Historic Crop Consumptive Use Analysis

White River Basin

Final Report

October 2009

Leonard Rice Engineers, Inc.

Acknowledgments

The work described in this report was funded by the State of Colorado, Colorado Water Conservation Board (CWCB) under the Colorado River Decision Support System (CRDSS) - Consumptive Use and Water Budget Project. The project was directed by Ray Alvarado with the Colorado Water Conservation Board. Leonard Rice Engineers' project manager, Erin M. Wilson, P.E., was assisted by Kara Sobieski, P.E. and Adam Kremers.

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1.0 Executive Summary

The White 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 updated in September 2009.

1.1 Background

The White River Basin is located in northeastern Colorado and encompasses approximately 3,570 square miles. The North and South Forks of the White River originate in the highlands of the Flat Tops formation at about 11,000 feet and flows westerly into Utah through Rangely, Colorado at an elevation of 5,280 ft. Major tributaries in the White River basin include Big Beaver Creek, the North, and South Forks of the White River, Piceance Creek, Yellow Creek, and Douglas Creek. Most of the runoff is attributable to snowmelt from the higher elevation areas. Average annual rainfall varies from over 40 inches in the Flat Tops to approximately 10 inches at Rangely.

1.2 Approach

The White 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 includes irrigated acreage, crop types, monthly climate data, and diversion records.

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 White 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 45,729 acre-feet per year while water supply-limited consumptive use averages 42,415 acre-feet per year. The average annual shortage in the basin is 7 percent.

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

Water District	1993 Acres	Irrigation Water Requirement (acre-feet)	Supply-Limited CU (acre-feet)	Percent Short
43	26,871	45,729	42,415	7%

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. The total irrigated acreage from 1950 to 2006 averaged 26,871 acres. As shown, grass pasture is grown on the majority of irrigated land in the basin.

Figure 1
Irrigated Acreage by Crop Type
1993 Irrigated Acreage Coverage

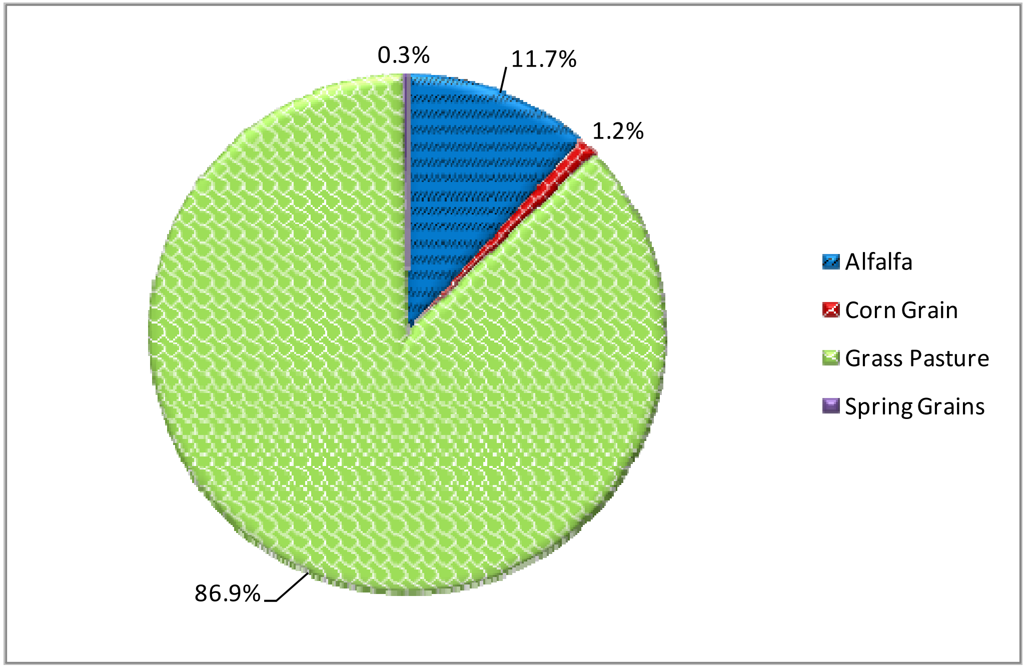


Figure 2 presents the annual historic acreage, irrigation water requirement and supply limited consumptive use for the study period. Because irrigated acreage and crop type do not vary

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 7 percent over the study period. Greater shortages from 1987 to 1991, 11 percent, represent below average stream flows. Shortages averaging 6 percent from 1992 through 2000 are consistent with normal to above average stream flows. Shortages increased to 16 percent in the early 2000s due to drought conditions.

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

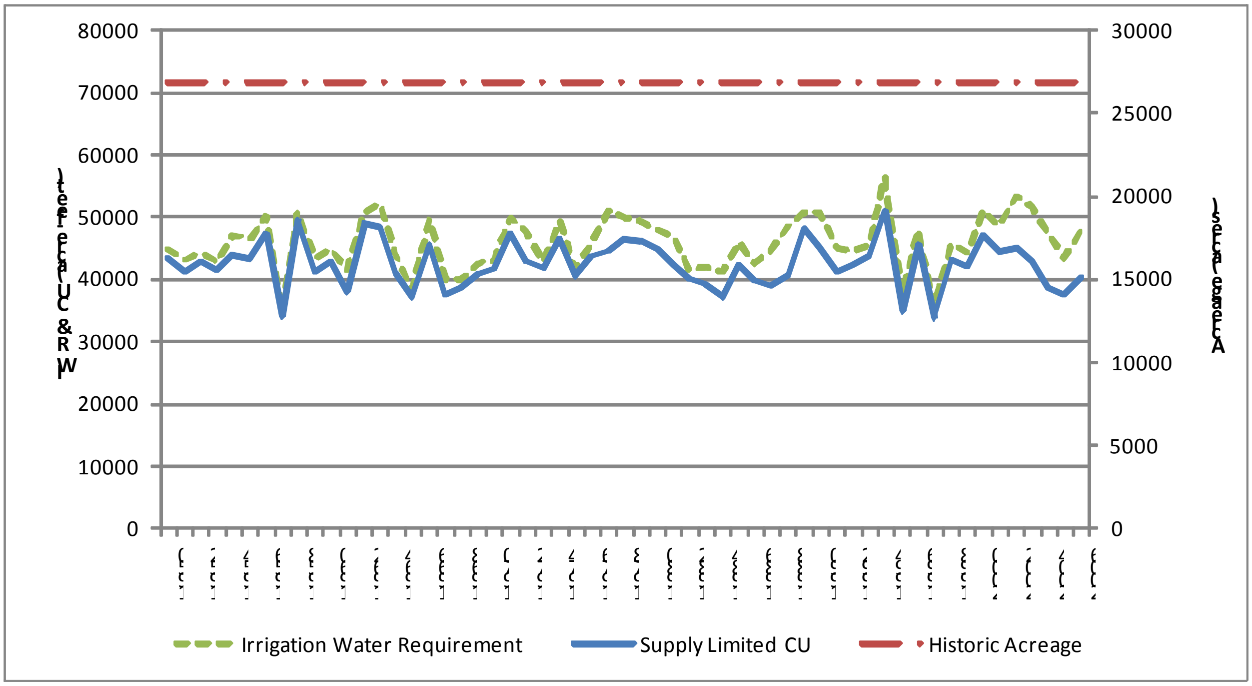
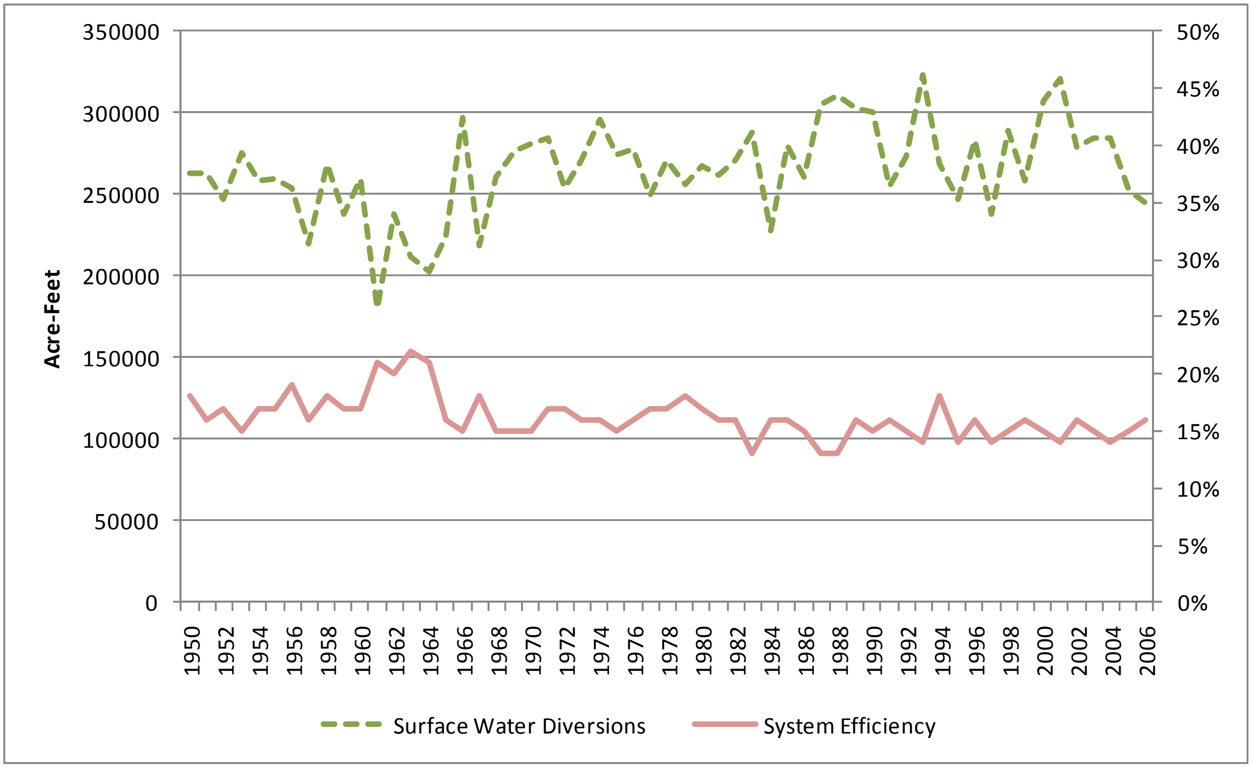


