Historic Crop Consumptive Use Analysis

Gunnison River Basin

Final Report

October 2009

Leonard Rice Engineers, Inc.

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1.0 Executive Summary

The Gunnison River Basin historic crop consumptive use analysis was performed on a monthly basis for the period from 1950 through 2006 as part of the Colorado River Decision Support System (CRDSS). The CRDSS project was developed jointly by the State of Colorado Water Conservation Board and the Division of Water Resources. The objective of the historic crop consumptive use portion was to quantify 100 percent of the basin's historic crop consumptive use.

This report documents the input and results of the historic crop consumptive use analysis completed in October 2009.

1.1 Background

The Gunnison Basin is located in western Colorado and encompasses approximately 7,800 square miles. The Gunnison River headwaters start at an elevation of nearly 14,000 feet to 4,550 feet at Grand Junction. Major tributaries to the Gunnison River include Cimarron River, Ohio River, and East River. Most stream flow originates from snowmelt in the surrounding mountains. Average annual precipitation in the basin ranges from as little as 8 inches in the Uncompaghre Valley near the town of Delta to more than 40 inches in the high mountains.

1.2 Approach

The Gunnison River historic crop consumptive use analysis was performed using StateCU, a generic, data driven consumptive use model and graphical user interface. The objective of the model is to develop monthly consumptive use estimates for the assessment of historical and future water management policies. Key information used by the model to assess historic consumptive use include irrigated acreage, crop types, monthly climate data, diversion records, and well information.

The historic crop consumptive use analysis was originally performed to provide information and consumptive use estimates for the basin surface water model (StateMod) analysis of the Gunnison River Basin. Data used in the historic crop consumptive use has been revised, as well as documented, under this recent effort.

1.3 Results

Table 1 presents the average annual acreage and historic crop consumptive use analyses results for the 1950 to 2006 study period. As shown, the irrigation water requirement averages 618,521 acre-feet per year while water supply-limited consumptive use averages 515,890 acre-feet per year. The average annual shortage in the basin is 17 percent.

Table 1
Average Annual Acreage and Consumptive Use Results
1950 through 2006

1993 Acres	Irrigation Water Requirement (acre-feet)	Supply-Limited CU (acre-feet)	Percent Short
271,952	618,521	515,890	17%

Figure 1 presents historic acreage by crop type. Note that although there are two irrigated land coverages available on the western slope, the year 2000 coverage is currently under review and therefore omitted from the analysis. Table 1 represents the historic acreage by crop type based on the 1993 coverage only. As shown, grass pasture is grown on the majority of irrigated land in the basin.

Figure 1
Irrigated Acreage Crop Type by District
1993 Irrigated Acreage Coverage

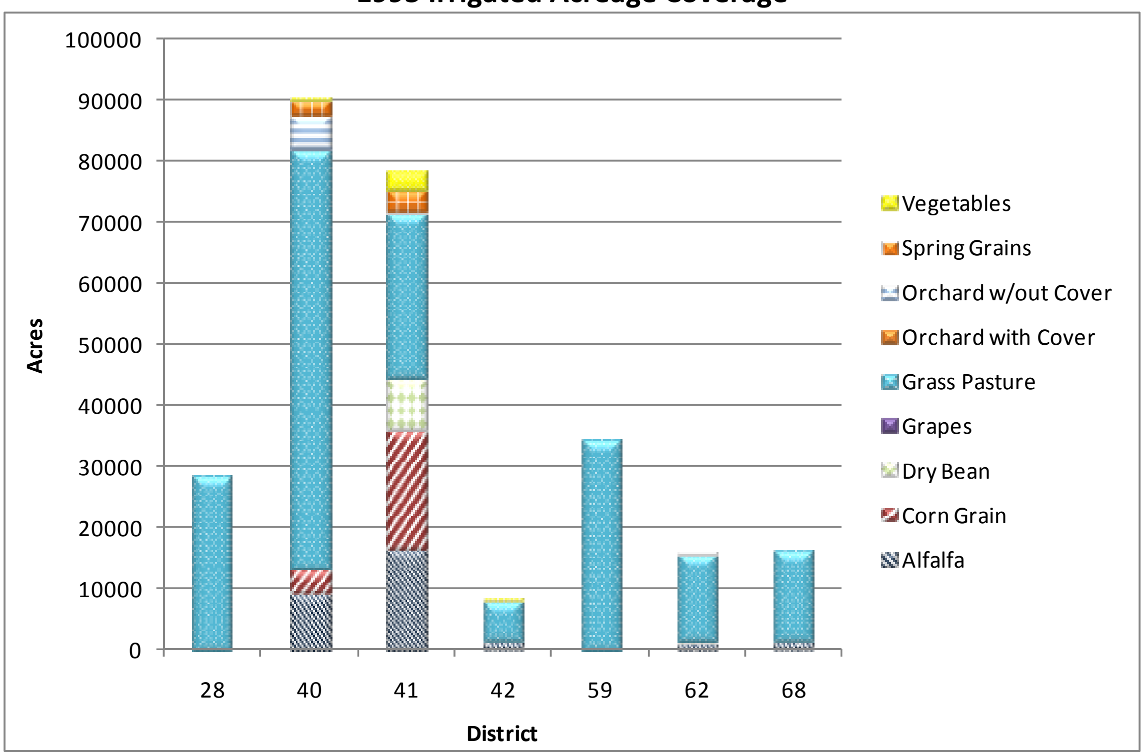


Figure 2 presents the annual historic acreage irrigation water requirement and supply limited consumptive use for the study period. Because irrigated acreage and crop type do not vary from year to year, the pronounced yearly variations in irrigation water requirement are attributed to climate data in the analysis (temperature and precipitation). The percent of irrigation water requirement not satisfied averaged 17

percent over the study period. Shortages averaging 17 percent from 1990 through 1996 are consistent with normal average flows. Shortages increased to a 22 percent average over a period in the early 2000s due to drought conditions. Shortages reached a maximum in 2002 of approximately 36 percent.

Figure 2
Historic Acreage, Irrigation Water Requirement and Supply Limited CU
1950 through 2006

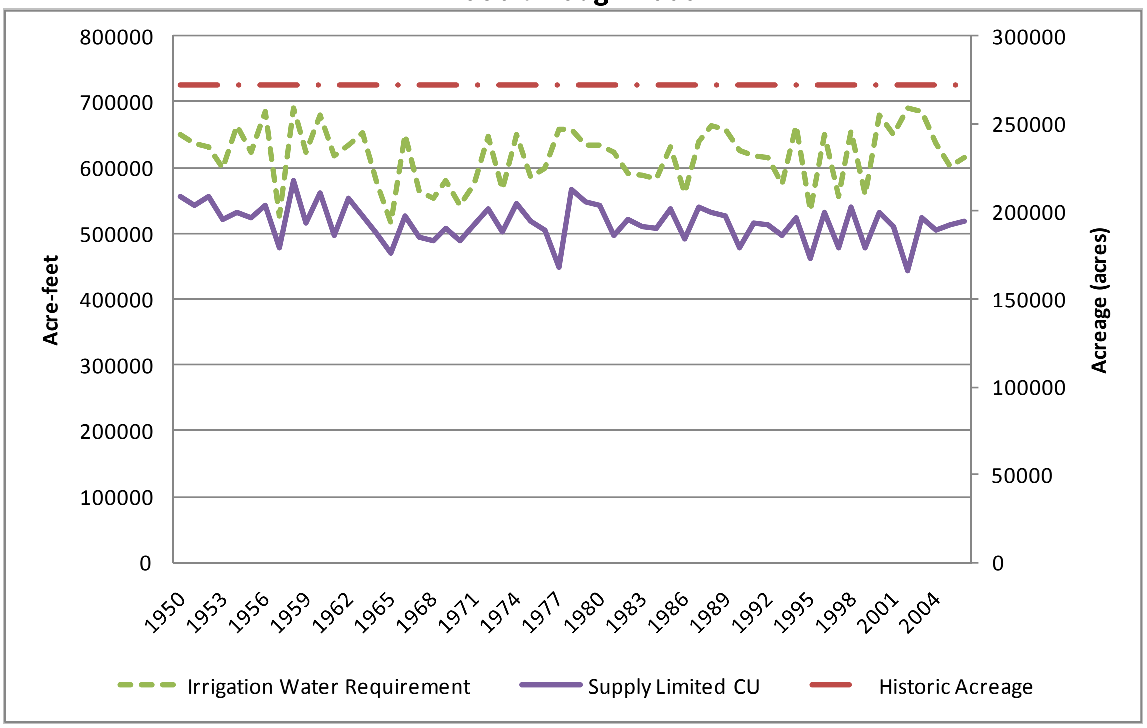
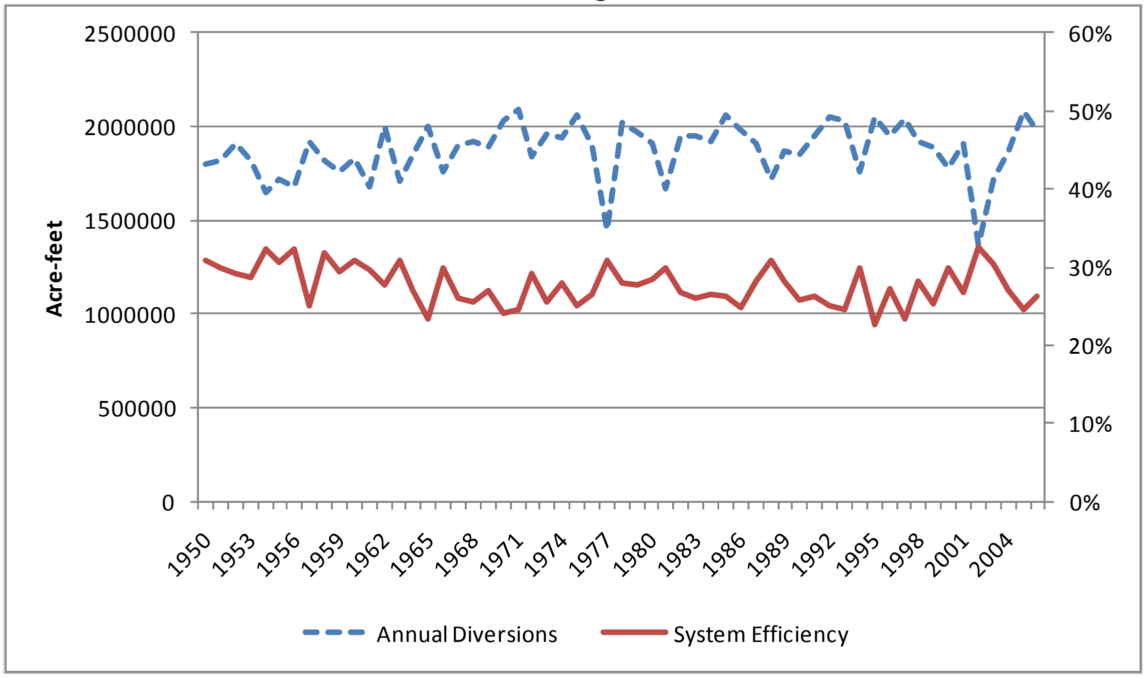


