CRWAS Phase I
White River – StateMod Model Brief

1. Introduction

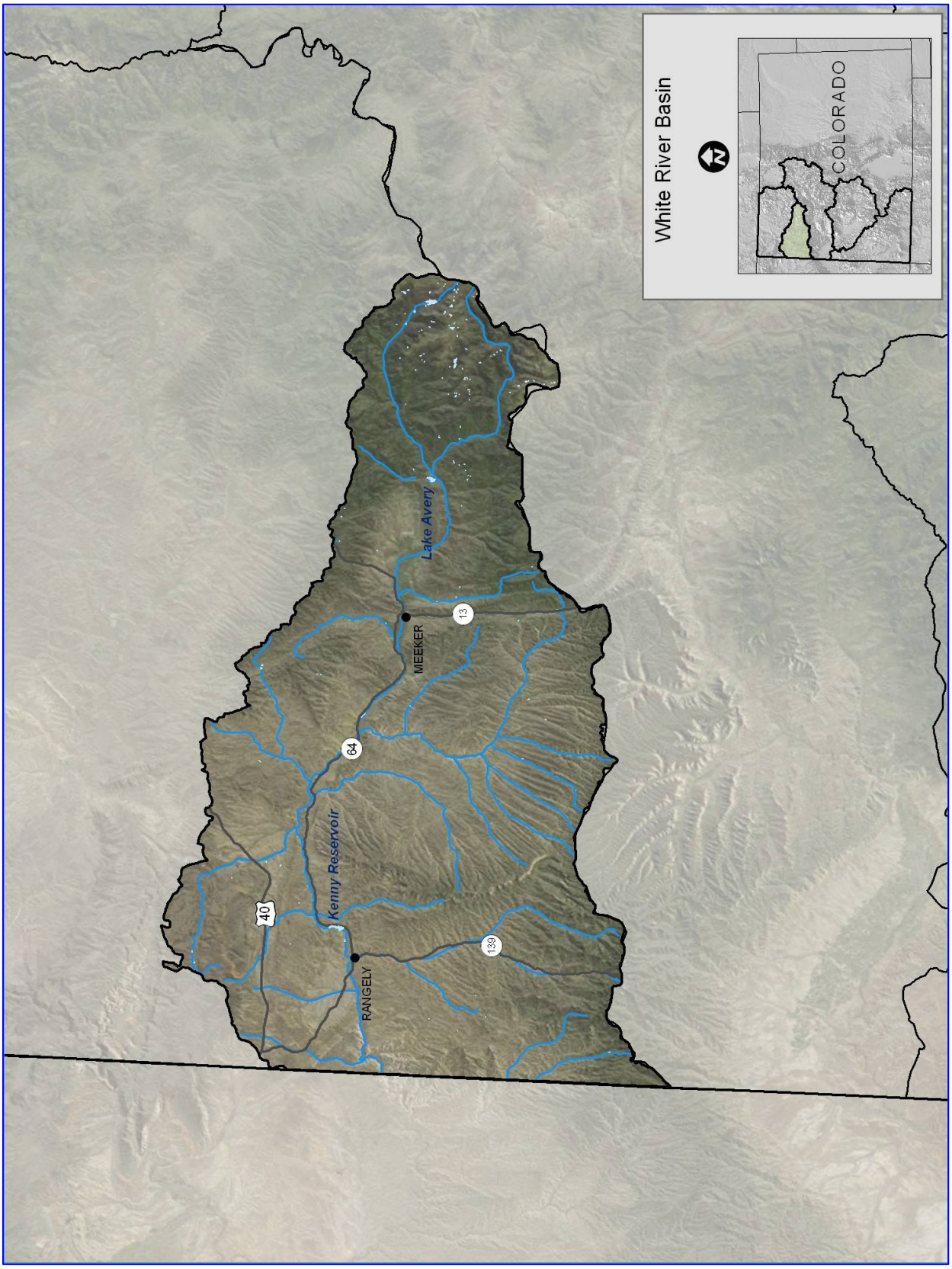
This document provides general descriptions of White River Basin model development and calibration. It is a companion document to ***"Overview of the Colorado Decision Support System"***, which summarizes the integrated Colorado Decision Support System (CDSS) and its primary components (including StateMod,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

- the four primary aspects of the White 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).