Figure 3 shows the annual estimated diversions from surface water to meet crop irrigation requirement and the average annual calculated system efficiency. The average annual surface water diversions from 1950 through 2006 were 265,101 acre-feet. The average annual surface water system efficiency from 1950 through 2006 was approximately 16 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 54 percent and varied 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 White 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 White River basin.

2. White River Basin Water Resources Planning Model User's Manual describes the development of the White 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.

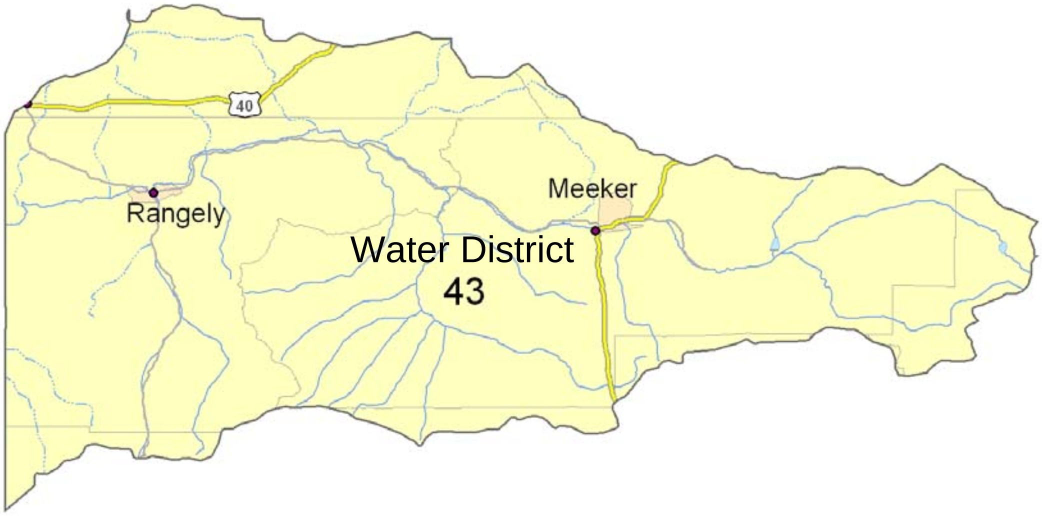
This Historic Crop Consumptive Use Analysis Report has not attempted to reiterate the detailed analyses and results of the previous efforts performed in support of the final historic crop consumptive use analysis. Instead, it summarizes the major results of each technical memorandum. Supporting memorandum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

2.1 Basin Description

The White River Basin, as shown in **Figure 4**, is located in northeastern Colorado and encompasses approximately 3,570 square miles. The North and South Forks of the White River originate in the highlands of the Flat Tops formation and flow generally west, meeting near Buford shortly outside the White River National Forest. The Flat Tops are a remnant of the White River Uplift, formed over 50 million years ago, and glaciated during the Pleistocene and possibly early Holocene. As a result, the landscape in the upper White River is characterized by many glacial lakes and U-shaped valleys. The uplift is bounded on the west by the Grand Hogback, a north-south trending, nearly vertical upturn of Mesa Verde sandstones and shales. This feature forms the east boundary of the Piceance Creek basin, a major tributary of the White River that drains the Roan Plateau to the south, flowing north and entering the White River between Meeker and Rangely. At Rangely, the White River is on the edge of the Colorado Plateau physiographic province. Here the terrain is typical of that province, with impressive mesas, cliffs, and rims. The White River enters Utah about 20 miles west of Rangely.

Major tributaries in the White River basin include Big Beaver Creek, the North, and South Forks of the White River, Piceance Creek, Yellow Creek, and Douglas Creek. Most of the runoff is attributable to snowmelt from the higher elevation areas. Average annual rainfall varies from over 40 inches in the Flat Tops to approximately 10 inches at Rangely. The various elevations in the basin define distinctive vegetation types and coverages. Lacking elevations over 12,500 feet, the White River basin has little land above treeline. At the upper, eastern end of the basin, Englemann spruce and sub-alpine fir are the dominant forest cover. Lodgepole pine, ponderosa pine, and spruce fir mingle with areas of high grasslands at slightly lower elevations. Below 9,000 feet, vegetation transitions to Gambel oak, pinion/juniper, and sagebrush-steppe communities. The western portion of the basin, at an elevation of approximately 5,500 feet, is dominated by sagebrush, grasslands, and salt desert shrublands.

Figure 4
White 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 White 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 74 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 26 percent of the basin irrigated acreage.

Table 2
1993 Irrigated Acreage by Structure Type

Structure Type	1993 Acres	Percent of Total
Key	19,956	74 %
Aggregated	6,915	26 %
Total All Structures	**26,871**	**100 %**

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

1. A White River Basin structure scenario was developed that includes 100% of the 1993 irrigated acreage in the White 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 **wm2009** for the White River crop consumptive use analysis, updated in 2009. Other official State historic consumptive use data *Analysis_descriptions* include SP2008 for the South Platte River, 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 the StateCU input files have been generated from HydroBase using the data management interfaces StateDMI (Version 3.08.00, 6/10/2009) and TSTool (Version 9.01.01, 3/10/2009). 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 (wm2009.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 White River Basin. Input file names in the response file can be revised through the StateCU Interface.