Figure 3 shows the annual estimated diversions from surface water to meet crop irrigation requirement and the average annual calculated system efficiency. The average annual surface water diversions from 1950 through 2006 were 1,873,048 acre-feet. The average annual surface water system efficiency from 1950 through 2006 was approximately 28 percent. System efficiency is calculated as total consumptive use met by diversions and soil moisture divided by total diversions, limited to a maximum efficiency of 50 percent and varies by month.

Figure 3
Average Annual Surface Water Diversions and System Efficiency
1950 through 2006



2.0 Introduction

The estimation of historic crop consumptive use in the Gunnison River Basin and the tool used to perform the analysis are documented in three major reports as follows:

1. The Historic Crop Consumptive Use Analysis Report describes the climate and crop data from HydroBase used in the historic consumptive use analysis, and the parameters used in analysis, including Blaney-Criddle crop coefficients and characteristics. The document summarizes the results of the analysis, total irrigation water requirement, and the supply-limited total consumptive use for the Gunnison River basin.

2. Gunnison River Basin Water Resources Planning Model User's Manual describes the development of the Gunnison River Basin StateMod surface water model. This document summarizes the process and results of developing the structure list of historic diversions for the historic consumptive use analysis.

3. The StateCU Documentation describes the consumptive use model and graphical user interface used to perform all consumptive use analyses conducted as part of the Colorado River Decision Support System.

This Historic Crop Consumptive Use Analysis Report has not attempted to reiterate the detailed analyses and results of the previous efforts performed in support of the final historic crop consumptive use analysis. Instead, it summarizes the major results of each technical memorandum. Supporting memorandum and reports are available on the CDSS website.

2.1 Basin Description

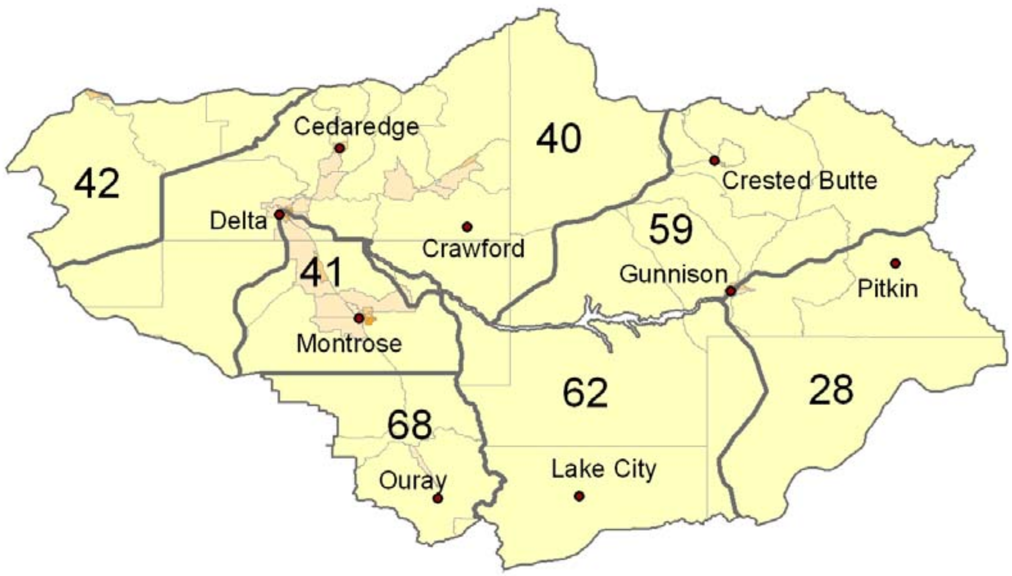
The Gunnison River basin is approximately 7,800 square miles in size, ranging in elevation from 14,000 feet in the headwaters to 4,550 feet at Grand Junction. Across this expanse, average annual rainfall varies from more than 40 inches in the high mountains to as little as 8 inches in the Uncompaghre Valley near the town of Delta. Temperatures generally vary inversely with elevation, and variations in the growing season follow a similar trend. The town of Gunnison has an average growing season of 144 days, while the growing season at Grand Junction has been estimated at approximately 228 days.

The Gunnison River begins at the confluence of the East and Taylor rivers, about 10 miles upstream from the city of Gunnison. The flow is increased as the river is joined by Cochetopa and Tomichi Creeks near the town of Gunnison. Just downstream, the river has carved through Precambrian rocks to form the Black Canyon of the Gunnison.

Annual flow through the town of Gunnison is 547,000 acre-feet per year (United States Geological Survey [USGS] gage near Gunnison).

The Uncompahgre River is the largest tributary to the Gunnison River, entering from the south near the town of Delta. Average annual flow of the Uncompahgre near the confluence is 220,000 acre-feet (USGS gage at Delta). The average annual flow of the Gunnison River near Grand Junction is over 1.8 million acre-feet (USGS gage near Grand Junction). Approximately 60 percent of this flow is attributable to snowmelt runoff in May, June, and July.

Figure 4
Gunnison River Basin



2.2 Definitions

Several terms used in this report have been broadly used in other studies. The following definitions are consistent with the American Society of Civil Engineers Manuals and Reports on Engineering Practice No. 70 - Evapotranspiration and Irrigation Water Requirement.

> **Potential Evapotranspiration (ET)** The total amount of water that would be used for crop growth if provided with an ample water supply, also called potential consumptive use.
>
> **Effective Precipitation** The portion of precipitation falling during the crop-growing season that is available to meet the evapotranspiration requirement of the crop.

Winter Effective Precipitation The portion of precipitation falling during the non-growing season that is available for storage in the soil reservoir, and subsequently available to crops during the next growing season.

Irrigation Water Requirement The amount of water required from surface or ground water diversions to meet crop consumptive needs. Calculated as potential evapotranspiration less effective precipitation and stored winter precipitation.

Water Supply-Limited Consumptive Use The amount of water actually used by the crop, limited by water availability; also called actual consumptive use.

The following terms are commonly used in the CDSS efforts:

Irrigated Parcel An irrigated "field" having the same crop type, irrigation method (sprinkler or flood), and water source - not divided by a large feature, such as river or highway.

Ditch Service Area The area of land that a ditch system has either the physical ability or the legal right to irrigate. Note that a ditch service area often includes farmhouses, roads, ditches, fallow fields and undeveloped lands. Therefore a ditch service area is typically greater than the land irrigated under that ditch.

Key Diversion Structure A ditch system that is modeled explicitly in both the StateCU historic consumptive use model efforts and the StateMod water resources planning model. Ditch systems are generally defined as key if they have relatively large diversions, have senior water rights, or are important for administration.

Diversion System Structure A group of diversion structures on the same tributary that operate in a similar fashion to satisfy a common demand.

Aggregated Diversion Structure A group of non-key structures. Aggregated diversions are typically aggregated based on location; e.g. diverting from the same river reach or tributary.

HydroBase The State of Colorado's relational database used in the CDSS efforts. HydroBase contains historic, real-time, and administrative water resources data.

Data Management Interface (DMI) A CDSS program that allows data to flow from HydroBase to the CDSS models using an automated data-centered approach.

StateMod The CDSS water allocation model used to analyze historic and future water management policies.

3.0 Model Development

The Gunnison River historic crop consumptive use analysis was performed using StateCU, a generic data driven consumptive use model and graphical user interface. The objective of the model is to develop monthly consumptive use estimates for the assessment of historic and future water management policies.

The model originated at the USBR and has undergone substantial enhancements while being applied to the Colorado River Decision Support System, the Rio Grande Decision Support System, and the South Platte Decision Support System. The *StateCU Documentation* provides a complete description of the model and its capabilities.