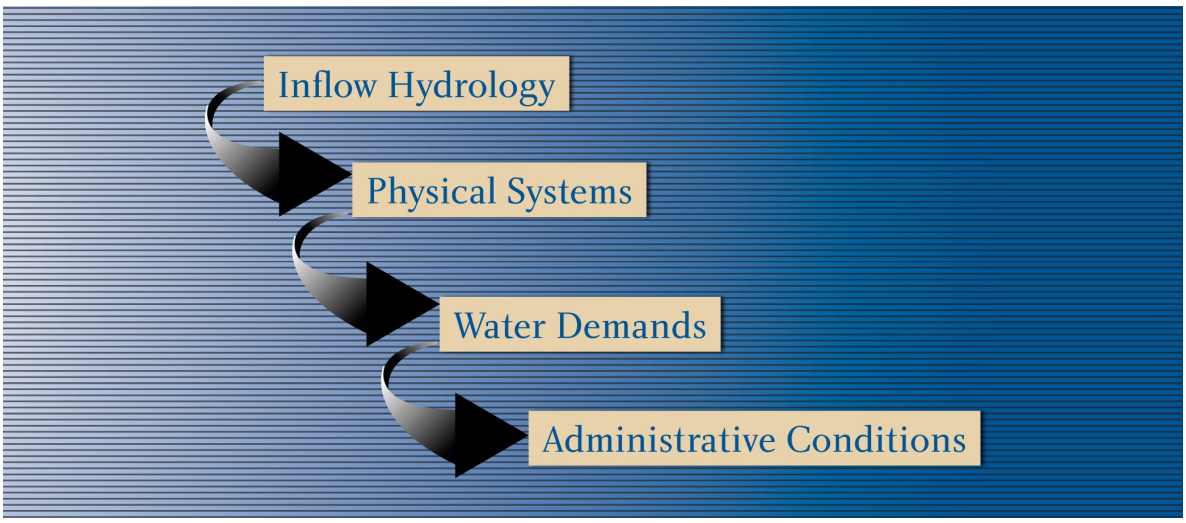
Figure 1 highlights the extent of the White River Basin Model and key rivers, streams, towns and water storage facilities.

Figure 1: White River Basin Key Hydrography and Facilities



2. Model Components

The major components of the White 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:



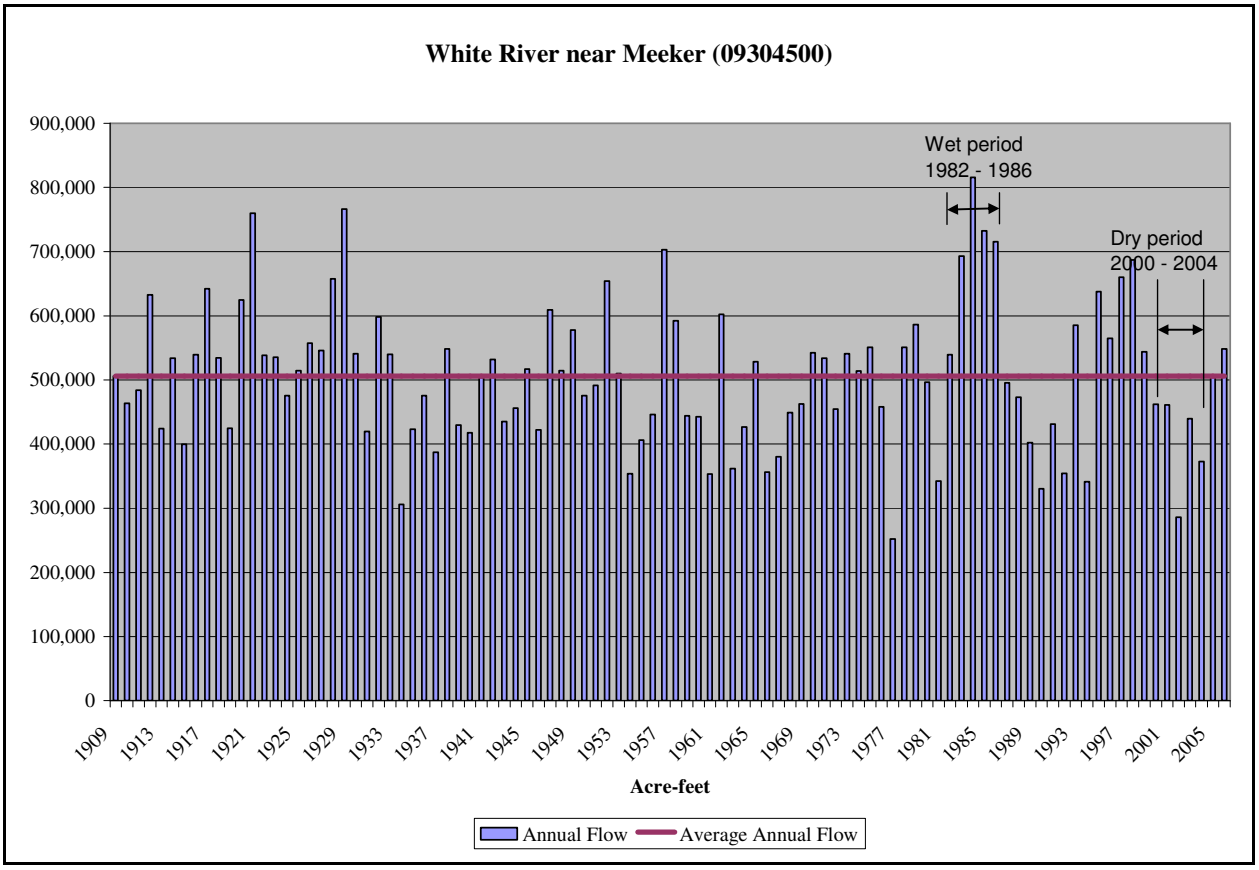
2.1 Inflow Hydrology

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 "natural flow" is synonymous with "baseflow", the term used in the White 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. White River basin natural flows were estimated in three steps: 1) remove effects of human activity 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). Additional 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 White River near Meeker 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., 2000-2004) constitute extended dry periods; conversely, successive years with flows above the average (e.g., 1982-1986) constitute extended wet periods.



Natural flows are introduced to the White Model at 45 gaged and headwater locations on 19 tributaries and the main stem. 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 13 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 White River, main tributaries represented include:

- North Fork
- South Fork
- Douglas Creek
- Big Beaver Creek
- Miller Creek
- Evacuation Creek
- Flag Creek
- Piceance Creek

Selection of streams to include in the model was generally based on the extent of acreage irrigated served by diversions.

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.

Historical streamflow 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 effects of human activity 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.

Historical diversions are recorded by water commissioners and stored in HydroBase. For most water districts in the White 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 for that ditch will be used.

Historical reservoir end-of-month contents for the larger reservoirs are generally measured by the reservoir operators. This information is then provided to the water commissioners and stored in HydroBase. These historical records are sporadic for the reservoirs in the White River model; missing records are filled based on linear interpolation if a limited number of consecutive months are missing. Otherwise, data are filled using the wet/dry/average approach described above. Again, this filling procedure has been automated using the CDSS DMIs.

Irrigation water requirements are determined, by ditch, for the period 1950 through 2006 using StateCU. The calculation methods require mean monthly temperature and total monthly precipitation. Four climate stations are used to represent temperature and precipitation in the White 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.

The same set of average net monthly evaporation rates is used for the two reservoirs in the White River model. It is based on annual gross free water surface evaporation per the National Oceanic and Atmospheric Administration (NOAA) Technical Report NWS 33. Annual net reservoir evaporation was estimated by subtracting the weighted average effective monthly precipitation at Meeker from the estimated gross monthly free water surface evaporation. The annual estimates of evaporation were then distributed to monthly values using factors adopted by the State Engineer's Office.

Where to find more detailed information:

- Section 4.7 of the White 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 White River Basin Water Resources Planning Model User's Manual lists the gaged locations where natural flows are introduced to the model.
- Section 4.4.1 of the White River Basin Water Resources Planning Model User's Manual describes the automated time series filling algorithms.
- Section 4.4.2 of the White 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 White River Basin Water Resources Planning Model User's Manual describes the evaporation rates and source used for each reservoir.

2.2 Physical Systems

The White 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 White 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 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 approximately 100 explicit structures and 16 aggregates.

Similarly, not every reservoir and stock pond is explicitly included in the White Model. Lake Avery and Kenney Reservoir are the only reservoirs represented explicitly. The remaining basin storage is grouped into two aggregate reservoirs and two aggregate stock ponds. These structures allow accounting for evaporation consumptive use in the basin.

There are seven instream flow segments modeled, accounting for CWCB instream flow rights decreed prior to 2006, which 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 is also a minimum bypass requirement for Kenney Reservoir, to simulate terms of the operating criteria for the project.

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.

Physical reservoir data (capacity, area-capacity curves, dead pool size) were gathered by the State, both from SEO documentation related to the dam's construction, and by contacting reservoir owners; this information is now available in Hydrobase. Operational information, such as reservoir accounts and manner of operating, was also gathered historically through interviews

with reservoir owners, and reviewed with them during the recent (2008) update of the White River model.