4.2 StateCU Model Control File (wm2009.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 White River Basin. Options in the model control file can be revised through the StateCU Interface.

4.3 StateCU Structure File (wm2009.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.

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, 4.8 cubic feet per second (cfs) was selected as the cutoff for explicit representation in the White River basin; key diversion structures are those with total absolute water rights equal to or greater than 4.8 cfs. The White River model includes 102 key diversion structures.

The use associated with irrigation diversions having total absolute rights less than 4.8 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, or if on the mainstem, gage location, critical administrative reaches, and instream flow reaches. To the extent possible, aggregations were devised so that they represented no more than 1,000 irrigated acres. In the White River model, 16 aggregated nodes were identified, representing 6,915 acres of irrigated crops. Their historical diversions were developed 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**, 74 percent of acreage with a surface water source was assigned to key structures. The approach and results for selecting key structures and aggregations are outlined in more detail in Section 4.2.2 and Appendix A of the *White 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	19,956	102	74 %
Aggregated Surface Water Structures	6,915	16	26 %
Total Structures	**26,871**	**118**	**100 %**

1) Number of total structure IDs included in the model. Aggregates structures 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 0.0560 to 0.1650 inches per inch.

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.

4.4 Crop Distribution File (wm2009.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 4** summarizes the 1993 acreage by crop type.

Table 4
1993 Irrigated Acreage by Crop Type

Crop	Acreage
Alfalfa	3,134
Corn	327
Pasture Grass	23,342
Spring Grains	68
Total Acreage	**26,871**

1993 Acreage and crop types were assigned to each year (1950 through 2006) reflecting the limited change in irrigated acreage in the White 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. 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 (wm2009.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)

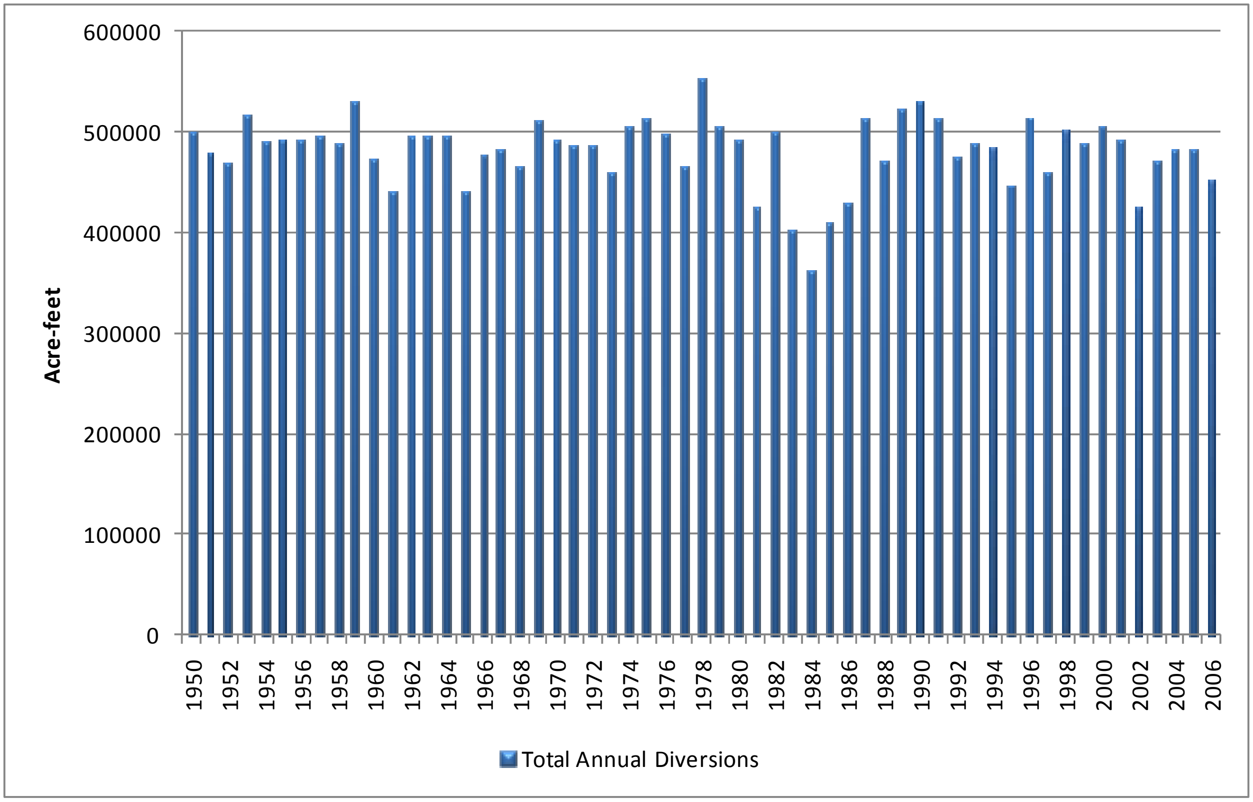
The conveyance efficiency accounts for losses between the river headgate and the farm headgate, including losses through canals, ditches and laterals. The maximum flood irrigation and sprinkler efficiencies account for application losses between the farm headgate and the crops. Note that conveyance and 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 White River Basin is set at 100 percent. Therefore the maximum flood irrigation and sprinkler irrigation efficiencies represent maximum overall system efficiencies were estimated to be 54 percent and 80 percent respectively. The maximum flood irrigation system efficiency was derived based on a maximum application efficiency of 60 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 (wm2009.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 265,000 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 an aggregate structure are first extracted and filled, then combined with other structures' diversion data in the 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 gage used in the White River basin is the White River near Meeker, CO (09304500). 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, StateMod diversion right file (*.ddr). Utilizing the administration number in the diversion right file, **StateDMI** 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 *White 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 5** lists the subset of climate stations used in the White 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 5
Key Climate Station Information

Station ID	Station Name	WD	Period of Record	Elevation (feet)	Percent Complete (1950 – 2006)	
					Temperature	Precipitation
5048	Little Hills	43	1948-1991	6140	68.42%	71.35%
5414	Marvine Ranch	43	1972-1998	7800	45.47%	45.18%
5484	Meeker 3 W *	43	1900-2009	6180	95.47%	95.47%
6832	Rangely 1 E	43	1950-2009	5290	94.44%	95.47%

* 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 6** summarizes the average annual temperature, frost dates and precipitation based on filled data for the subset of stations used in the White River analysis.