3.1 Modeling Approach

To perform the historic crop consumptive use analysis, irrigated acreage and their associated crop types were assigned to two types of structures; key and aggregated. As presented in **Table 2**, key diversion structures represent 77 percent of the 1993 irrigated acreage assigned to a surface water source. Aggregated structures, which are a geographical grouping of non-key surface water structures, represent 23 percent of the basin irrigated acreage.

Table 2
1993 Irrigated Acreage by Structure Type

Structure Type	1993 Acres	Percent of Total
Key	208,625	77%
Aggregated	63,327	23%
Total All Structures	**271,952**	**100%**

The general methodology used to estimate historic consumptive use for the Gunnison River Basin is as follows (See the *StateCU Documentation* for a more complete description of the calculation methods):

1. A Gunnison River Basin structure scenario was developed that includes 100% of the 1993 irrigated acreage in the Gunnison River using the key and aggregated structures and their associated acreage and crop patterns.
2. Climate stations were assigned to each structure based on spatial determination of climate station weights by hydrologic unit code (HUC).
3. Potential ET was determined using the SCS Modified Blaney-Criddle consumptive use methodology with TR-21 crop characteristics for acreage below 6500 feet and the Original Blaney-Criddle consumptive use methodology with high-altitude crop coefficients developed for Denver Water for acreage above 6500 feet. As recommended in the ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements (1990), an elevation

adjustment of 10% adjustment upward for each 1,000 meters increase in elevation above sea level was applied to the Modified Blaney-Criddle method, i.e. for crops below 6500 feet. The SCS effective rainfall method outlined in the SCS publication Irrigation Water Requirement Technical Release No. 21 (TR-21) was used to determine the amount of water available from precipitation, resulting in irrigation water requirement.

4. Water supply-limited consumptive use was determined by including diversion records, conveyance efficiencies, application efficiencies, and soil moisture interactions. The model determined water supply-limited consumptive use by first applying surface water to meet irrigation water requirement for land under the ditch system. If excess surface water still remained, it was stored in the soil moisture reservoir. Then if the irrigation water requirement was not satisfied, surface water stored in the soil moisture reservoir was used to meet remaining irrigation water requirement.

3.2 File Directory Convention

To assist in the file organization and maintenance of official State data, the files associated with a historic consumptive use analysis will install to the default subdirectory \cdss\data\ *Analysis_description*\StateCU. *Analysis_description* is **gm2009** for the Gunnison River crop consumptive use analysis, updated in 2009. Other official State historic consumptive use data *Analysis_descriptions* include rg2009 for the Rio Grande River, cm2009 for the Upper Colorado River Basin, etc. Note that these directory conventions are not a requirement of the model, simply a data management convention for official State data.

3.3 File Naming Convention

Specific file names or extensions are not a requirement of the model except for the StateCU response file (*.rcu). Standard extensions have been adopted by the State for data management purposes, and are outlined in **Section 4.0 Data Development**.

3.4 Data Centered Model Development

Nearly all CRDSS StateCU input files have been generated from HydroBase using the data management interfaces **StateDMI** (Version 2.18.00, 10/18.2007) and **TSTool** (Version 8.02.00, 12/03/2007). A description of these tools as applied to StateCU is included in **Section 4 Data Description,** where applicable.

3.5 Product Distribution

The **StateCU** model and CRDSS input files can be downloaded from the State of Colorado's CDSS web page at http://cdss.state.co.us.

4.0 Data Description

The following sections provide a description of each input file, the source of the data contained in the input file, and the procedure for generating the input file. More detailed information regarding the file contents and formats can be found in the *StateCU Documentation*.

1. Simulation information files
   - StateCU Response File ***Section 4.1***
   - StateCU Control File ***Section 4.2***
2. Structure specific files
   - StateCU Structure File ***Section 4.3***
   - Crop Distribution File ***Section 4.4***
   - Annual Irrigation Parameter File ***Section 4.5***
   - Historical Diversion File ***Section 4.6***
3. Climate data related files
   - Climate Station Information File ***Section 4.7***
   - Climate Data Files ***Section 4.8***
4. Blaney-Criddle specific files
   - Blaney-Criddle Crop Coefficient File ***Section 4.9***
   - Crop Characteristics File ***Section 4.10***

4.1 StateCU Response File (gm2009.rcu)

The StateCU response file contains the names of input files used for a StateCU analysis. The StateCU response file was created using a text editor for the Gunnison River Basin. Input file names in the response file can be revised through the StateCU Interface.

4.2 StateCU Model Control File (gm2009.ccu)

The StateCU Model control file contains the following information used in the historic consumptive use analysis:

- Beginning and ending year for simulation – The simulation period for the analysis was 1950 through 2006.
- Consumptive use analysis method – Monthly SCS Modified Blaney-Criddle, described in TR-21, and the monthly Original Blaney-Criddle analysis were used.
- Effective precipitation method – The SCS Effective Precipitation method, defined in TR-21 was used.
- Scenario type – The analysis was defined as a “structure” scenario.

- Water supply/rights consideration – The water supply/rights consideration switch was set to "1" which specifies that water supply-limited consumptive use was calculated considering surface water sources.
- Soil moisture consideration – The soil moisture switch was set to “1” indicating the analysis should include soil moisture accounting.
- Initial soil moisture information – The initial soil moisture was set to 50 percent of the capacity for each structure.
- Winter carry-over precipitation percent – The winter carry-over precipitation defines the amount of non-irrigation season precipitation that is available for storage in the soil moisture reservoir. Winter carry-over precipitation was not used for this scenario; set to zero.
- Output options – The output summary switch was set to "3" indicating a detailed water budget output should be generated.

The **StateCU** model control file was created using a text editor for the Gunnison River Basin. Options in the model control file can be revised through the **StateCU** Interface.

4.3 StateCU Structure File (gm2009.str)

A structure file defines the structures to be used in the analysis. The structure file contains physical information and structure-specific information that does not vary over time including location information; available soil capacity; and assignments of climate stations to use in the analysis. Location information includes the latitude, elevation, and county for each structure. The latitude is used in the Blaney-Criddle method to determine the hours of daylight during the growing season. The elevation is used to incorporate the standard elevation adjustment for TR-21 coefficients for structures.

The Redlands Water & Power Company diverts water from the Gunnison basin for irrigation and power in the Colorado basin. To accurately represent the consumptive use of the Gunnison basin water exported for Redlands irrigation, the Redlands irrigation structure (960050) has been included in the Gunnison consumptive use analysis.

Key and Aggregate Structures

The structure file used in the historic consumptive use analysis was created using **StateDMI** to extract diversion structure location information stored in HydroBase. 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. Seventy-five percent of use in the basin, however, should be represented at strictly correct river locations relative to other users, with strictly correct priorities relative to other users, in both the StateCU and StateMod models. With this objective in mind, key structures to be “explicitly” modeled were determined by:

- Identifying net absolute water rights for each structure and accumulating each structure’s decreed amounts
- Ranking structures according to net total absolute water rights
- Identifying the decreed amount at 75 percent of the basin-wide total decreed amount in the ranked list
- Generating a structures/water rights list consisting of structures at or above the threshold decreed amount
- Field verifying structures/water rights, or confirming their significance with basin water commissioners, and making adjustments

Based on this procedure, 9 cubic feet per second (cfs) cutoff value was selected for the Gunnison River basin. Key diversion structures are generally those with total absolute water rights equal to or greater than 9.0 cfs. The Gunnison model includes approximately 320 key diversion structures. Of the 320 key diversions, there are 16 diversion systems structures. Diversion system structures represent a group of diversion structures on the same tributary that serve a single irrigation demand but are modeled under a single structure. Note that for surface water modeling purposes, Fruitland Canal (400549) is represented by the structure ID 40_Fruitl and Cimmaron Canal (620560) is represented by the structure ID 62_IrrCim.

In general, the use associated with irrigation diversions having total absolute rights less than 9.0 cfs were included in the StateCU and StateMod models at “aggregated nodes.” These nodes represent the combined historical diversions, demand, and water rights of many small structures within a prescribed sub-basin. The aggregation boundaries were based generally on tributary boundaries, gage location, critical administrative reaches, and instream flow reaches. To the extent possible, aggregations were devised so that they represented no more than 2,200 irrigated acres. In the Gunnison model, 44 aggregated nodes were identified, representing over 63,000 acres of irrigated crops. The diversion system structures and aggregates are read by **StateDMI** from list files. **StateDMI** then develops the historical diversions by summing the historical diversions of the individual structures, and their irrigation water requirement is based on the total acreage associated with the aggregation.

As presented in **Table 3**, 77 percent of acreage with a surface water source was assigned to key structures. The approach and results for selecting key structures and aggregations as well as more information on the Redlands Canal, are outlined in more detail in the *Gunnison River Basin Water Resources Planning Model User’s Manual.*

Table 3
Key and Aggregate Structure Summary

Structure Type	1993 Acres	Number of Structures[1]	Percent of Total Acreage
Key/Diversion System Structures	208,625	295	77%
Aggregated Surface Water Structures	63,327	44	23%
Total Structures	**271,952**	**339**	**100%**

1) Number of total structure IDs included in the model. Aggregates and diversion systems represent more than one physical structure.

Available Soil Moisture Capacities

Available soil moisture capacities were estimated from Natural Resources Conservation Service (NRCS) digital mapping and assigned to individual structures in the structure file. Soil moisture capacities for each structure, in inches of holding capacity per inch of soil depth, were provided for key and aggregate structures from comma separated list files. Structure soil moisture capacity by structure ranges from 0.0117 to 0.1465 inches per inch. Note that the Redlands irrigation structure was assigned an available soil moisture capacity of 0.0808, representative of Water District 42. **Table 4** summarizes the range of soil moisture capacities used in the consumptive use analysis by Water District.

