presence of a transbasin diversion.

2.1.1 Data Sources and Filling Techniques

Data required to generate natural flows include historical streamflow data, diversion records, reservoir storage data, irrigation water requirements, and net evaporation rates.

<u>Historical streamflows</u> data used to generate natural flows were recorded by the USGS and by Division of Water Resources (DWR). Historical streamflow data from both sources (USGS and DWR) are stored in HydroBase. The natural flow algorithm does not require that historical streamflow records be complete. Gaps in the data are filled only for natural flows estimated at gage locations, after the affects of man have been removed, using the automated USGS Mixed Station Model. The name refers to its ability to use regression correlations to fill missing natural flows for many stations, using natural flows from available stations.

<u>Historical diversions</u> are recorded by water commissioners and stored in HydroBase. For most water districts in the Upper Colorado River basin, diversion records have been digitized from field notebooks and are generally complete from 1974 on. Many of the larger structures have diversion records in HydroBase back to the early 1950s. Diversion records are filled prior to being used in the natural flow calculation using a wet/dry/average month approach using an automated algorithm available in the CDSS DMIs. Each water district is associated with a long-term gage used to statistically assign each month in the study period a wet, dry, or average hydrologic designation. If diversion records for a ditch are missing in a designated "wet" month, then the average of diversion records for available "wet" months will be used.

<u>Historical reservoir end-of-month contents</u> for the larger reservoirs are generally measured by the reservoir operators. This information is then provided to the water commissioners and stored in HydroBase. The only exception for reservoirs included in the Upper Colorado Model is Vega Reservoir; end-of-month contents data were supplied directly from the Grand Junction USBR office. Historical records are complete for most reservoirs. Missing records are filled based on linear interpolation if a maximum of three consecutive months are missing, then remaining missing data is filled using the wet/dry/average approach. Again, this filling procedure has been automated using the CDSS DMIs.

<u>Irrigation water requirements</u> are determined, by ditch, for the period 1950 through 2005 using StateCU. The calculation methods require mean monthly temperature and total monthly precipitation. Twelve climate stations are used to represent temperature and precipitation in the Upper Colorado River basin. The climate stations selected for the analysis are maintained by the National Oceanic and Atmospheric Administration (NOAA). NOAA provides recorded data to DWR, and it is stored in HydroBase. Most of the climate stations used in the analysis have complete data for this period, therefore only minor filling was required. Mean monthly temperature was filled based on nearby climate station's data using monthly regression and monthly precipitation was filled based on monthly averages for the measured data, automated using the CDSS DMIs. Irrigation water requirements for the study period prior to 1950 are estimated using the automated wet/dry/average approach discussed above.

Average net monthly evaporation rates are based on annual pan evaporation and precipitation measurements made at several climate stations stored in HydroBase, many located at reservoir sites in the basin.

Where to find more detailed information:

- Section 4.7 of the Upper Colorado River Basin Water Resources Planning Model User's Manual, available on the CDSS website, provides details of the Baseflow (Natural Flow) Estimation process.
- Table 5.2 of the Upper Colorado River Basin Water Resources Planning Model User's Manual lists the gaged locations where natural flows are introduced to the model.
- Section 4.4.2 of the Upper Colorado River Basin Water Resources Planning Model User's Manual describes the automated time series filling algorithms.
- Section 4.4.3 of the Upper Colorado River Basin Water Resources Planning Model User's Manual describes the natural flow filling using the Mixed Station Model.
- Section 5.6.2 of the Upper Colorado River Basin Water Resources Planning Model User's Manual describes the evaporation rates and source used for each reservoir.

2.2 Physical Systems

The Upper Colorado Model includes active diversion structures, reservoirs, carrier systems, and instream flow reaches. Although every active diversion structure or reservoir is not explicitly included in the Upper Colorado Model, 100 percent of the estimated irrigated acreage and storage in the basin is represented. Early in the CDSS process it was decided that, while all consumptive use should be represented in the models, it was not practical to model each and every water right or diversion structure individually. Explicit structures were selected based on a variety of criteria including amount and seniority of water rights, quantity of historical diversions, importance in administration, and participation in reservoir projects.

Seventy-five percent of use in the basin is explicitly represented at correct river locations relative to other users, with strictly correct priorities relative to other users. The remaining structures are grouped into "aggregates" based generally on tributary boundaries, gage locations, critical administrative reaches, and instream flow reaches. The model includes over 400 explicit structures and 65 aggregates.

Similarly, not every reservoir and stock pond is explicitly included in the Upper Colorado Model. Reservoirs with minimum decreed capacities of 4,000 acre-feet are considered key reservoirs, and are explicitly modeled. There are 18 key reservoirs with a combined total capacity of approximately 1,370,000 acre-feet, or 94 percent of the total modeled storage capacity of the basin. The remaining basin storage is grouped into ten aggregate reservoirs and one aggregate stock pond. Wolcott Reservoir is physically included in the model for future scenarios, but its water rights are turned off for the Baseline simulation.

There are 66 CWCB instream flow segments modeled, accounting for instream flow segments decreed prior to 2005 that may affect basin operations. Headwater instream flow segments above the most upstream modeled diversions have, in some cases, been excluded. Instream flow segments on tributaries not specifically represented in the model are also not included. There are also 23 minimum bypass requirements for reservoirs and transbasin diversions included. The 15-mile reach fish flow segment is also represented.