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 White 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 White 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 White River Basin Water Resources Planning Model User's Manual lists each of the key structures represented in the White Model. It gives the ditch capacity, number of acres served, and average annual demand for each.
- Appendix A and Appendix B of the White River Basin Water Resources Planning Model User's Manual describes the aggregation process for irrigation and non-irrigation structures and reservoirs.
- Section 5.6.1 of the White River Basin Water Resources Planning Model User's Manual provides details on physical data and account information for the reservoirs included in the model.

2.3 Water Demands

The White Baseline Model demands reflect current levels of irrigation, population, and reservoir capacity superimposed over historical natural flow hydrology from 1909 through 2006. 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 2006 for the entire model period of 1909 through 2006. Diversions

by the Town of Meeker were an exception. These were based on 2003 through 2006 because of changes in metering methods at the end of 2002.

Instream flow demands are set to the decreed monthly rates for the entire period of 1909 through 2006. The bypass flow requirements for Kenney Reservoir are set to 200 cfs, per operating criteria pursuant to the NEPA process for the project.

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. Minimum targets for Kenney Reservoir and Lake Avery were set to zero, and maximum targets were set to capacity, effectively disabling this feature of the model. This approach was selected because both reservoirs are kept full to the extent possible. They store to the extent of physical capacity or decree limit, whenever in priority, and generally make no releases.

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 White 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 2006, 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 White 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.

Where to find more detailed information:

- Section 4.9.1 and Section 5.4.4 of the White 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 Kenney Reservoir is just senior to the water right for the reservoir. StateMod then meets the minimum bypass prior to allowing any storage in the reservoir.

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.

Operational rights in the model specify, typically, 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 only system requiring operational rights in the White River model is the Town of Meeker.

Town of Meeker

The Town of Meeker Demand is satisfied by diversions from a wellfield several miles upstream from the Town. The demand resides at the model node representing the Town, and carrier operational rights are used to move water from the wellfield to the demand.

Right #	Destination	Admin #	Right Type	Description
1	Town of Meeker Demand	27265.19854	11	Carrier to direct diversion
2	Town of Meeker Demand	36648.00001	11	Carrier to direct diversion
3	Town of Meeker Demand	39313.00001	11	Carrier to direct diversion

The three operational rights correspond to the wellfield's three most senior water rights, which are the source of water. These rights are alternate points for rights originally decreed to the Town's historical surface diversion structure. Therefore the administration number is just junior to the original water rights' administration numbers.

Where to find more information

Section 5.8 of the White River Basin Water Resources Planning Model User's Manual provides details regarding project operations and operating rules.

Section 2 of the White River Basin Information Report provides historical and overview information on White River Projects and Special Operations.

Section 3 of the White River Basin Information Report provides Division 6 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.

3. Model Calibration

As noted above, the White 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, 2000-2004) and wet cycles (1982-1986).

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 parameters adjusted during calibration relate to basic hydrology, and include parameters for spatially distributing baseflow gains and return flows.

The model is calibrated on a basin-wide level, meaning that major tributaries, diversions, and basin operations were specifically reviewed and modified, if necessary, so they are represented appropriately. 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 (1975-2006)
Calibration Run (acre-feet/year)

Gage ID	Historical	Simulated	Historical minus Simulated		Gage Name
			Volume	Percent	
09303000	232,859	232,789	70	0	North Fork White River at Buford
09303400	142,366	142,366	0	0	South Fork White River near Budges Resort, CO.
09303500	189,830	189,841	-10	0	South Fork White River Near Buford
09304000	185,547	185,578	-32	0	South Fork White River at Buford
09304200	400,250	400,243	7	0	White River above Coal Creek
09304500	446,709	446,701	7	0	White River near Meeker
09304800	478,759	478,769	-10	0	White River below Meeker
09306007	15,199	15,237	-38	0	Piceance Creek below Rio Blanco
09306200	23,412	23,472	-60	0	Piceance Creek below Ryan Gulch
09306222	27,632	27,694	-62	0	Piceance Creek at White River
09306224	684,953	684,982	-29	0	White River above Crooked Wash near White River City
09306290	532,851	532,907	-57	0	White River below Boise Creek near Rangely
09306395	598,942	599,144	-202	0	White River near Colorado State Line

As shown in the Table 3.1, calibration at each stream gage is within tens of acre-feet on an average annual basis.

Where to find more detailed information:

- Section 7 of the White 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.