Table 4
Average Soil Moisture Capacity (inches/inch)

District	Average AWC
28	0.1054
40	0.1179
41	0.1096
42	0.0828
59	0.1100
62	0.1012
68	0.1221
Basin Average	**0.1111**

Climate Station Assignment

Climate stations were selected for use in the consumptive use calculation based on their period of records and location with respect to irrigated land (see Section 4.3 for more information on climate stations). Climate weights were assigned to structures based on the proximity of irrigated lands to climate stations for each structure. Climate stations and respective weights were assigned to county/hydrologic unit code (HUC) combinations, originally based on USBR assignments. Structures were assigned to county and HUC areas based on the location of their irrigated acreage. Climate station weights were then assigned to structures based on this county/HUC area combination method. Note the Redlands irrigation structure was assigned the Grand Junction 6 ESE climate station, representative of Water District 42.

4.4 Crop Distribution File (gm2009.cds)

The crop distribution file contains acreage and associated crop types for each key and aggregate surface water structures for every year in the analysis period (1950 through 2006). The irrigated acreage assessment for CRDSS was originally developed by the State Engineer's Office and the USBR. The irrigated acreage, along with crop type identification, is available spatially through GIS shapefiles and is also available in HydroBase. Each irrigated parcel was assigned a crop type and provided a structure identifier (SWID) based on service area locations. **Table 5** summarizes the 1993 acreage by crop type.

Table 5
1993 Irrigated Acreage by Crop Type

Crop Type	Acreage
Alfalfa	30,232
Corn Grain	23,291
Dry Beans	8,955
Grapes	6
Grass Pasture	193,338
Orchard with Cover	248
Orchard without Cover	5,791
Spring Grains	6,543
Vegetables	3,547
Total Acreage	**271,952**

1993 acreage and crop types were assigned to each year (1950 through 2006) reflecting the limited change in irrigated acreage in the Gunnison River Basin. Note that although there are two irrigated acreage coverages available for the western slope, the year 2000 coverage is currently under review and therefore omitted from the analysis. Redlands irrigation structure's acreage and crop type was set to the cropping information under Redlands Power Canal (7204713) in Division 5. The crop distribution file used in the historic consumptive use analysis was created using **StateDMI. StateDMI** was used to extract the acreage and crop type information from HydroBase and develop the crop distribution file.

4.5 Annual Irrigation Parameter File (gm2009.ipy)

The annual irrigation parameter file contains yearly (time series) structure information required to run consumptive use simulations, including the following:

- conveyance efficiencies
- maximum flood irrigation efficiencies
- maximum sprinkler irrigation efficiencies
- acreage flood irrigated with surface water only
- acreage sprinkler irrigated with surface water only
- acreage flood irrigated with ground water only or supplemental to surface water
- acreage sprinkler irrigated with ground water only or supplemental to surface water
- maximum permitted or decreed monthly pumping capacity
- ground water use mode (ground water primary or secondary source)

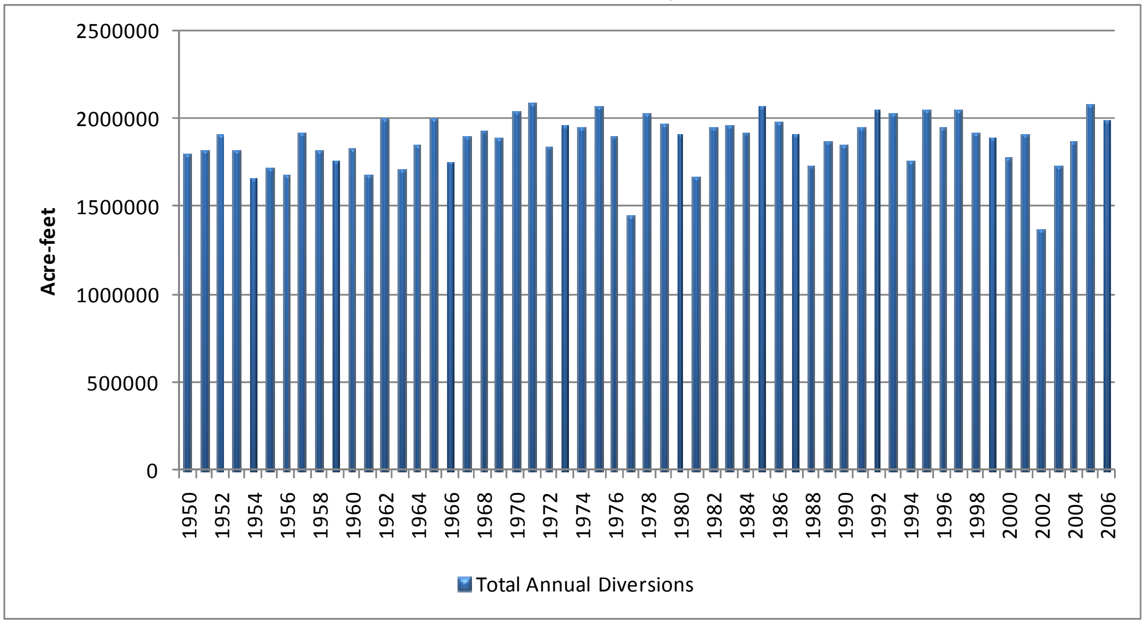
The conveyance efficiency accounts for losses between the river headgate and the farm headgate, including losses through canals, ditches and laterals. The maximum flood irrigation and sprinkler efficiencies account for application losses between the farm headgate and the crops. Note that conveyance and maximum application efficiency data input data were not adjusted by year. However, a structure's overall, system efficiency may change by year due to changes in the percent of land served by sprinkler or flood application methods, or due to surface water supply in excess of crop requirement.

Maximum conveyance efficiency for all structures in the Gunnison River Basin is set at 100 percent. Therefore, the maximum flood irrigation and sprinkler irrigation efficiencies represent maximum overall system efficiency estimated to be 50 percent and 72 percent respectively. The maximum flood irrigation system efficiency was set to either 40 or 50 percent based on water user's comments in the basin. The maximum sprinkler irrigation system efficiency was derived based on a maximum application efficiency of 80 percent and 90 percent conveyance efficiency. Efficiency numbers are derived and are not stored in HydroBase. Irrigation methods (flood vs sprinkler), however are stored in HydroBase. **StateDMI** was used to extract the time series information from HydroBase, set the derived efficiency values, and create the annual irrigation parameter file.

4.6 Historical Irrigation Diversion File (gm2009.ddh)

The historical diversion file provides surface water supply information required to estimate supply-limited consumptive use. Irrigation diversions are provided for each modeled key and aggregate surface water diversion structure. **Figure 5** shows how surface water diversions for irrigation in the basin have changed over time. Surface water diversions for irrigation averaged approximately 1,873,048 acre-feet per year over the 1950 through 2006 study period. The variation seen in **Figure 5** is due to water supply limitations for the basin as a whole.

Figure 5
Total Annual Surface Water Irrigation Diversions



StateDMI was used to extract diversion records from HydroBase and fill missing diversion data**.** Diversion data for structures included in a diversion or aggregate structure are first extracted and filled then combined with other structures' diversion data in the diversion system or aggregate structure. Note that diversion comments were considered when extracting data from HydroBase; for instance, if the diversion comment for a specific structure indicated the structure was not usable for a specific year, that year of data for that structure was set to zero.

Missing data was filled using a wet/dry/average pattern according to an 'indicator' gage. Each month of the streamflow at the indicator gage was categorized as a wet/dry/average month through a process referred to as 'streamflow characterization'. Months with gage flows at or below the 25th percentile for that month are characterized as 'dry', while months at or above the 75th percentile are characterized as 'wet', and remaining months are characterized as 'average'. Using this characterization, missing data points were filled based on the wet, dry, or average pattern. For example, a data point missing for a wet March was filled with the average of other wet Marches in the partial time series, rather than all Marches. The pattern streamflow gages used in the Gunnison River basin are the East River at Almont, CO (09112500), Uncompahgre River at Colona, CO (09147500), Gunnison River near Grand Junction, CO (09152500), and Colorado River near Cameo, CO (09095500). If missing data still existed after filling with a pattern file, historical monthly averages were used to fill the remaining data.

Filled diversion data is then limited by the structure's water rights, as supplied to **StateDMI** from the diversion right file (*.ddr). Utilizing the administration number in the diversion right file, **StateMod** determines the total amount of the water right during the time of the missing data, and constrains the filled diversion data accordingly. For example, a ditch has two decrees, one for 2.5 cfs with an appropriation date of 1896, and the other for 6 cfs with an appropriation date of 1972. When StateDMI estimates diversions prior to 1972, it limits them to a constant rate of 2.5 cfs for the month, regardless of the average from available diversion records. **StateDMI** then writes out the complete diversion data to the historic direct diversion file. See the *Gunnison River Basin Planning Model User's Manual* for more information on the development of diversion data.

4.7 Climate Station Information File (COclim2006.cli)

The climate station information file provides climate station location information for climate stations used in the analysis, including latitude, elevation, county and HUC. A single climate station information file was developed for the entire western slope and therefore includes all key climate stations used in the Colorado River basin models (Gunnison, White, Yampa, Upper Colorado, San Juan/Dolores). **Table 6** lists the subset of climate stations used in the Gunnison River analysis, their period of record, and their percent complete for temperature and precipitation data. The climate station information file was created using **StateDMI** to extract location information stored in HydroBase based on a list of climate stations to be used in the analyses.