Table 6
Average Annual Filled Climate Values 1950 through 2006

Station Name	Station ID	Average Annual (1950 – 2006)		Frost Dates - Degrees F			
		Temperature (Degrees F)	Precipitation (Inches)	Spring 28 Deg	Spring 32 Deg	Fall 32 Deg	Fall 28 Deg
Little Hills	5048	42.5	13.82	7-Jun	19-Jun	12-Aug	4-Sep
Marvine Ranch	5414	36.7	26.61	15-Jun	24-Jun	17-Jul	14-Aug
Meeker 3 W *	5484	44.6	16.15	22-May	5-Jun	12-Sep	23-Sep
Rangely 1 E	6832	46.8	10.03	30-Apr	16-May	24-Sep	4-Oct

* 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 Rangley 1 E (6832) climate station, located in the western portion of the White 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
Rangley 1 E Climate Station
1950 through 2006

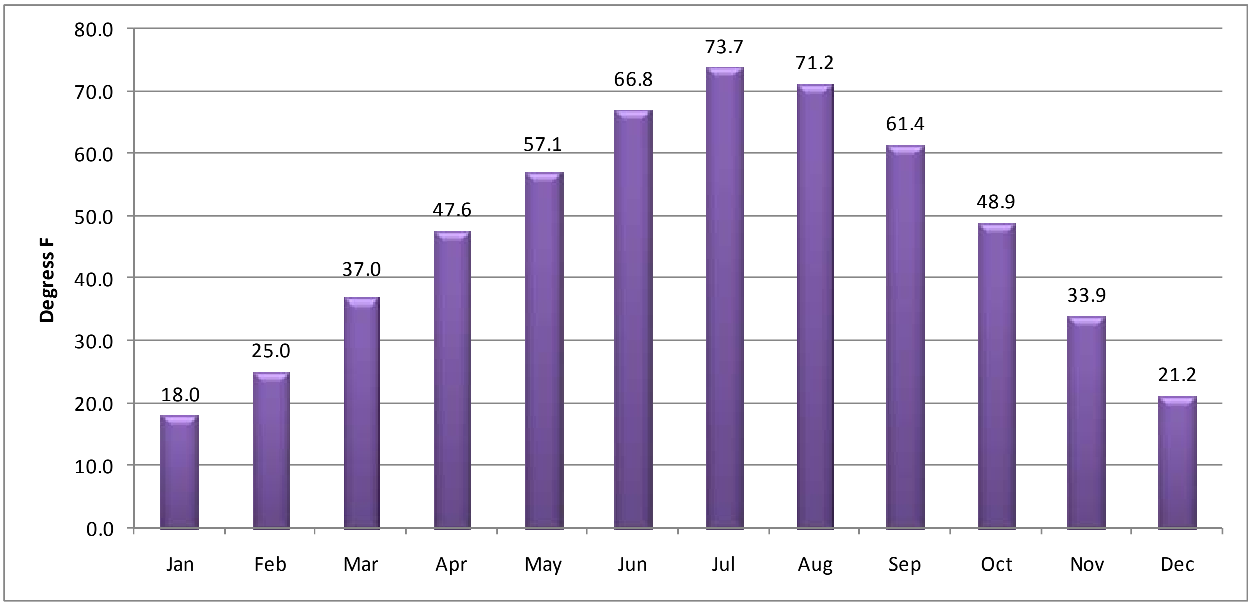
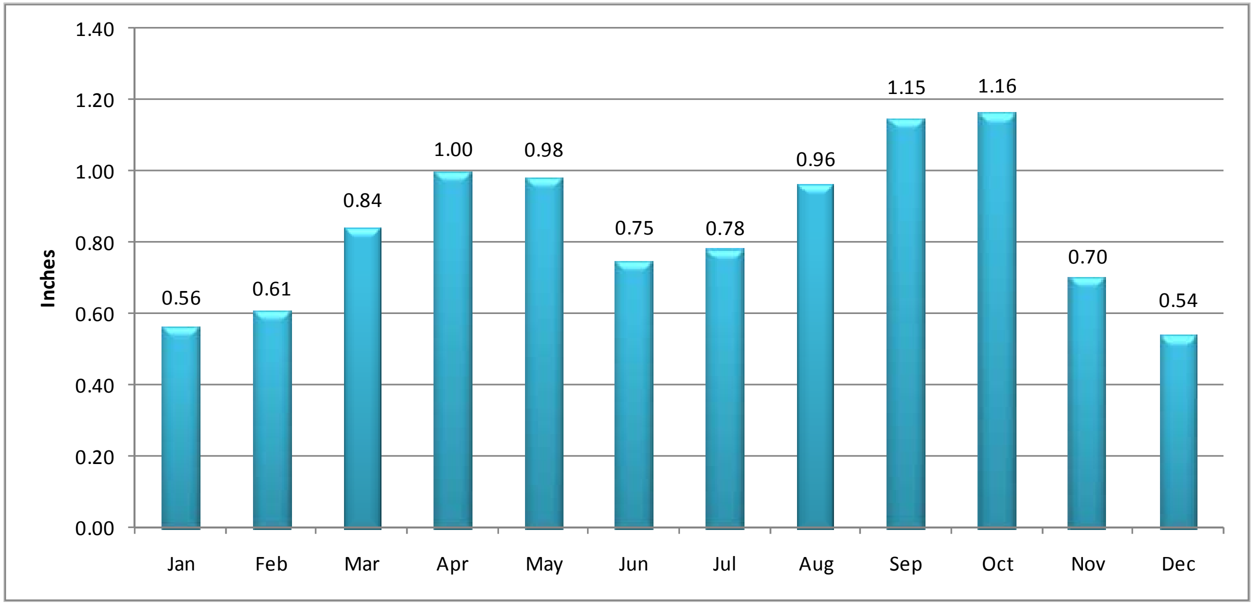


Figure 7
Average Mean Monthly Precipitation
Rangley 1 E Climate Station
1950 through 2006



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 four TR-21 crops are modeled in the White River Basin; grass pasture, alfalfa, corn and spring grains.

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 previous lysimeter studies, 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 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 adaptedin the analysis. Crop characteristics from the Denver Water study were used for grass pasture above 6,500 feet in elevation. The beginning temperature and ending calibrated temperature used to define the growing season of high altitude grass pasture is 42 degrees Fahrenheit. Because grass pasture is a perennial crop, the length of season is set to 365 days. **Table 7** illustrates the crop characteristics for the crops grown in the White 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 7
Characteristics of White River Basin Crops

Crop Type	Source	Length of Season	Beginning Temperature	End Temperature
Alfalfa	TR-21	365	50	28
Corn Grain	TR-21	140	55	32
Grass Pasture	TR-21	365	45	45
Spring Grains	TR-21	137	45	32
High Altitude Grass Pasture	Denver Water Study	365	42	42

5.0 Results

The White 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 Results

Tables 8 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 8
Basin Average Annual Results
1950 through 2006 (acre-feet)

	Surface Water Diversion Accounting					Estimated Crop CU		
Irrigation Water Required	River Headgate Diversion	Surface Water Diversion To:			Calculated System Efficiency	From SW	From Soil	Total
		CU	Soil	Non-Consumed				
45,729	265,101	39,048	3,422	222,631	16%	39,048	3,368	42,415

Note that a conveyance loss of 10 percent is factored directly into the maximum system application efficiencies, as presented 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