The location of each structure or instream flow segment, in relationship to tributaries and other structures (upstream or downstream), is defined based on CDSS GIS coverages, available straight-line diagrams, and discussions with water commissioners. Physical information about diversion structures and reservoir capacities is required to constrain modeled water use – diversion structures are not allowed to divert more than canal capacity and reservoirs are not allowed to store more than reservoir storage capacity. In addition, the model will constrain controlled releases from reservoirs to downstream river channel capacity.

Physical information that represents the location of irrigated land, in terms of timing and location of return flows, is also incorporated into the model input files. Information required for reservoirs includes area/capacity curves, minimum reservoir pools, and user accounts within a reservoir.

2.2.1 Data Sources and Filling Techniques

Physical information regarding capacities (ditches and reservoirs) is stored in HydroBase. Little information was available from original permits and decrees, therefore ditch capacities were often set in HydroBase as the sum of direct water rights under the ditch and reservoir capacity was often set as the sum of storage rights. As information continues to be gathered during the CDSS efforts, capacity information in HydroBase is updated to reflect user-provided information. Therefore, for the larger ditches that warranted user interviews, ditch capacities are set based on user-supplied information. For the remaining ditches, the data centered DMI approach allows ditch capacity to be set based on the maximum daily diversion recorded.

Reservoir capacity, area-capacity curves, dead pool and user-account information was collected based on interviews with the reservoir owners and operators. As noted above, much of that information has now been incorporated into HydroBase and is extracted directly for use in the modeling effort.

Irrigation return flow locations have been estimated based on the location of irrigated land and topography, using CDSS GIS available coverages. Each irrigation structure has been assigned a generic return flow delay pattern that recognizes the proximity of the irrigated acreage to a surface stream or drainage. Glover or other lagging analyses have not been performed for each irrigation structure.

Where to find more detailed information:

- Section 4.2.2 of the Upper Colorado River Basin Water Resources Planning Model User's Manual provides details and criteria used to select explicit versus aggregate structures. Section 4.2.3 of the Upper Colorado River Basin Water Resources Planning Model User's Manual provides details and criteria used to select explicit versus aggregate reservoir structures.
- Table 5.4 of the Upper Colorado River Basin Water Resources Planning Model User's Manual lists each of the key structures represented in Upper Colorado Model.
- Appendix A and Appendix B of the Upper Colorado River Basin Water Resources Planning Model User's Manual describes the aggregation process for irrigation and non-irrigation structures and reservoirs.

2.3 Water Demands

The Upper Colorado Baseline Model demands reflect current levels of irrigation, population, and reservoir capacity superimposed over historical natural flow hydrology from 1909 through 2005. Irrigation headgate demands are set to the irrigation water requirement for the specific time step and structure, divided by the historical efficiency for that month of the year. Irrigation water requirements allow demands to reflect full supply, and not be limited by water rights and administration. Historical system efficiencies reflect irrigation practices associated with application methods, conveyance losses, and other user choices such as early and late season diversions to fill the soil reservoir.

Municipal demands in the baseline data set are based on average monthly diversions over the recent period 1998 through 2005 for the entire model period of 1909 through 2005. Industrial demand estimations varied based on the specific use. For instance, Henderson Mine demand was set to the 1975 through 1991 average depletion while Shoshone Power Plant demand was set to the decree limits of its associated water rights.

In general, transbasin diversion demands were set to average monthly diversions over the period 1998 through 2005 for the entire model period of 1909 through 2005.

Instream flow demands are set to the decreed monthly rates for the entire period of 1909 through 2005. Bypass flow requirements are set to monthly decreed amounts or amounts agreed to in operational agreements. Two structures have minimum streamflow demands that vary monthly and annually: the USFWS Recommended Fish Flow for the 15-mile reach between Cameo and the confluence with the Gunnison River and the Granby Reservoir Minimum Release. These two demands are based on hydrologic conditions.

Minimum and maximum reservoir target storage limits are set as reservoir “demands”. Reservoirs may not store more than the maximum target, or release to the extent that storage falls below the minimum target. In the Baseline data set, the minimum targets were set to zero, and the maximum targets were set to capacity for reservoirs that operate primarily for agricultural and municipal diversion storage. Maximum targets were set to operational targets according to rule curves provided by USBR for Ruedi, Green Mountain, and Willow Creek reservoirs; and rule curves provided by Denver Water for Williams Fork reservoir.

2.3.1 Data Sources and Filling Techniques

Irrigation water requirements and average historical monthly efficiencies used to estimate irrigation demands are calculated by StateCU. Data sources and filling techniques used to determine Baseline irrigation water requirements are described in Section 4.9.1 of the Upper Colorado River Basin Water Resources Planning Model User’s Manual. Average historical monthly efficiency is the average system efficiency (combined conveyance and application efficiency) over the period 1975 through 2004, capped at 60 percent. These efficiencies are calculated by StateCU based on historical acreage for the period and historical diversions. Historical diversion records are extracted from HydroBase and filled if needed, as described in Section 4.4.1 of the Upper Colorado River Basin Water Resources Planning Model User’s Manual.

Monthly decreed demands for instream flow segments are extracted from the water rights tabulation stored in HydroBase. Minimum bypass requirements are based on agreements, and USFS fish flows are based on review of specific decrees, user-interviews, and information provided by water commissioners and CWCB staff.

As discussed above, operational targets for some USBR and Denver Water reservoirs were obtained directly from those sources.