Table 6
Key Climate Station Information

Station ID	Station Name	WD	Period of Record	Elevation (feet)	Percent Complete (1950 – 2006)	
					Temperature	Precipitation
1440	Cedaredge *	40	1948-2006	6244	94.74%	94.44%
1609	Cimarron	40	1951-2009	6896	93.42%	93.86%
1713	Cochetopa Creek	28	1948-2009	8000	99.85%	100.00%
1959	Crested Butte	59	1910-2009	8860	98.25%	98.83%
2196	Delta 3 E *	40	1900-2009	5010	92.40%	92.11%
3489	Grand Junction 6 ESE	72	1962-2009	4760	77.34%	77.19%
3662	Gunnison 3 SW	59	1900-2009	7640	95.32%	94.74%
4734	Lake City	62	1958-2009	8670	83.77%	99.27%
5722	Montrose No 2	41	1903-2009	5785	99.85%	99.85%
6306	Paonia 1 SW *	40	1905-2009	5693	98.68%	98.98%
7020	Ridgway	68	1982-2009	7200	41.96%	42.54%
8184	Taylor Park	59	1948-2009	9206	99.56%	99.56%

* Represents a combined climate station whereby the data from two or more stations has been combined to create a single key climate station.

4.8 Climate Data Files (COclim2006.tmp, COclim2006.prc, COclim2006.fd)

StateCU requires historical time series data, in calendar year, for temperature, frost dates, and precipitation. The CRDSS climate data files, developed using the **TSTool**, contain monthly data for fifty-four stations. Note that a single set of climate data files were developed for the entire western slope and therefore include data for all key climate stations used in the Colorado River basin models (Gunnison, White, Yampa, Upper Colorado, San Juan/Dolores). **Table 7** summarizes the average annual temperature, frost dates and precipitation based on filled data for the subset of stations used in the Gunnison River analysis.

Table 7
Average Annual Filled Climate Values 1950 through 2006

Station Name	Station ID	Average Annual		Frost Dates - Degrees F			
		Temperature (Degrees F)	Precipitation (Inches)	Spring 28 Deg	Spring 32 Deg	Fall 32 Deg	Fall 28 Deg
Cedaredge *	1440	49.2	12.66	29-Apr	16-May	1-Oct	12-Oct
Cimarron	1609	41.5	13.41	2-Jun	19-Jun	12-Aug	15-Sep
Cochetopa Creek	1713	37.8	11.07	11-Jun	21-Jun	8-Aug	9-Sep
Crested Butte	1959	34.7	24.42	12-Jun	24-Jun	19-Jul	25-Aug
Delta 3 E *	2196	50.5	7.41	24-Apr	8-May	29-Sep	13-Oct
Grand Junction 6 ESE	3489	53.2	8.94	8-Apr	28-Apr	14-Oct	27-Oct
Gunnison 3 SW	3662	37.7	10.60	8-Jun	20-Jun	10-Aug	6-Sep
Lake City	4734	39.1	14.04	7-Jun	14-Jun	29-Aug	11-Sep
Montrose No 2	5722	49.3	9.59	24-Apr	10-May	6-Oct	18-Oct
Paonia 1 SW *	6306	49.9	14.64	28-Apr	10-May	8-Oct	19-Oct
Ridgway	7020	42.5	17.20	31-May	15-Jun	27-Aug	17-Sep
Taylor Park	8184	32.6	16.75	8-Jun	20-Jun	14-Aug	9-Sep

* Represents a combined climate station whereby the data from two or more stations has been combined to create a single key climate station.

Figures 6 and **7** show the 1950 through 2006 average monthly precipitation and temperature for the Gunnison 3 SW (3662) climate station, located in the eastern portion of the Gunnison River Basin. Historic missing data for these climate stations were filled from 1950 through 2006 using **TSTool.** Historic month averages were used to fill missing precipitation data and linear regression techniques were used to fill missing temperature data**.**

Figure 6
Average Mean Monthly Temperature
Gunnison 3 W Climate Station
1950 through 2006

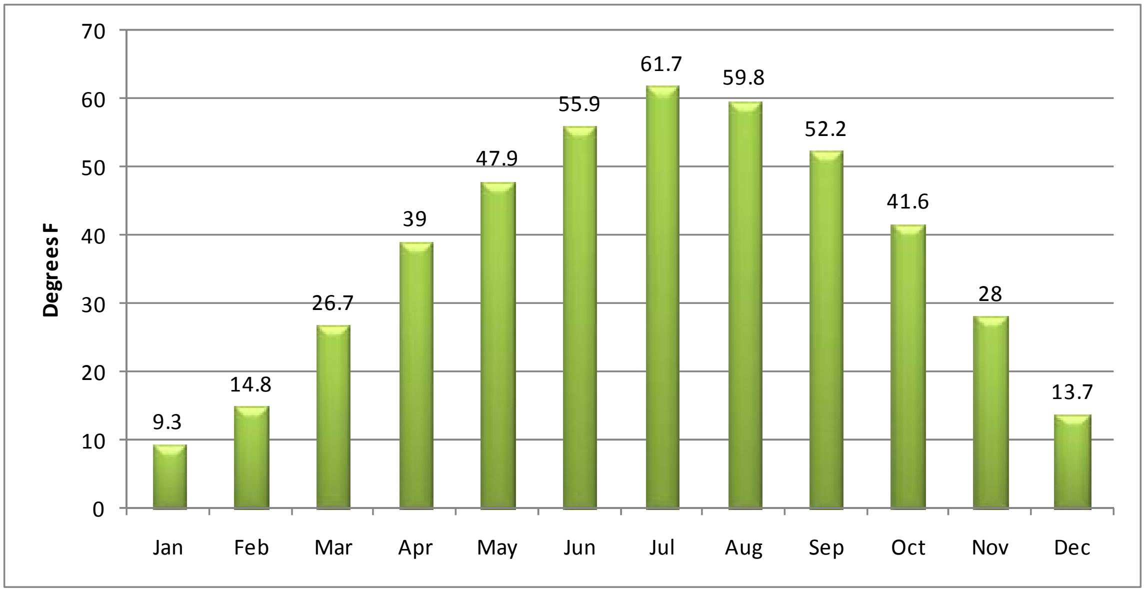
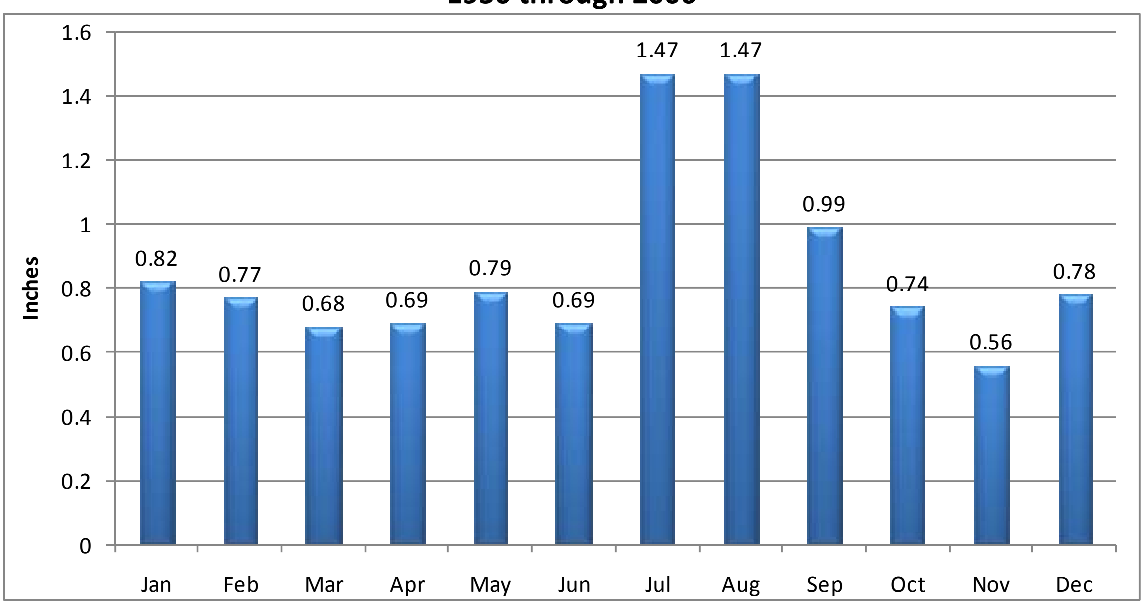


Figure 7
Average Mean Monthly Precipitation
Gunnison 3 W Climate Station
1950 through 2006



4.9 Blaney-Criddle Crop Coefficient File (CDSS.kbc)

The Blaney-Criddle crop coefficient file contains crop coefficient data used in the CRDSS historic consumptive use analysis. Standard TR-21 Blaney-Criddle crop coefficient curve data is available for the Modified Blaney-Criddle method. The crop coefficient file contains TR-21 curve data for several crops, however only nine TR-21 crops are modeled in the Gunnison River Basin; alfalfa, corn grain, dry beans, grapes, grass pasture, orchard with cover, orchard without cover, spring grains and vegetables.