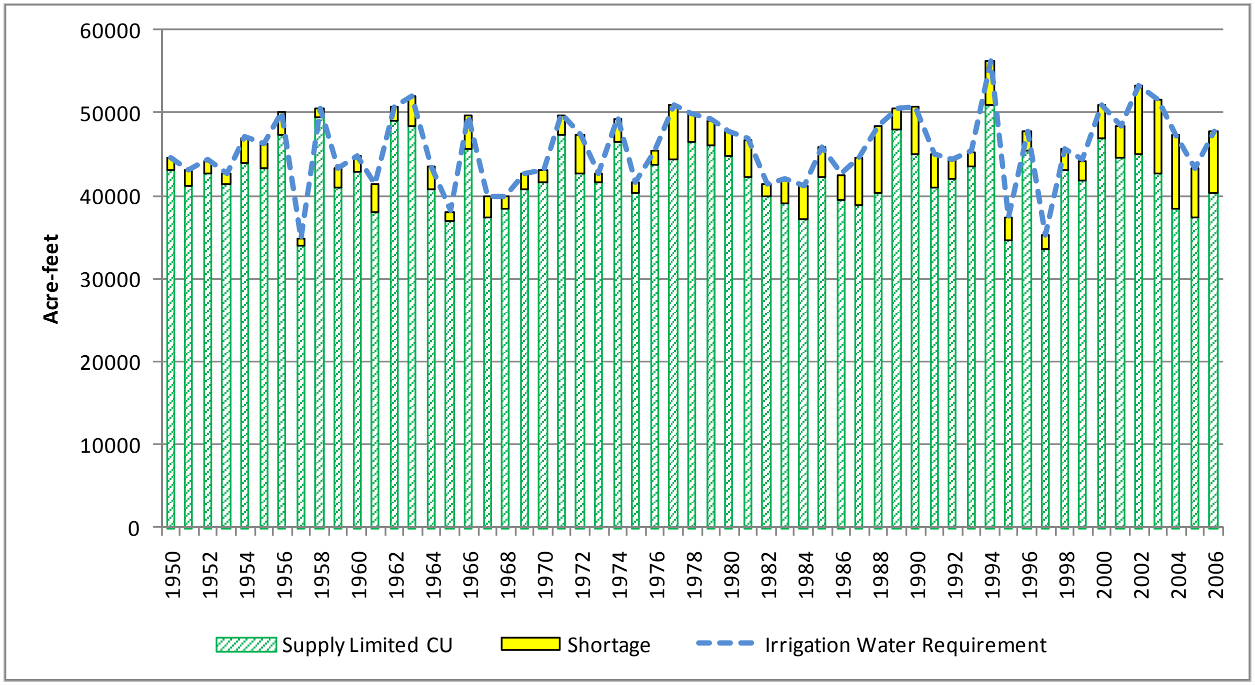
Table 9 presents the historic crop consumptive use analysis results for the 1950 to 2006 study period. Irrigation water requirement in the White River basin is satisfied from surface water diversions, resulting in an estimate of water supply limited consumptive use. The White River basin averages 42,415 acre-feet of water supply limited consumptive use annually. The average annual shortage in the basin is 7 percent. Note the consumptive use from surface water includes excess surface water stored in the soil moisture and then subsequently used by crops.

Table 9
Average Annual Consumptive Use Results
1950 through 2006

1993 Acres	Irrigation Water Requirement (acre-feet)	Supply-Limited CU (acre-feet)	Percent Short
26,871	45,729	42,415	7%

Figure 8 presents basin crop consumptive use results by year. As shown, the percent of irrigation water requirement is directly related to water supply. Greater shortages from 2002 through 2007, averaging 16 percent, represent limited water supply due to below average stream flows. Shortages averaging 6 percent from 1991 through 2000 are consistent with normal to above average stream flows.

Figure 8
Irrigation Water Requirement and Supply Limited CU



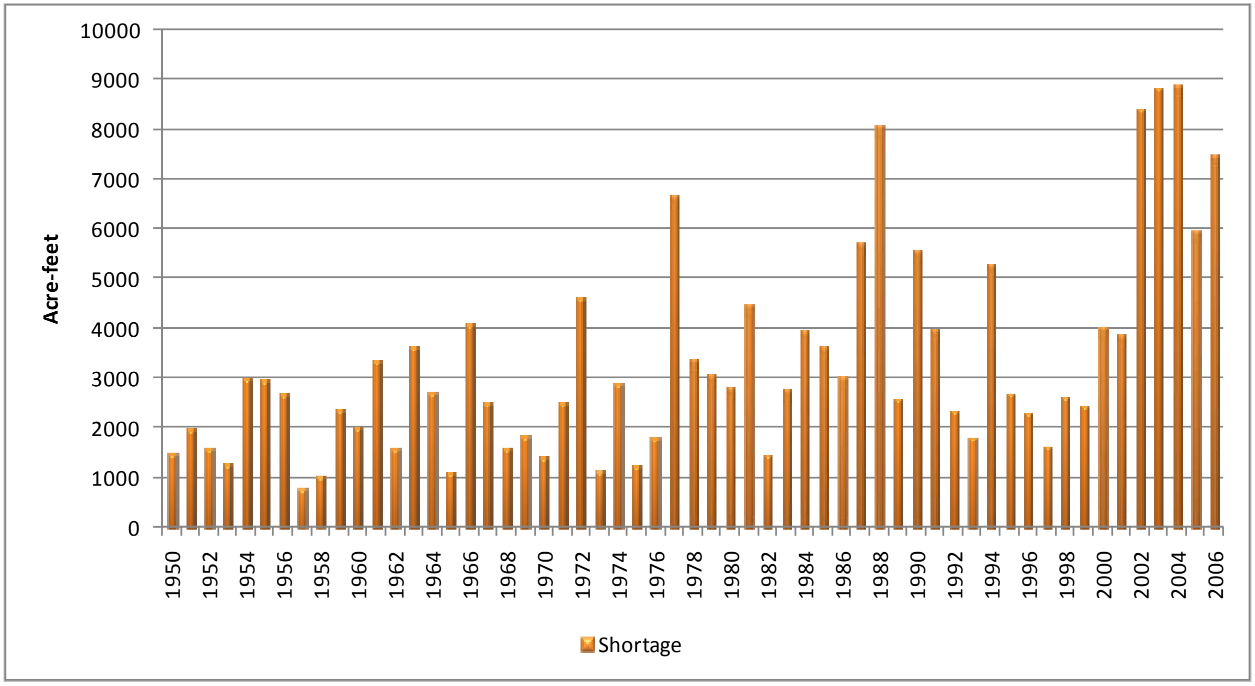
Average monthly shortages for the study period vary from a low of 4.9 percent in June to a high of 14 percent in October, as shown in **Table 10**. In general the shortages throughout the basin are relatively low.

Table 10
Average Monthly Shortages
1950 through 2006

Apr	May	Jun	Jul	Aug	Sep	Oct
9.5%	5.8%	4.9%	6.7%	8.1%	11.3%	14.1%

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 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.

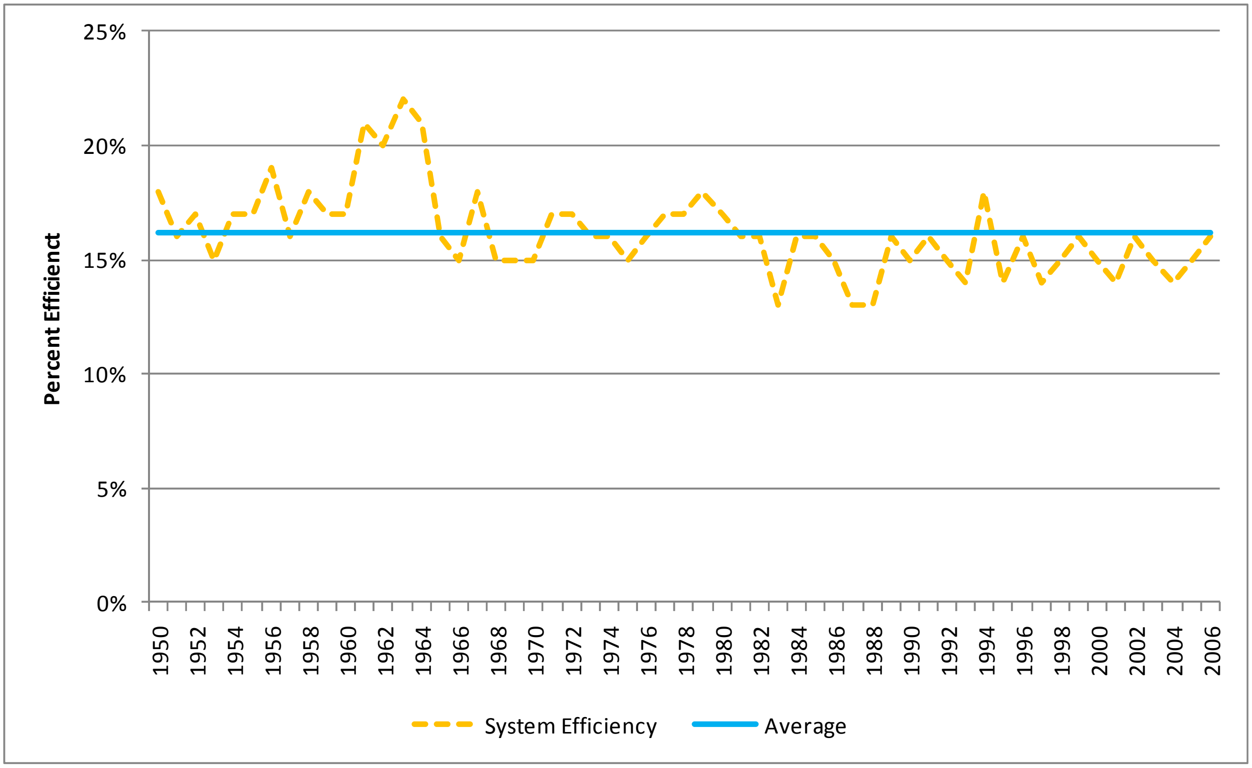
Maximum system efficiencies for surface water diversions are provided as input to StateCU, as described in **Section 4.5**. Actual system efficiencies are calculated based on the amount of water available to meet crop demands and the application method (e.g. flood or sprinkler). Based on the 1993 irrigated acreage assessment, only 400 acres, or 1.4 percent of the total irrigated acreage in the basin, is served by sprinklers. The remaining acreage is irrigated with flood irrigation practices.