Where to find more detailed information:

- Section 4.9.1 and Section 5.4.4 of the Upper Colorado River Basin Water Resources Planning Model User’s Manual provides details and criteria used to estimate calculated demands for diverting structures.

2.4 Legal and Administrative Conditions

Legal and administrative conditions include water rights (direct, storage, instream flow); policies and agreements such as minimum bypass flows; and reservoir operations. The method used to impose these conditions on the demands highlights why StateMod is an appropriate tool for representing Colorado's water rights system. Each water right and operational right is assigned an administration number. For water rights, the administration number is calculated from the appropriation and adjudication dates.

For bypass requirements, the administration number reflects the agreed upon "order" that the bypass requirement must be met. For instance, the administration number assigned to the minimum bypass requirement downstream of Denver Water's transbasin diversion on Jim Creek is just senior to the Jim Creek diversion. StateMod then "allocates" water to the minimum bypass prior to "allocating" water to the Jim Creek diversion. Similarly, the administration number assigned to an operating rule that defines a reservoir release to an irrigation structure with a direct flow right is just junior to the direct flow right. StateMod allocates water to meet the irrigation demand using the direct flow, and then allocates reservoir releases if the demand is not fully satisfied.

Primary project operations requiring operational rights in the model include the following which are further described in Appendix A:

- Colorado-Big Thompson and Windy Gap Project Operations
- Green Mountain Operations
- Continental-Hoosier Project Operations
- Denver-Dillon Reservoir Operations
- Wolford Mountain Reservoir Operations
- Williams Fork Reservoir and Moffat Tunnel Operations
- Fryingpan-Arkansas Project and Ruedi Reservoir Operations
- Grand Valley Operations
- Homestake Project Operations
- Silt Project Operations
- Colbran Project and Vega Reservoir Operations
- Blue River Decree Operations
- 15-Mile Reach Endangered Fish Flow Operations
- Other Project Operations

More specific information on these primary project operations is presented in the Appendix at the end of this document.

2.4.1 Data Sources and Filling Techniques

Direct flow water rights are assigned to each diversion structure; storage rights are assigned to each reservoir; and instream flow rights are assigned to each instream flow segment. The CDSS

DMIs automate the assignment of these rights directly from the water rights tabulation in HydroBase.

Seventeen different operating rules types are used in the Upper Colorado Model Baseline data set. The complexity of the basin requires a total of 334 operational rights. Typically, these are operations involving two or more structures, such as a release from a reservoir to a diversion structure, a release from one reservoir to a second reservoir, or a diversion to an off-stream reservoir. The appropriate rules to apply to each complex operation were generally determined based on information from reservoir operators and water administrators.

3. Model Calibration

As noted above, the Upper Colorado River Model study period for CRWAS from 1950 through 2005 was selected to include representative hydrologic periods. A subset of the study period, 1975 through 2005 was selected for model calibration. This calibration period was selected because historical diversion data were readily available (limited data filling required) and the period includes both drought (1977, 2002-2003) and wet cycles (1983-1985).

Calibration is the process of simulating the river basin under historical conditions, and judiciously adjusting parameter values to achieve agreement between observed and simulated values of streamflow gages, reservoir levels, and diversions. The Upper Colorado Model was calibrated in a two-step process as follows:

3.1 First Step Calibration

In the first calibration run, the model was executed with relatively little freedom with respect to operating rules. Headgate demand was simulated by historical diversions, and historical reservoir contents served as operational targets. The reservoirs would not fill beyond the historical content even if water was legally and physically available. Operating rules caused the reservoir to release to satisfy beneficiaries' demands, but if simulated reservoir content was higher than historical after all demand was satisfied, the reservoir released water to the river to achieve the historical end-of-month content. In addition, multiple-headgate collection systems would feature the historical diversion as the demand at each diversion point.

The objective of the first calibration run was to refine natural flow hydrology and return flow locations before introducing uncertainties related to rule-based operations. Diversion shortages, that is, the inability of a water right to divert what it diverted historically, indicated possible problems with the way natural flows were represented or with the location assigned to return flows back to the river. Natural flow issues were also evidenced by poor simulation of the historical gages. Generally, the parameters that were adjusted related to the distribution of natural flows (i.e., the method for distributing natural flows to ungaged locations), and locations of return flows.

3.2 Second Step Calibration

In the second calibration run, constraints on reservoir operations were relaxed. As in the first calibration run, reservoirs were simulated for the period in which they were on-line historically. Reservoir storage was limited by water rights and availability and reservoir releases were controlled by downstream demands. The objective of the second calibration step was to refine operational parameters. For example, poor calibration at a reservoir might indicate poor representation of administration or operating objectives. Calibration was evaluated by comparing simulated gage flows, reservoir contents, and diversions with historical observations of these parameters. The model at the conclusion of the second step is considered the calibrated model. In some cases, reservoir operations have changed during our calibration period. Because we want our model to reflect current operations, calibration may be satisfied by explaining the differences in modeled versus measured condition. For instance, Green Mountain Reservoir operations include the Division 5 Interim Agreement approach to operating the Blue River Decree, which was not in place during the entire calibration period.