Several high-altitude crop studies, performed by Leonard Rice Engineers, Inc. and others, were reviewed to determine appropriate coefficients to represent grass pasture grown in the high elevation meadows of the CRDSS study area. The calibrated crop coefficients recommended in the comprehensive study sponsored by Denver Water were selected for use in the analysis. Additional information regarding Denver Water high altitude crop coefficients, including a review of the recent coefficients, is provided in **Appendix A**. Structures with irrigated grass pasture acreage located above 6500 feet in elevation were assigned the Denver Water High Altitude crop coefficients, included in the CDSS.kbc file, for use with the Original Blaney-Criddle methodology.

The flag to indicate an elevation adjustment to specific crops in the analysis is located in the crop coefficient file. It is recommended in the ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements (1990) that an elevation adjustment of 10% adjustment upward for each 1,000 meters increase in elevation above sea level should be applied to the Modified Blaney-Criddle method when using TR-21 coefficients, i.e. for crops below 6500 feet. For this analysis, an elevation adjustment was applied for all Modified Blaney-Criddle crops. The elevation adjustment is applied based on the elevation of the structure, if provided in the structure file. However, in general, structure elevations are not available in HydroBase. If no structure elevation is provided, the elevation of the weighted climate station(s) is used for the elevation adjustment. An analysis determining the impact of an elevation adjustment based on structure elevations compared to climate station elevations was performed and is summarized in **Appendix B**. The recommendation of this analysis was to use climate station elevations as the basis for the elevation adjustment.

The crop coefficient file used in the historic consumptive use analysis was created using **StateDMI** to extract the representative crop coefficients from HydroBase.

4.10 Crop Characteristic File (CDSS.cch)

The crop characteristic file contains information on planting, harvesting, and root depth. Standard TR-21 Blaney-Criddle crop characteristics were adapted in the analysis. Crop characteristics from the Denver Water study were used for grass pasture above

6,500 feet in elevation. **Table 8** illustrates the crop characteristics for the crops grown in the Gunnison River basin, including high altitude grass pasture.

The crop characteristic file used in the historic consumptive use analysis was created using **StateDMI** by extracting the representative crop characteristics from HydroBase and develop the crop characteristics input file.

Table 8
Characteristics of Crops in the Gunnison River Basin

Crop Type	Source	Length of Season	Beginning Temperature	End Temperature
Alfalfa	TR-21	365	50	28
Corn Grain	TR-21	140	55	32
Dry Beans	TR-21	112	60	32
Grapes	TR-21	365	55	50
Grass Pasture	TR-21	365	45	45
Orchard with Cover	TR-21	365	50	45
Orchard w/out Cover	TR-21	365	50	45
Spring Grains	TR-21	137	45	32
Vegetables	TR-21	146	55	45
High Altitude Grass Pasture	Denver Water Study	365	42	42

5.0 Results

The Gunnison River Basin historic crop consumptive use results are a product of the input files described in **Section 4**. This section provides a summary of historic crop consumptive use and system efficiencies. Results for individual key and aggregated structures can be easily viewed and printed by obtaining the StateCU input files and StateCU model from the CDSS web site (see **Section 3.5**).

5.1 StateCU Model Result Presentation

Table 9 shows the average annual basin consumptive use water budget accounting for the period 1950 through 2006. The individual component results are discussed in detail in the following sections.

Table 9
Basin Average Annual Results 1950 through 2006

Irrigation Water Required	Surface Water Diversion Accounting					Estimated Crop CU		
	River Headgate Diversion	Surface Water Diversion To:			Calculated System Efficiency	From SW	From Soil	Total
		CU	Soil	Non-Consumed				
618,521	1,873,048	476,116	40,049	1,356,884	28%	476,116	39,774	515,890

Note that a conveyance loss of 10 percent is factored directly into the maximum system application efficiencies, as discussed in **Section 4.5**. Therefore the *River Headgate Diversion* is adjusted for conveyance and application efficiency through the maximum application efficiency value. The *Non-Consumed* represents the total water not consumed by the crops; loss through canal conveyance or during application of the irrigation water. *Irrigation Water Required* is potential consumptive use less the amount of precipitation effective in meeting crop demands directly during the irrigation season.

5.2 Historic Crop Consumptive Use

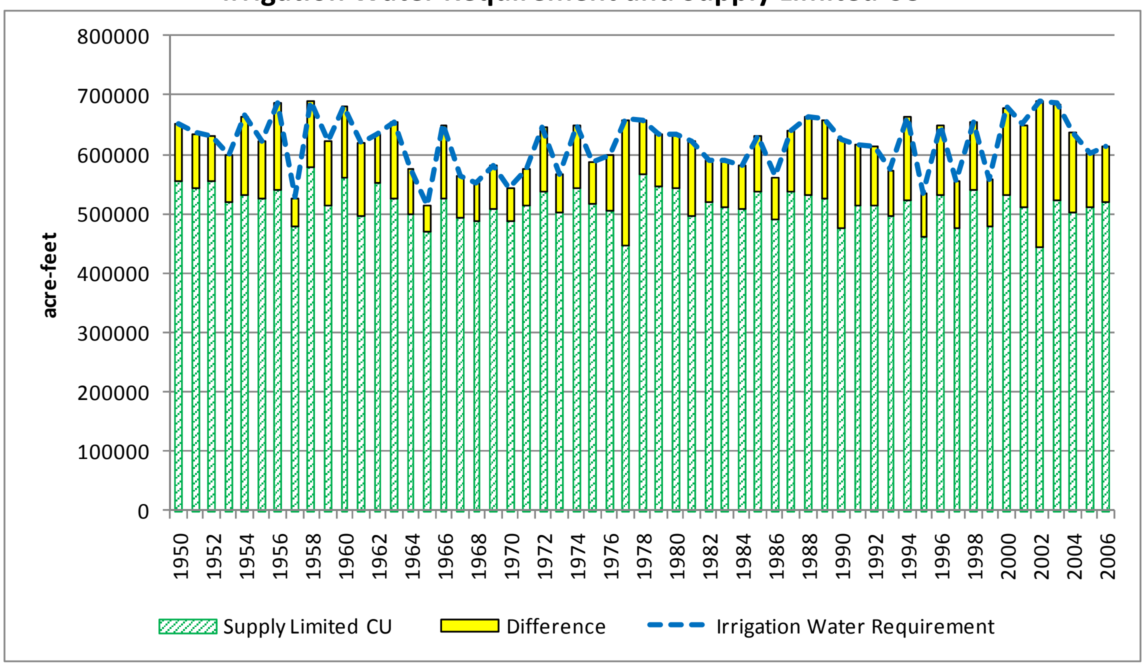
Table 10 presents the historic crop consumptive use analysis results for the 1950 to 2006 study period. Irrigation water requirement in the Gunnison River basin is satisfied from surface water diversions, resulting in an estimate of water supply limited consumptive use. The Gunnison River basin averages 515,890 acre-feet of water supply limited consumptive use annually. The average annual shortage in the basin is 17 percent. Note the consumptive use from surface water includes excess surface water stored in the soil moisture and then subsequently used by crops.

Table 10
Average Annual Consumptive Use Results - 1950 through 2006

1993 Acres	Irrigation Water Requirement (acre-feet)	Supply-Limited CU (acre-feet)	Percent Short
271,952	618,521	515,890	17%

Figure 8 presents basin crop consumptive use results by year. As shown, the percent of irrigation water requirement not satisfied is directly related to water supply. Shortages averaging 17 percent from 1990 through 1996 are consistent with normal average flows. Shortages increased to a 22 percent average over a period in the early 2000s due to drought conditions. Shortages reached a maximum in 2002 of approximately 36 percent.

Figure 8
Irrigation Water Requirement and Supply Limited CU



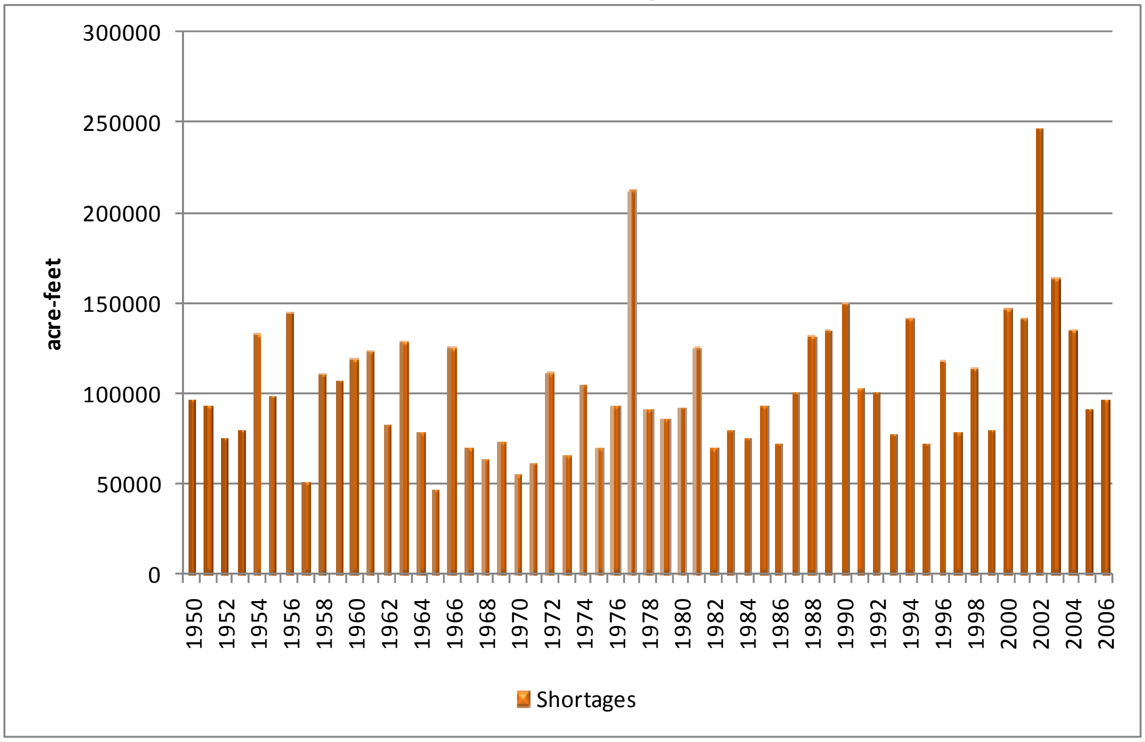
Average monthly shortages for the study period vary from a low of 12 percent in June to a high of 28 percent in October, as shown in **Table 11**.