Table 11 provides the average monthly calculated system efficiencies for surface water supplies and **Figure 11** 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 11
Average Monthly Calculated System Efficiencies
1950 through 2006

Apr	May	Jun	Jul	Aug	Sep	Oct
14%	17%	16%	19%	18%	13%	7%

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 judgement. 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 judgement 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:

Develop Locally Calibrated Blaney-Criddle Crop Coefficients

CRDSS Supporting Memorandum

Subject: Recommend Locally Calibrated Blaney-Criddle Crop Coefficients

Note that this supporting memorandum includes selected sections from the **SPDSS Task 59.1 Memorandum Titled "Develop Locally Calibrated Blaney-Criddle Crop Coefficients"** that discuss the review of previous lysimeter studies and the recommendation to utilize lysimeter-derived coefficients from the South Park study by Walter et al. for use with the original Blaney-Criddle method for high altitude areas throughout Colorado.

Introduction

The modified SCS Blaney-Criddle consumptive use methodology estimates potential consumptive use (PCU) on a monthly basis using monthly average temperature and daylight hours estimated from latitude. Because this data is readily available for long study periods, the methodology is widely used and recommended for use in the SPDSS. However, the modified Blaney-Criddle crop coefficients available from the SCS publication Irrigation Water Requirements Technical Release No. 21 (TR-21) were developed to represent general conditions around the west and may not represent local conditions in the South Platte, North Platte, and Laramie River basins (SPDSS study area). Therefore locally calibrated Blaney-Criddle crop coefficients, were available, are recommended CRDSS basins. The SPDSS *Task 58 – Review Previous Estimates of Potential CU* memo discusses the methods used throughout Colorado for calculating potential crop consumptive use. As summarized in Task 58, local coefficients can be developed based on lysimeter data or results of a more detailed evapotranspiration equation.

The locally calibrated crop coefficients recommended under this task will be used to estimate potential crop consumptive use under conditions of a full water supply. The potential crop consumptive use will then be compared to historical water supply, using a soil moisture balance, to estimate supply-limited crop evapotranspiration.

Information in this memorandum is believed to be accurate. However, information should not be relied upon in any legal proceeding.

Approach and Results

Gather and Review Appropriate Data and Literature from Previous Lysimeter Studies to Develop Local Blaney-Criddle Crop Coefficients

As described in Task 58, the most common means of calculating PCU at high elevations throughout Colorado is by use of lysimeter-derived crop coefficients with the original Blaney-Criddle method (temperature coefficient $K_t = 1$). Several lysimeter studies for high altitude irrigated grasses/meadow were identified under Task 58. It was originally anticipated that some of the lysimeter studies of interest might present data but not actually provide calibrated coefficients. As described below, calibrated coefficients were developed as part of each study. Therefore, it was not necessary to develop any calibrated coefficients for this task.

The following lysimeter studies were investigated for this task:

1. **South Park** – Leonard Rice Consulting Water Engineers, Inc. (1993) and other consultants have used a pattern of derived crop coefficients for water rights changes cases in South Park. These coefficients are based on a simple averaging of reported coefficients from a number of lysimeter studies. The individual studies evaluated data collected from 1968 through 1970, 1973 through 1974, and 1977 through 1979.
2. **South Park** – In a report prepared for the Denver Water Board, Walter, Siemer, Quinlan and Burman (1990) evaluated a number of previous lysimeter studies conducted around South Park. Walter et al. developed a set of recommended crop coefficients and compared PCU with those coefficients against measured lysimeter results. The individual studies evaluated data collected from 1968 through 1970, 1974, 1975, 1977, and 1978 through 1979 (note that a number of these studies were also used by LRCWE, 1993).
3. **Division 6 Lysimeter Program** – This ongoing lysimeter data collection program was initiated in 1978 by Energy Fuels Corporation and subsequently taken over by personnel in Division VI (Division of Water Resources, 2003) in 1983. Lysimeters are principally located in the Yampa River drainage, however a lysimeter was installed in year 2000 in the SPDSS study area near Walden, Colorado.
4. **Grand County** – Denver Water commissioned lysimeter studies of consumptive use of mountain meadows at high altitudes in Grand County from 1987 through 1990. Results from these studies are reported by Carlson, Pollara, and Le (1991).
5. **South Park and Gunnison River Basin** – Lysimeter studies were conducted near South Park from 1968 through 1970 and Gunnison from 1969 through 1971 (Kruse and Haise, 1974). Note that the South Park component of this study was reviewed by Walter, et al. (1990).
6. **Gunnison River Basin** – The Upper Gunnison Water Conservancy District sponsored lysimeter-based investigations of irrigated meadow grass consumptive use from 1999 through 2003 at ten sites in the Gunnison River Basin. This investigation was conducted by Colorado State University (Smith, 2004).

Because the principal crop grown at high elevations in Colorado is pasture or meadow grasses, these studies focused on the PCU of high altitude grasses (**Table 1** and **Figure 1**).

Table 1
Lysimeter-Derived Grass Crop Coefficients [1]
(for use with the Original Blaney-Criddle Method)

Lysimeter Study	Apr	May	Jun	Jul	Aug	Sep	Oct	Elevation
South Park – LRCWE	0.58	1.11	1.28	1.26	1.07	1.14	0.78	~ 9500'
South Park – Walter	-	**1.18**	**1.40**	**1.22**	**0.81**	**0.86**	**0.75**	~ 8900' - 9420'
So Park – Kruse	-	0.996	1.163	0.983	0.729	0.890	-	~ 9100'
Div 6 – CYCC	-	0.93	0.96	1.02	0.92	0.79	0.86	~ 6670'
Div 6 – Catamount	-	0.74	0.93	0.84	0.73	0.71	0.78	~ 7000'
Div 6 – No Park (Walden)	-	0.87	1.13	1.12	0.97	0.86	-	~ 8220'
Grand County	-	1.05	1.08	1.01	0.83	0.98	-	~ 7500' - 7850'
Gunnison – Kruse	-	1.253	1.095	0.959	0.908	0.988	-	~ 8000' - 9100'
Gunnison – Smith	-	1.24	1.42	1.13	0.82	0.87	-	~ 7774' - 8685'

[1] Lysimeter-derived crop coefficients used to estimate potential crop consumptive use under full water supply conditions.