The model is calibrated on a basin-wide level, meaning that major projects, diversions, and basin operations were specifically reviewed and modified, if necessary, so they are represented appropriately. Because calibration efforts concentrated on gage and reservoir locations, ungaged tributaries were not reviewed to the level of detail as gaged areas. The purpose of the Colorado River Water Availability Study is to determine the potential basin-wide effects of climate variability, therefore the calibrated model provides an appropriate prediction tool. When using this model for future analyses involving areas of the basin without historical stream gages that rely on derived hydrology, it is recommended that further stream flow evaluations be conducted. A refined calibration will improve results of local analyses. Average annual streamflow calibration results are presented in the **Table 3.1** for gages with complete records during the calibration period.

Table 3.1
Historical and Simulated Average Annual Streamflow Volumes (1975-2005)
Calibration Run (acre-feet/year)

Gage ID	Historical	Simulated	Historical -Simulated		Gage Name
			Volume	Percent	
09010500	45,792	45,792	0	0%	Colorado R Below Baker Gulch, Nr Grand Lake, CO.
09011000	57,764	57,764	0	0%	Colorado River Near Grand Lake, CO.
09019500	39,532	39,385	147	0%	Colorado River Near Granby
09021000	31,132	31,412	-280	-1%	Willow Creek Below Willow Creek Reservoir
09024000	13,309	13,384	-76	-1%	Fraser River At Winter Park
09025000	10,289	10,387	-98	-1%	Vasquez Creek At Winter Park, CO.
09026500	15,221	15,230	-9	0%	St. Louis Creek Near Fraser, CO.
09032000	8,860	9,368	-508	-6%	Ranch Creek Near Fraser, CO.
09032499	8,064	8,064	0	0%	Meadow Creek Reservoir Inflow
09034250	183,828	182,902	926	1%	Colorado River At Windy Gap, Near Granby, CO.
09034500	168,786	169,056	-270	0%	Colorado River At Hot Sulphur Springs, CO.
09034900	7,564	7,564	0	0%	Bobtail Creek Near Jones Pass, CO.
09035500	14,124	14,183	-59	0%	Williams Fork Below Steelman Creek, CO.
09036000	72,517	72,576	-59	0%	Williams Fork River Near Leal, Co
09037500	79,248	78,914	333	0%	Williams Fork River Near Parshall, Co
09038500	92,719	92,406	313	0%	Williams Fork River Below Williams Fork Reservoir
09039000	22,365	22,625	-260	-1%	Troublesome Creek Near Pearmont, CO.
09040000	22,498	22,596	-99	0%	East Fork Troublesome C Near Troublesome, CO.
09041000	49,395	49,501	-106	0%	Muddy Creek Near Kremmling, CO.
09041500	66,565	64,680	1,885	3%	Muddy Creek At Kremmling, CO.
09046600	69,345	69,146	199	0%	Blue River Near Dillon, CO.
09047500	45,449	45,454	-5	0%	Snake River Near Montezuma, CO.
09050100	75,063	75,202	-140	0%	Tenmile Creek Below North Tenmile Creek At Frisco
09050700	146,624	146,889	-265	0%	Blue River Below Dillon Reservoir
09052800	18,677	18,677	0	0%	Slate Creek At Upper Station, Near Dillon, CO.

Gage ID	Historical	Simulated	Historical -Simulated		Gage Name
			Volume	Percent	
09053500	312,566	323,369	-10,802	-3%	Blue River Above Green Mountain Reservoir, CO.
09054000	22,776	22,776	0	0%	Black Creek Below Black Lake, Near Dillon, CO.
09055300	14,558	14,558	0	0%	Cataract Creek Near Kremmling, CO.
09057500	301,300	299,296	2,005	1%	Blue River Below Green Mountain Reservoir
09058000	718,265	719,296	-1,031	0%	Colorado River Near Kremmling
09060500	24,031	24,031	0	0%	Rock Creek Near Toponas, CO.
09063000	28,262	28,283	-21	0%	Eagle River At Red Cliff, CO.
09064000	19,824	20,231	-406	-2%	Homestake Creek At Gold Park, CO.
09065100	37,802	37,802	0	0%	Cross Creek Near Minturn
09065500	22,232	22,232	0	0%	Gore Creek At Upper Station, Near Minturn, CO.
09070000	407,419	407,597	-179	0%	Eagle River Below Gypsum
09070500	1,455,699	1,458,108	-2,409	0%	Colorado River Near Dotsero
09071300	9,755	9,755	0	0%	Grizzly Creek Near Glenwood Springs, CO.
09073400	71,114	71,299	-185	0%	Roaring Fork River Near Aspen
09074000	30,203	30,239	-36	0%	Hunter Creek Near Aspen
09074800	31,675	31,675	0	0%	Castle Creek Above Aspen, CO.
09075700	50,076	50,076	0	0%	Maroon Creek Above Aspen, CO.
09078600	76,881	77,136	-255	0%	Fryingpan River Near Thomasville
09080400	123,912	124,148	-236	0%	Fryingpan River Near Ruedi
09081600	215,575	215,575	0	0%	Crystal River Above Avalanche Creek Near Redstone
09082800	10,923	10,923	0	0%	North Thompson Creek Near Carbondale, CO.
09085000	860,602	861,584	-982	0%	Roaring Fork River At Glenwood Springs
09085100	2,370,982	2,374,373	-3,392	0%	Colorado River Below Glenwood Springs
09085200	40,635	40,728	-93	0%	Canyon Creek Above New Castle, CO.
09089500	30,280	30,280	0	0%	West Divide Creek Near Raven
09092500	3,591	3,591	0	0%	Beaver Creek Near Rifle
09093000	35,518	35,518	0	0%	Parachute Creek Near Parachute CO.
09093500	22,997	23,271	-273	-1%	Parachute Creek At Parachute, CO.
09093700	2,816,135	2,820,844	-4,708	0%	Colorado River Near De Beque
09095000	38,970	39,416	-447	-1%	Roan Creek Near De Beque, CO.
09095500	2,726,210	2,730,046	-3,837	0%	Colorado River Near Cameo
09096500	22,259	29,370	-7,111	-32%	Plateau Creek Near Collbran, CO.
09097500	30,446	31,166	-720	-2%	Buzzard Creek Near Collbran
09105000	154,723	156,867	-2,144	-1%	Plateau Creek Near Cameo
09152500	1,841,072	1,841,070	2	0%	Gunnison River Near Grand Junction
09163500	4,585,370	4,590,846	-5,477	0%	Colorado River Near Colorado-Utah State Line