Table 11
Average Monthly Shortage - 1950 through 2006

Apr	May	Jun	Jul	Aug	Sep	Oct
11%	15%	12%	16%	18%	24%	28%

Figure 9 present shortages by year. Shortages increased dramatically in the drought years in the early 2000s.

Figure 9
Annual Shortages



5.3 Estimated Actual Efficiencies

As described in the StateCU Documentation, the amount of surface water available to meet the crop demand is the river headgate diversion less conveyance losses and application losses. If the surface water supply exceeds the irrigation water requirement, water can be stored in the soil moisture up to its water holding capacity.

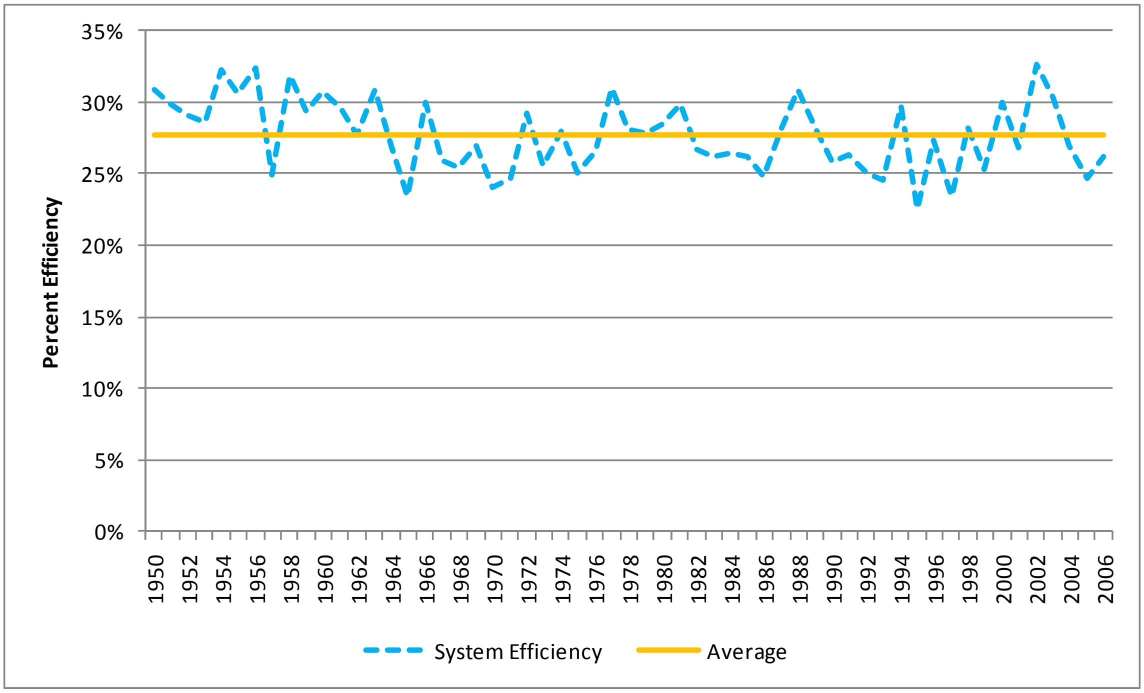
Maximum system efficiencies for surface water and ground water diversions are provided as input to StateCU, as described in **Section 4.5**. Actual system efficiencies are calculated based on the amount of water available to meet crop demands and the application method (e.g. flood or sprinkler). Based on the 1993 irrigated acreage assessment, only 4,400 acres, or 1.6 percent of the total irrigated acreage in the basin, is served by sprinklers. The remaining acreage is irrigated with flood irrigation practices.

Table 12 provides the average monthly calculated system efficiencies for surface water supplies and **Figure 10** presents this same data by year graphically. Surface water system efficiencies have remained relatively constant throughout the study period, with the slight variations due to water availability.

Table 12
Average Monthly Calculate System Efficiencies

Apr	May	Jun	Jul	Aug	Sep	Oct
16%	25%	28%	33%	35%	29%	16%

Figure 10
Annual System Efficiencies



6.0 Comments and Concerns

The historic crop consumptive use estimates are based on measured and recorded data; information from other studies; information provided by local water commissioners and users; and engineering judgment. The results developed for this project are considered appropriate to use for CRDSS planning efforts. Areas of potential improvement or concern include:

- Historic Acreage. The irrigated acreage assessed for year 1993 serves as the basis for estimating historic acreage and is considered relatively accurate. Irrigated acreage estimates for year 2000 are currently under review, and were therefore not used in the analysis. In general, any additional reliable irrigated acreage assessment years would improve the historical analysis.
- System Efficiencies. Maximum system efficiency estimates were set for the basin as a whole, in general based on user-supplied information. Limited conveyance efficiency information based on actual canal loss studies exists for systems in the basin. Canal loss studies, specifically for the larger systems, could improve the estimate of maximum system efficiencies used in the historic consumptive use estimate. Additionally, conveyance efficiency estimates based on soil type and ditch length, determined by the GIS soil type and canal coverages, could be used to also increase the accuracy of the maximum system efficiency estimates.
- Water Use. The results presented are based on an approach that attempts to represent how water is actually applied to crops in the basin. The approach used is based on engineering judgment and informal discussions with water users. The effort did not include determining surface water shares for each owner under a ditch or determining different application rates based on crop types. Instead water was shared equally based on acreage. Therefore, this basin-wide historical crop consumptive use analysis is appropriate for CRDSS planning purposes. However, it should be used as a starting point only for a more detailed ditch level analysis.

Appendix A:

Comparison of High Altitude Crop Coefficients

Gunnison River Basin

Final
Memorandum

To: Matt Brown and Blaine Dwyer, AECOM

From: Kara Sobieski and Erin Wilson, Leonard Rice Engineers, Inc.

Subject: Comparison of High Altitude Crop Coefficients, Gunnison River Basin

Date: July 29, 2009

Introduction

As presented in the Colorado Water newsletter, January/February 2008, the Upper Gunnison Water Conservancy District and Colorado State University conducted field studies to refine methods that would accurately account for consumptive water use of irrigated meadows in the Gunnison River basin. Dan H. Smith of the Department of Soil and Crop Sciences at Colorado State University directed the studies, which included measuring actual evapotranspiration (consumptive water use) using compensating lysimeters under fully irrigated conditions.

The studies were conducted over five consecutive growing seasons, 1999 to 2003. Monthly water use observations at the lysimeters were compiled and used to calculate monthly crop coefficient values. Preliminary crop coefficients were developed in 2003, however further analysis provided a revised set of crop coefficients presented in the 2008 article. The crop coefficients developed from these studies were then compared to other lysimeter-derived crop coefficients developed in the Gunnison, South Park and Upper Colorado River basins.