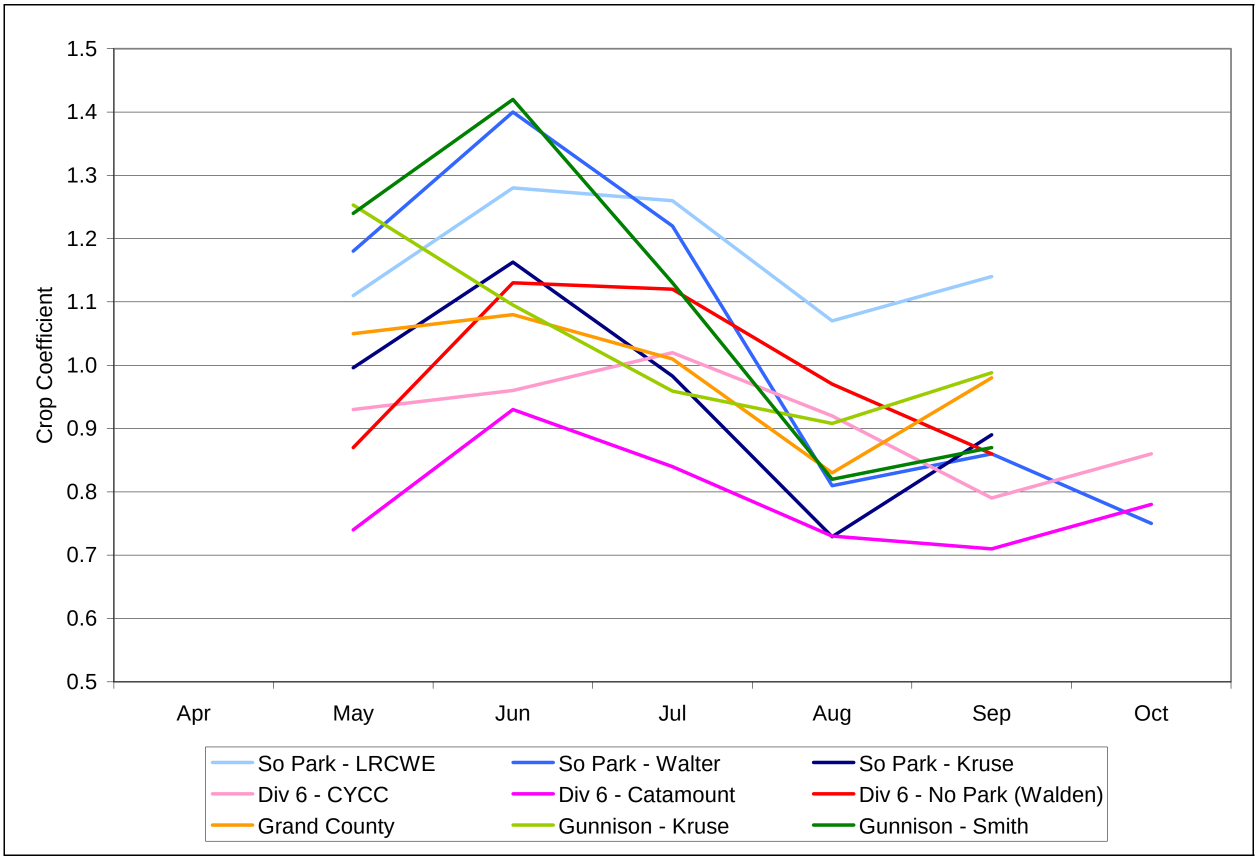


Figure 1 – Lysimeter-Derived Grass Crop Coefficients

It is important when evaluating data from different lysimeters to recognize differences between haying practices, irrigated environment around the lysimeters, means of filling the lysimeter, changes of vegetative matter, operational problems, etc. Examples of inconsistencies found include:

- The Division VI lysimeters are filled manually rather than automatically filling from a reservoir controlled by a float. According to Division VI staff, the sites were flooded at least once a month or when necessary to prevent drought stress to the plants (an attempt is made to irrigate before wilting occurs). These lysimeters are also surrounded by large non-irrigated pasture that may make them unrepresentative of irrigated meadows. While one would typically believe that the location of the lysimeter sites in non-irrigated meadows would increase the measured consumptive use, we believe that the manual filling of the lysimeters based on visual observation produces measured consumptive use more similar to an actual consumptive use value (with limited irrigation) rather than potential consumptive use.

- The South Park lysimeter data used by LRCWE (1993) was not adjusted to reflect haying practices. Adjustment for haying (which usually occurs in early August in South Park) would reduce the averaged coefficients for August and September. The derivation of the crop coefficients also appears to have included less detailed review for consistency and adjustment when compared to the Walter 1990 study. While the Walter Study considered some of the same lysimeter data, Walter discarded from further consideration a number of the sites that were not considered representative of high altitude irrigated meadows and adjusted the crop coefficients of other sites to be consistent with a hayed meadow.

- The Gunnison – Kruse crop coefficient pattern has a different shape than most of the crop coefficient curves derived from high altitude lysimeter studies which tend to peak in June, bottom out in August (with harvest) and then recover some after harvest in September. The Kruse study did not provide an explanation for the Gunnison bowl-shaped coefficient curve.

Both the Walter study for the South Park area and the Smith study for the Upper Gunnison River Basin appear to have made a reasonable effort to identify and exclude lysimeter data that was not reflective of irrigated meadows, and adjust data for consistency (i.e. haying practices). The Walter and Smith crop coefficient curves shown in Figure 1 each represent an average of lysimeter results from several different sites. A summary of the individual lysimeter studies reviewed by Walter are shown below in **Figure 2** and the individual site results from the Smith study are shown in **Figure 3**. So while the Walter and Smith curves shown in Figure 1 appear to be at the upper extent of the studies reviewed, they are actually the average of a subset of studies and individual site curves. These are the two most comprehensive and complete lysimeter studies reviewed and while producing independent derivations of crop coefficients, the resulting average monthly crop coefficients are very similar. Application of either set of coefficients with the original Blaney-Criddle method would be reasonable for SPDSS, however, due to the level of documentation provided with the Walter study we recommend the South Park – Walter coefficients be used for SPDSS (Table 1 shown in bold). The South Park – Walter study showed that the season of significant plant growth was well-approximated by using a five-day temperature threshold of 42 degrees, as opposed to the 45 degrees mean temperature outlined in TR-21. When applying the South Park – Walter coefficients for SPDSS, the growing season will be defined by a mean temperature of 42 degrees for both spring and fall.

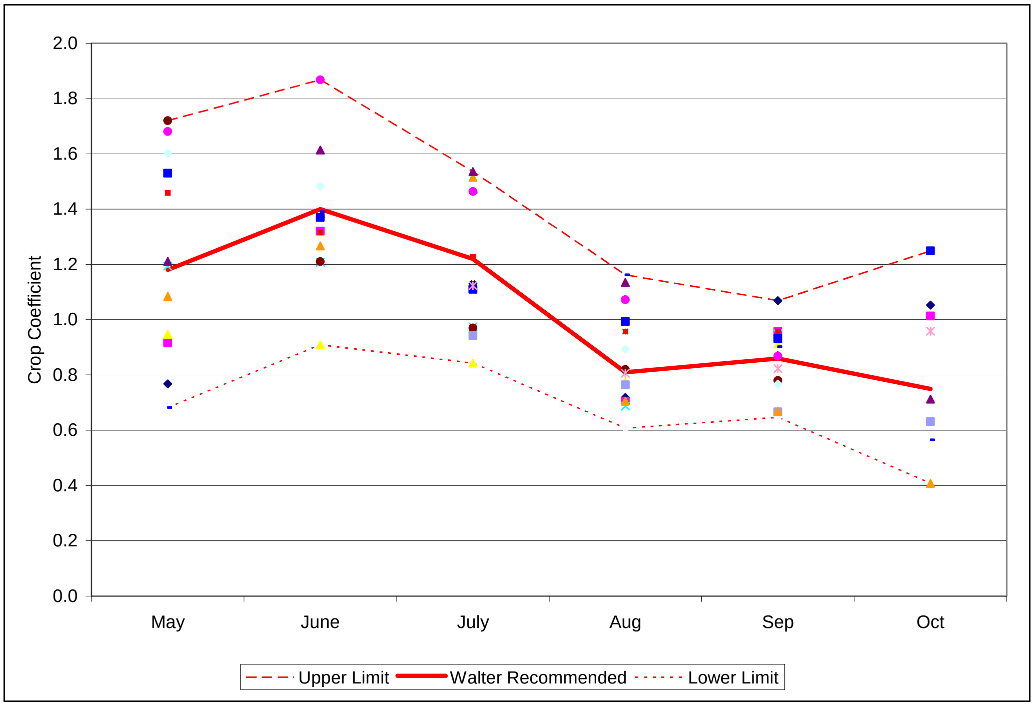


Figure 2 – Lysimeter-Derived Grass Crop Coefficients Evaluated by Walter et al.