As shown in the Table 3.1, calibration at each stream gage is within three percent with the exception of two gages. Plateau Creek near Collbran gage deviated from historical information due to limited reservoir and gage data and inadequate understanding of operations. Although calibration at the lower Plateau Creek gage is good, there is still some uncertainty in project operations regarding reservoir feeder canals and the South Side Canal deliveries, despite assistance from project operators. Similarly, the lack of gaged diversions and streamflow data on Ranch Creek contributed to greater differences in simulated versus gaged flow.

Table 3.2 summarizes the average annual shortage for water years 1975 through 2005, by tributary or sub-basin in Colorado. On a basin-wide basis, average annual diversions differ from historical diversions by around 1 percent in the calibration run.

Table 3.2
Historical and Simulated Average Annual Diversions by Sub-basin (1975-2005)
Calibration Run (acre-feet/year)

Tributary or Sub-basin	Historical	Simulated	Historical minus Simulated	
			Volume	Percent
Colorado Main Stem	3,090,881	3,064,110	26,771	1%
Fraser River	83,553	82,351	1,202	1%
Williams Fork River	41,297	41,235	62	0%
Blue River	157,539	154,238	3,301	2%
Eagle River	121,772	120,627	1,145	1%
Roaring Fork River	454,984	446,031	8,954	2%
Plateau Creek	132,689	129,999	2,690	2%
Basin Total	**4,082,716**	**4,038,590**	**44,125**	**1%**

Where to find more detailed information:

- Section 7 of the Upper Colorado River Basin Water Resources Planning Model User's Manual provides detailed calibration results, including time-series graphs and scatter plots of streamflow and reservoir calibrations.

Appendix: Upper Colorado River Basin Primary Project Operations

1. Colorado-Big Thompson and Windy Gap Project Operations

The Colorado-Big Thompson (CBT) and Windy Gap Project divert water from the Upper Colorado River basin via the Alva B. Adams Tunnel for irrigation and municipal use in the South Platte River basin.

Nine operating rules are used to simulate the project Baseline operations. Storage rights allow Shadow Mountain/Grand Lake, Granby, and Willow Creek to store water from their local drainages without the need to specify operating rules. Operating rules used to allow the model to perform the following Colorado-Big Thompson Project operations:

- Transfer water from Granby Reservoir to Shadow Mountain/Grand Lake through the Granby Pumping Plant
- Divert from Shadow Mountain/Grand Lake to meet demands assigned to Adams Tunnel
- Divert direct flow through the Willow Creek Feeder Canal for storage in Granby Reservoir
- Release water from Willow Creek Reservoir for storage in Granby Reservoir through the Willow Creek Feeder Canal
- Release water from Granby Reservoir to maintain a seasonal minimum flow downstream
- Divert direct flow from Windy Gap to Granby Reservoir through the Windy Gap Pipeline

2. Green Mountain Operations

Green Mountain Reservoir serves as the replacement reservoir for the CBT system. In addition to the CBT replacement account, Green Mountain has a Historic Users Pool (HUP) western slope account for agriculture and municipal users; a Contract account for diverters other than the CBT and HUP beneficiaries; a Silt Project account, which stores water for demand met by the Silt Pump Canal; and a Surplus Fish account for future applications of the Upper Colorado Model.

Twenty-three operating rules are used to simulate the Baseline operations associated with Green Mountain Reservoir. Storage rights allow Green Mountain to store water from the Blue River without the need to specify operating rules. Operating rules are used to allow the model to perform the following Green Mountain Reservoir operations:

- Carry water from Elliot Creek for storage in Green Mountain Reservoir through the Elliot Creek Feeder Canal
- Exchange water from the CBT account in Green Mountain Reservoir for storage in Granby, Shadow Mountain/Grand Lake, and Willow Creek
- Release water from the Silt account in Green Mountain for diversion through the Silt Pump Canal

- Release water from the HUP account in Green Mountain, either directly or by exchange, to meet unsatisfied demands for eligible HUP recipients. Note that there is a volumetric limitation of 66,000 acre-feet annually for HUP pool use.
- Release water from the Contract account in Green Mountain, either directly or by exchange, to meet unsatisfied demands for contract users
- Release excess water in the HUP pool to meet endangered fish demands in the 15-mile reach
- Allow Green Mountain to store under a 1955 right the amount of water that was diverted and stored out-of-priority to Green Mountain's senior first fill right by Denver and Colorado Springs. When water is stored under this right it reduces the out-of-priority obligation owed by Denver and Colorado Springs proportionately (Blue River Decree Operations)

3. Continental-Hoosier Project Operations

The Continental-Hoosier Project, sometimes called the Blue River Project, diverts water from the headwaters of the Blue River and its tributaries into the South Platte River Basin for the City of Colorado Springs municipal water supply. Upper Blue Lakes provide water to the Continental-Hoosier Tunnel when the tunnel's direct diversion rights are not in priority. Both Continental-Hoosier Tunnel and Upper Blue Lakes operate out-of-priority to Green Mountain Reservoir as part of the Blue River Decree.