Comparison of Crop Coefficients

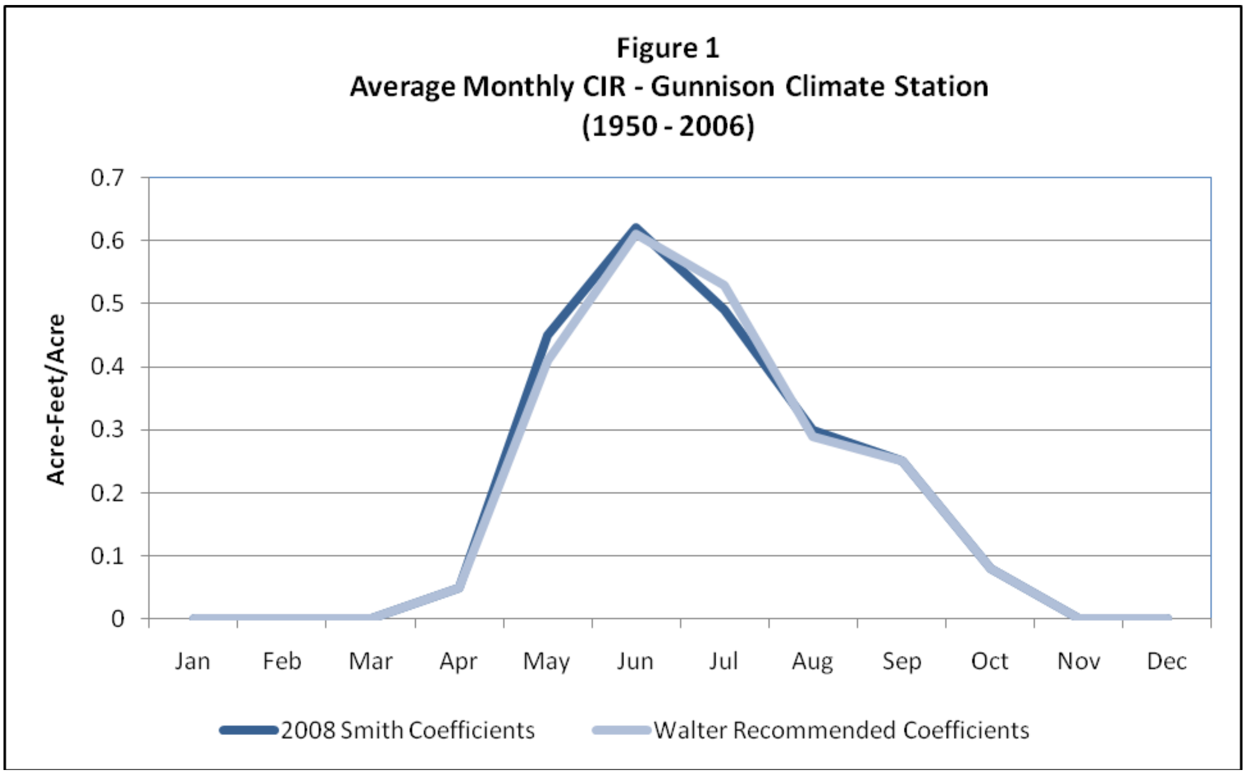
Currently, the datasets developed through the Colorado Decision Support System (CDSS) efforts estimate irrigation water requirements for grass pasture above 6500 feet in elevation throughout the State using the high altitude coefficients recommended by Walter et al. in *Evapotranspiration & Agronomic Responses in Formerly Irrigation Mountain Meadows, South Park, CO - Denver Water Board*. This set of recommended crop coefficients, as well as those developed through the CSU lysimeter studies are shown in **Table 1**. Note that October coefficients were not published by Smith, therefore Walter coefficients were used for that month. It is important to represent coefficients through October when considering the effects of alternate climate in CRWAS.

Table 1
Monthly High-Altitude Grass Pasture Coefficients

Month	Walter Recommended	Gunnison - Smith 2008
May	1.18	1.29
June	1.40	1.42
July	1.22	1.13
August	0.81	0.83
September	0.86	0.86
October	0.75	0.75 *

*October coefficients not available from Smith

A crop irrigation water requirement (CIR) analysis was performed at the Gunnison climate station (ID 3662) over the 1950 to 2006 period with StateCU using both grass pasture crop coefficients. Figure 1 shows the average CIR comparison.



As shown, the 2008 Smith coefficients result in slightly higher CIR in May and June, and slightly lower CIR in July. The average annual CIR was 2.22 acre-feet/acre using the recommended Walter coefficients, and 2.24 acre-feet /acre using the 2008 Smith coefficients; less than 1 percent difference.

Recommendation

It is our recommendation that the consumptive use analysis performed to support the CRWAS efforts continue to use the Walter coefficients to estimate consumptive use for high altitude grass pasture. Application of either set of coefficients appears to be reasonable for CRWAS, as there is minimal difference between the results; however we were unable to find additional documentation on the Smith Study besides the *Colorado Water* article to review. We recommend the continued use of the Walter coefficients due to 1) maintaining consistency with other CDSS efforts; 2) the extensive peer review of the Walter coefficients by experts; and 3) the level of documentation available.

References

Smith, D. H. (2008). "Consumptive Irrigation Water Use Intermountain Meadows of Colorado", Colorado Water, Newsletter of the Water Center of Colorado State University, January/February 2008.

Walter, I.A., Siemer, J.P., Quinlan and Burman, R.D. (1990). "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.

Appendix B:

Impact of Elevation Adjustment based on Structure Elevations

Yampa River Basin

Final
Memorandum

To: Ray Alvarado, CWCB

From: Kara Sobieski and Erin Wilson, Leonard Rice Engineers, Inc.

Subject: Impact of Elevation Adjustment based on Structure Elevations, Yampa River Basin

Date: July 13, 2009

Introduction

The *ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements (1990),* recommends an elevation adjustment for both the SCS and the FAO-24 Blaney-Criddle methods of 10% adjustment upward for each 1,000 meters increase in elevation above sea level. The adjustment corrects for lower mean temperatures that occur at higher elevations at a given level of solar radiation (i.e. mean temperatures do not reflect crops' reactions to warm daytime temperatures and cool nights). The adjustment is applied to the potential consumptive use estimate and can be used on a crop – specific basis. Calibrated crop coefficients will generally account for the elevation adjustment during the calibration; therefore they should not have an elevation adjustment in addition to the calibration. In StateCU, the adjustment is based on the elevation of the diversion structure if available, or the elevation of the climate station assigned to the diversion structure. If more than one climate station is assigned to the diversion structure using climate weights, the weighted average of the climate stations elevations is used.

Currently, the consumptive use datasets developed for the CDSS efforts do not include elevation information for each structure; the elevation adjustment is currently based on the weighted climate station elevation. Structure elevation information is not available in HydroBase, and therefore could not be queried and was not used in the datasets.

This memorandum addresses the question of the impact on irrigation water requirement when using the CDSS standard of elevation data based on weighted climate stations versus using elevation data based on the actual location of irrigated parcel. This memorandum summarizes the approach and results of a consumptive use analysis using an elevation adjustment based on weighted climate station elevations compared to an analysis using an adjustment based on structure elevations. The structure elevations were based on the elevation of the centroid of the 1993 irrigated acreage served by each structure.

Approach

Explicit structures in Water District 44 in the Yampa River Basin consumptive use analysis were used as the subset for the comparison. This subset includes 80 diversion structures, representing over 19,100 acres of irrigated acreage, of which 93 percent is grass pasture, 6 percent is alfalfa, and 1 percent is small grains. A consumptive use analysis was performed using StateCU for the 1950 through 2006 study period for this subset, using weighted climate station elevations as the basis for the elevation adjustment.

To determine the structure elevations for the comparison analysis, the centroid elevation of parcels served by structures in the subset were extracted from a 30 meter Colorado digital elevation model using the 1993 Division 6 irrigated acreage coverage. These structure elevations were included in the structure file for the comparison consumptive use analysis. There was no technical need to change other input parameters between the two analyses. Structure elevations for the subset range in elevation from 5639 feet to 8145 feet above sea level.

As outlined in SPDSS Task Memorandum 59.1, it was recommended for the Yampa River basin dataset that structures irrigating grass pasture above 6500 feet in elevation should use the recommended high altitude coefficients developed in the *Evapotranspiration and Agronomic Responses in Formerly Irrigated Mountain Meadows, South Park, Colorado (Walter et. al, Denver Water Board, 1990)*. These Denver Water lysimeter-based high altitude coefficients are already incorporated into the StateCU analysis for the Western Slope. Since they already include the effect of the high elevation at South Park, no further elevation adjustment is needed. Structures in the subset that irrigate grass pasture above 6500 feet use the Denver Water high altitude coefficients. When using these coefficients, StateCU will not use an additional elevation adjustment to calculate the irrigation water requirement. Thirty-seven of the eighty structures in the subset are assigned the Denver Water high altitude coefficients, representing 6,516 acres of high altitude grass pasture.

Results

The irrigation water requirement for the CDSS standard weighted climate station elevation scenario was 34,594 acre-feet on average per year as compared to 34,570 acre-feet per year on average for the structure elevation scenario. The following table shows the monthly irrigation water requirement for both scenarios, and the percent difference between the two scenarios. The overall percent difference is less than one percent.

Subset of Yampa River Basin StateCU
Average Annual Irrigation Water Requirement (acre-feet)
1950 - 2006

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Weighted Climate Station Elevation Scenario	0	0	0	572	4689	8089	9539	6840	3844	1021	0	0	34,594
Acreage Elevation Scenario	0	0	0	572	4686	8084	9533	6835	3841	1020	0	0	34,570
Percent Difference	0%	0%	0%	0.10%	0.06%	0.06%	0.06%	0.07%	0.09%	0.12%	0.00%	0.00%	0.07%

As discussed above, thirty-seven of the structures use the Denver Water high altitude coefficients. Therefore only forty-three structures will be impacted by the elevation adjustment based on the use of the structure elevation. The irrigation water requirement for the forty-three structures was isolated and provided in the table below to better compare the impact of using the structure elevations.

Non-High Altitude Structures
Subset of Yampa River Basin StateCU
Average Annual Irrigation Water Requirement (acre-feet)
1950 – 2006

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Weighted Climate Station Elevation Scenario	0	0	0	377	2331	4286	5802	4733	2325	483	0	0	20,337
Acreage Elevation Scenario	0	0	0	376	2327	4280	5794	4726	2320	482	0	0	20,306
Percent Difference	0%	0%	0%	0.16%	0.16%	0.14%	0.14%	0.15%	0.18%	0.27%	0.00%	0.00%	0.15%

Recommendation

It is our recommendation that the weighted climate station elevations continue to be used as the basis for the elevation adjustment (in cases where calibrated coefficients are not already used) in the CDSS consumptive use scenarios in support of the CRWAS analyses. The accuracy gained from using the structure acreage-based elevations is negligible, and does not warrant the effort required to update all of the models with structure elevations. Structure elevations based on irrigated acreage can be problematic because the elevations are not available in HydroBase and the irrigated acreage is variable over time. Based on these concerns and the limited increase in accuracy, we recommend continuing to use the weighted climate station elevations.