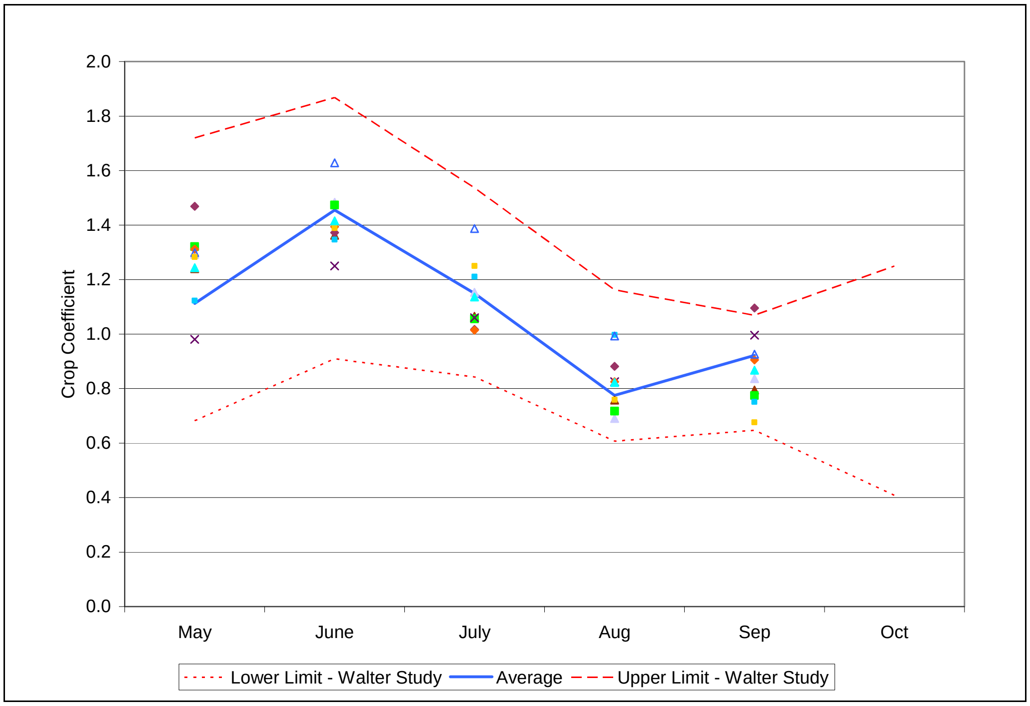


Figure 3 – Lysimeter-Derived Grass Crop Coefficients from the Smith Study

Recommendations

Lysimeter-derived crop coefficients, because they represent actual field experiments, produce more accurate results than using a generalized consumptive use method with standardized crop coefficients. Even if an adjustment for elevation is made to the generalized method and standardized coefficients, consumptive use results are not typically as accurate as those based on local lysimeter data. As an example, the original Blaney-Criddle consumptive use method was analyzed using the lysimeter-derived coefficients from the Walter study (Table 1) and compared to the modified Blaney-Criddle method run with the TR-21 crop coefficients and an upward elevation adjustment of 10% for each 1,000 meters increase in elevation above sea level (as recommended in ASCE, 1990). While PCU is a linear function of the crop coefficients with the original Blaney-Criddle method, the relationship is not linear with the modified Blaney-Criddle method due to the additional temperature adjustment. Therefore, crop coefficients for the two methods cannot be compared directly. However, the resulting PCU of pasture/meadow grass can be compared and are provided in **Table 2** at two high altitude climate stations, Antero Reservoir and Bailey.

Table 2

Ave. Annual (1950 – 2003) PCU for Pasture Grass using Lysimeter-Derived Crop Coefficients vs. Standardized Coefficients with Elevation Adjustment

Climate Station	Lysimeter-Derived Coefficients	Modified Blaney-Criddle w/Elev Adj	Ratio (Elev Adj/Lysimeter)
Antero	2.17 feet	1.33 feet	61%
Bailey	2.52 feet	1.66 feet	66%

As presented above, even with an elevation adjustment, use of the modified Blaney-Criddle method and standard TR-21 coefficients significantly understates (by over 30%) the estimated potential consumptive use of grass pasture when compared to lysimeter data. This is also shown in Figure 7.49 of Manual No. 70 where South Park lysimeter results are compared to several temperature-based ET methods (ASCE, 1990). It is recommended that lysimeter-derived coefficients from the South Park study by Walter et al. (Table 1) be used with the original Blaney-Criddle method for high altitude areas throughout Colorado, using the growing season trigger of 42 degrees mean temperature.

As discussed in the SPDSS Task 58 memorandum, if lysimeter data is not available, a preferred option is to calibrate coefficients based on a more detailed daily method, such as the ASCE Penman method. However, in the CRDSS study area, daily climate information is not available. Therefore, as noted in the SPDSs Task 58 memorandum, the use of an elevation adjustment applied to TR-21 crop coefficients is recommended for estimate potential ET for crops grown below 6,500 feet in elevation.

Comments and Concerns

None.

Where to find more information

- The Task 58 – Review Previous Estimates of Potential CU memo provides additional information on several potential consumptive use equations.

References

ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements, Edited by Jensen, M.E., Burman, R.D., and Allen, R.G., 1990.

Carlson, N. C., Pollara, J.R., and Le, T. (1991). “Evapotranspiration in High Altitude Mountain Meadows, in Grand County”, Report for the Board of Water Commissioners, City and County of Denver, CO. November, 1991.

Division of Water Resources (2003), “CUSUM, Summary Report, Irrigation Consumptive Use and Data Collection Program, 1983-2003”, Division of Water Resources, Water Division VI. Also relied on were miscellaneous communications with Andy Schaffner, Water Commissioner for Districts 57 and 58, about the nature of the program.

Kruse, E.G. and H.R. Haise (1974). “Water Use by Native Grasses in High Altitude Colorado Meadows”, Agricultural Research Service, U.S. Dept. of Agriculture, ARS-W-6, Feb.

LRCWE (1993). “Change of Water Rights of the Ralph Johnson Ranch”, Leonard Rice Consulting Water Engineers, Prepared for City of Aurora, August, 1993.

Smith, D. H. (2004). “Special Report to: Statewide Water Supply Initiative (on Upper Gunnison River Basin Irrigation Water Consumptive Use Studies)”, May 19, 2004. Numerous data and spreadsheets were also provided by Mr. Smith related to the Upper Gunnison Basin lysimeter studies.

The ASCE Standardize Reference Evapotranspiration Equation, Edited by Allen, R.G., Walter, I.A., Elliott, R., Howell, T., Itenfisu, D., and Jensen, M., 2005.

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.