Seventeen operating rules are used to simulate the Baseline operations associated with the Continental-Hoosier Project. Storage rights allow Upper Blue Lakes to store water from the Blue River without the need to specify operating rules. Operating rules are used to allow the model to perform the following Continental-Hoosier Project operations:

- Carry water from the collection nodes on the Blue River tributaries to the tunnel node, where the demand is represented
- Divert water out-of-priority to Green Mountain Reservoir storage right (Blue River Decree Operations)
- Release water from Upper Blue Lakes to the tunnel demand node
- Release water on August 1st to simulate a trade with Wolford Mountain Reservoir
- Release water from Upper Blue Lakes to replace out-of-priority obligations during substitution years, depending on obligations, water is released to Dillon or Green Mountain (Blue River Decree Operations)

4. Denver-Dillon Reservoir Operations

The City of Denver diverts water from the upper Blue River basin to the South Platte basin through the Harold D. Roberts Tunnel (Roberts Tunnel). Dillon Reservoir provides water to Roberts Tunnel when the tunnel's direct diversion right is not in priority. Both Roberts Tunnel and Dillon Reservoir operate out-of-priority to Green Mountain Reservoir as part of the Blue River Decree. Dillon Reservoir also stores water for the beneficiaries of the original Summit County Agreement and the Clinton Reservoir Agreement. In substitution years, when Denver's out-of-priority diversions need to be paid back to Green Mountain Reservoir, Dillon supplies water for the 50 cfs instream flow below Dillon Reservoir.

Thirty-five operating rules are used to simulate the Baseline operations associated with Dillon Reservoir and Roberts Tunnel. Storage rights allow Dillon Reservoir to store water from the Blue River without the need to specify operating rules. Operating rules are used to allow the model to perform the following project operations:

- Divert water through Roberts Tunnel out-of-priority to Green Mountain Reservoir (Blue River Decree Operations)
- Store water in Dillon Reservoir out-of-priority to Green Mountain Reservoir (Blue River Decree Operations)
- Release water from Dillon Reservoir to meet Roberts Tunnel demands
- Release water from Dillon Reservoir to Green Mountain replace Denver's out-of-priority obligations during substitution years (Blue River Decree Operations)
- Release water from Dillon to meet minimum stream flow requirement (Blue River Decree Operations)
- Release water from Clinton Gulch Reservoir via pipeline to Climax-Ten Mile Creek Diversion (Clinton Gulch Agreement)
- Release water from Dillon to beneficiaries of the Summit County and Clinton Reservoir-Fraser River agreements (Town of Breckenridge, Town of Dillon, Town of Keystone, Breckenridge Ski Area, Copper Mountain Ski Area, Keystone Ski Area)

5. Wolford Mountain Reservoir Operations

Wolford Mountain Reservoir is operated by the Colorado River Water Conservation District. Wolford Mountain includes a West Slope account, plus accounts for Denver and Colorado Springs that can be used to meet replacement requirements or fish flows in lieu of other higher reservoirs.

Seventy-seven operating rules are used to simulate the Baseline operations associated with Wolford Mountain Reservoir. Storage rights allow Wolford Mountain Reservoir to store water from Muddy Creek without the need to specify operating rules. Operating rules are used to allow the model to perform the following project operations:

- Release water from Wolford Mountain to meet the USFWS fish flow demand in the 15-Mile reach
- Release water in exchange for diversions by Fraser and other Middle Park water users
- Release water from Colorado Springs and Denver accounts directly or by exchange to meet Green Mountain Reservoir obligations

6. Williams Fork Reservoir and Moffat Tunnel Operations

The City of Denver diverts water from the upper Fraser basin into the South Platte River basin via the Moffat Tunnel. The city of Englewood also diverts their Englewood Cabin-Meadow Creek Project water through the Moffat Tunnel. These systems include several collection points in the upper Fraser basin, Williams Fork Reservoir and Meadow Creek Reservoir.

Sixty-nine operating rules are used to simulate the Baseline operations associated with Williams Fork Reservoir, Meadow Creek Reservoir, and diversion through the Moffat Tunnel. Storage rights allow Williams Fork Reservoir to store water from Williams Fork and Meadow Creek Reservoir to store water from Meadow Creek without the need to specify operating rules. Operating rules are used to allow the model to perform the following project operations:

- Carry water from the Moffat Tunnel collection points on Jim, Vasquez, St. Louis, Ranch, Cabin, and Meadow Creeks to Moffat Tunnel for diversions to the South Platte basin
- Release water form Meadow Creek Reservoir to Vail Ditch for irrigation use and to the Moffat Tunnel collection points for diversion to the South Platte basin
- Release water from Williams Fork Reservoir in exchange for diversions through Gumlick (Jones Pass) Tunnel and subsequent diversion through the Moffat Tunnel collection points
- Release water from Williams Fork Reservoir in exchange for diversions through the Moffat Tunnel collection points
- Release water from Williams Fork Reservoir directly or by exchange to meet Green Mountain Reservoir obligations
- Release water from Williams Fork Reservoir to meet the USFWS fish flow demand in the 15-Mile reach

7. Fryingpan-Arkansas Project and Ruedi Reservoir Operations

The Fryingpan-Arkansas (Fry-Ark) Project diverts water from the Fryingpan River and Hunter Creek basins into the Arkansas River basin via Boustead Tunnel for use on the Front Range. Ruedi Reservoir provides replacement water for out-of-priority diversions through Boustead Tunnel and contract water for western slope uses, and water to meet the USFWS fish flow demand in the 15-Mile reach.

Eighteen operating rules are used to simulate the Baseline operations associated with the Fryingpan-Arkansas Project. Storage rights allow Ruedi Reservoir to store water from the Fryingpan River without the need to specify operating rules. Operating rules are used to allow the model to perform the following project operations:

- Carry water from the collection North Side and South Side collection points to Boustead Tunnel for diversion to the Arkansas River
- Release water from Ruedi Reservoir by exchange for out-of-priority diversions through the Boustead Tunnel collection points
- Release water from Ruedi Reservoir to meet the USFWS fish flow demand in the 15-Mile reach
- Release water from Ruedi Reservoir to meet “Round 1” and “Round 2” west slope municipal and industrial demands

8. Grand Valley Operations

Grand Valley Operations include diversions for the Government Highline Canal, Orchard Mesa Irrigation District (OMID) irrigation, OMID hydraulic pump, and the Grand Valley Power Plant

(USA Power Plant). These structures receive water by a series of operational rules that pull water from the Grand Valley Project roller dam.

Eleven operating rules are used to simulate the Baseline operations associated with the Grand Valley operations. Operating rules are used to allow the model to perform the following project operations:

- Carry water from the roller dam to the individual Grand Valley Project demands
- Operate the Orchard Mesa Check to allow return flows from power diversions to be returned upstream of the Grand Valley Irrigation Canal headgate

9. Homestake Project Operations

The Homestake Diversion Project exports water from Homestake Creek, a tributary of the Eagle River, into the Arkansas River basin for the cities of Colorado Springs and Aurora. The project includes Homestake Project Tunnel, Missouri Tunnel collection system, and Homestake Reservoir.

Two operating rules are used to simulate the Baseline operations associated with the Homestake Project. Direct diversion rights on Homestake Creek allow water to be diverted directly through the Homestake Project Tunnel without the need to specify operating rules. Operating rules are used to allow the model to perform the following project operations:

- Carry water from the Missouri Tunnel collection system to Homestake Reservoir
- Release water from Homestake Reservoir to Homestake Tunnel

The Baseline data set includes operating rules allowing Homestake Reservoir to be used as an alternate replacement source for Green Mountain Reservoir (similar to Denver's operations of Wolford Mountain Reservoir). At the time the model was developed, these operations were not decreed; therefore these operating rules are turned off.

10. Silt Project Operations

The Silt Project provides supplemental water for irrigation use in the general vicinity of Rifle Creek. The two primary facilities of the project include Rifle Gap Reservoir on Rifle Creek and the Silt Pump Plant, located on the main stem of the Colorado River. The project also uses Grass Valley Canal, East Lateral, West Lateral, and Grass Valley Reservoir (a.k.a. Harvey Gap Reservoir), owned by the Farmers Irrigation Company. The project demands are represented by two structures – Dry Elk Valley Irrigation demand and Farmers Irrigation Company demand. Grass Valley Canal is operated as a carrier structure to both demands and to Harvey Gap Reservoir.

Twelve operating rules are used to simulate the Baseline operations associated with the Silt Project. Storage rights allow Rifle Gap Reservoir to store water from Rifle Creek without the need to specify operating rules. Operating rules are used to allow the model to perform the following project operations:

- Carry water to Dry Elk Valley Irrigation through Grass Valley Canal
- Carry water for storage in Harvey Gap Reservoir through Grass Valley Canal
- Release water from Rifle Gap Reservoir in exchange for diversions through Grass Valley Canal to meet Dry Elk Valley Irrigation demands
- Release water from Rifle Gap Reservoir in exchange for diversions through Grass Valley Canal to store in Harvey Gap Reservoir
- Release water from Rifle Gap Reservoir for diversion by Davie Ditch
- Release water from Harvey Gap Reservoir to meet Farmers Irrigation Company demands
- Divert water at the Silt Pump Plant to meet Farmers Irrigation Company demands

11. Colbran Project and Vega Reservoir Operations

The Colbran Project provides supplemental irrigation water for diverters in the Plateau Creek basin and generates hydroelectric power through the Molina Power Plant. The primary features include Vega Reservoir, the Southside Canal, and the Molina Power Plant. The Molina Power Plant is served by two carrier ditches, Bonham Branch Pipeline and Cottonwood Branch Pipeline, on Big and Cottonwood Creeks, respectively. Small upstream reservoirs are represented in an aggregated fashion by the Bohnam Aggregate Reservoir and the Cottonwood Aggregated Reservoir.

Sixty-four operating rules are used to simulate the Baseline operations associated with the Colbran Project. Storage rights allow Vega Reservoir to store water from Plateau Creek without the need to specify operating rules. Operating rules are used to allow the model to perform the following project operations:

- Carry water from Leon Creek through the Leon Creek Feeder Ditch and from Park Creek through the Park Creek Ditch for storage in Vega Reservoir
- Divert water through the Bohnam Branch and Cottonwood Branch Pipelines to meet demands at the Molina Power Plant
- Release water from the Bohnam and Cottonwood Aggregate Reservoirs to meet demands at the Molina Power Plant
- Release water from Vega Reservoir to the Southside Canal carrier to meet project irrigation demands on tributaries to Plateau Creek
- Release water from Vega Reservoir by exchange to project irrigation demands above Vega Reservoir

12. Blue River Decree Operations

Consolidated Case Nos. 2782, 5016 and 5017 (the Blue River Decree). In this 1955 adjudication, the relative priorities of the storage rights and hydroelectric rights for Green Mountain Reservoir and the upstream rights at Dillon Reservoir and the Continental-Hoosier System (Colorado Springs) were specified. Model operations of the Blue River Decree follow the Interim Policy adopted by the State Engineer.

When Denver incurs an obligation to repay Green Mountain Reservoir for water stored or diverted out-of-priority, operating rules allow Denver to meet those obligations by releasing their water in Williams Fork, Wolford Mountain, or Dillon Reservoirs. Likewise Colorado Springs can meet their obligations by releasing from the Upper Blue Lakes or from Wolford Mountain Reservoir.

Denver and Colorado Springs out-of-priority diversions are tracked using the StateMod Accounting Plan feature. On August 1st, the amount of water in the two Accounting Plans is reduced by the unsatisfied portion of Green Mountain's first fill right. If there is a remaining obligation (termed a substitution) Denver and Colorado Springs obligations can be "moved" to preferred reservoirs and used to meet Green Mountain general replacement requirements. The USBR provided the current release order shown in the following table, which is represented in the Baseline model operating rules. The amount that Denver and Colorado Springs release from their reservoirs is capped by their out-of-priority obligation.

Reservoir	Account Name	Capacity (acre-feet)
Wolford Mountain	Denver Replacement 1	5,000
Williams Fork	Green Mountain Replacement 1	10,000
Wolford Mountain	Colorado Springs Replacement	1,750
Wolford Mountain	Denver Replacement 2	20,610
Williams Fork	Green Mountain Replacement 2	25,000
Homestake	Homestake Reservoir Green Mountain Replacement (not represented, decree pending when developed)	21,440
Green Mountain	Historic Users Pool	66,000

13. 15-Mile Reach Endangered Fish Flow Operations

The reach of the Upper Colorado River between the headgate of the Grand Valley Irrigation Canal (GVIC) and the confluence of the Upper Colorado River and the Gunnison River is often referred to as the 15-Mile Reach. This reach is considered a critical flow reach for the protection of endangered fish species because the river can be physically dried up at the GVIC headgate. The USFWS recommended flows for the months of July through October are 1630 cfs, 1240 cfs, and 810 cfs under wet, average, and dry hydrologic conditions. In 1997, the Recovery Implementation Program – Recovery Action Plan (RIPRAP) was developed and set aside storage within the Upper Colorado River Basin to be released to the 15-Mile Reach during times of low flows.

Weekly phone conferences are held from July through October to determine the quantity and source of releases required to meet the fish demands. Although there is not a set sequence of reservoir releases, the USBR and CWCB provided the following general reservoir account and release order adopted in the Baseline model operations to meet the minimum flow requirements:

Reservoir	Account Name	Capacity (acre-feet)
Ruedi	Unallocated / 5,000 acre-feet	5,000
Williams Fork	Temporary Fish	5,413
Wolford Mountain	Temporary Fish	5,413
Ruedi	CWCB Fish	10,825
HUP Surplus		
Wolford Mountain	Denver Replacement 1	5,000
Williams Fork	Green Mountain Replacement 1	10,000
Wolford Mountain	Colorado Springs Replacement	1,750
Wolford Mountain	Denver Replacement 2	20,610
Williams Fork	Green Mountain Replacement 2	25,000
Homestake	Homestake Reservoir Green Mountain Replacement	21,440
Green Mountain	Historic Users Pool	66,000
Ruedi	USFWS 5,000 acre-feet 4/5	5,000
Wolford Mountain	Fish Account	6,000

14. Other Project Operations

Other projects that require more complex representation than simple direct flow right or storage use include Glenwood Springs Operations, Owen Creek Ditch Transbasin Operations, Leon Creek Reservoir Operations, and Ute Water Conservancy District Operations.

- Glenwood Springs is modeled with a single municipal demand that can receive water via carriers from both Grizzly Creek and No Name Creek.
- Divide Creek Highline Ditch receives imported water from both from Division 4 and (Clear Fork Feeder/Divide Creek Feeder) and from the Owens Creek Ditch.
- Ute Water Conservancy District is modeled with a single municipal demand that can receive "carrier" water via from Mason Eddy Ditch, Ute Pipeline Headgate No. 1, Rapid Creek Pumping Plant, and Coon Creek Pipeline.
- Storages in the upper reaches of Leon Creek are represented together and deliver water to the Leon Tunnel, Kiggins Salisbury Ditch, and Leon Ditch.

Where to find more detailed information:

- Section 5.9 of the Upper Colorado River Basin Water Resources Planning Model User's Manual provides details regarding project operations and operating rules.

- Section 2 of the Upper Colorado River Basin Information Report, available on the CDSS website, provides historical and overview information on Upper Colorado River Projects and Special Operations.

- Section 3 of the Upper Colorado River Basin Information Report provides Division 5 personnel recommendations on how to model basin project operations.

- 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.