RGDSS Memorandum
Phase 6 – Historical Crop Consumptive Use Analysis (StateCU Process)
Final

To: File

From: Modeling and Decision Support Systems Team,
Colorado Division of Water Resources (CDWR)

Subject: RGDSS Groundwater Model - Phase 6 Historical Crop Consumptive Use Analysis (StateCU Process)

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1. Summary

The Phase 6 Rio Grande Basin historical crop consumptive use analysis was performed on a monthly basis for the period from 1950 through 2010 as part of Phase 6 of the Rio Grande Decision Support System (RGDSS) Groundwater Model development. The RGDSS project was developed jointly by the State of Colorado Water Conservation Board (CWCB) and the CDWR.

This memorandum documents the process and input data for the historical crop consumptive use analysis completed for the 6P98 version of the RGDSS Groundwater Model. It is an update and enhancement of the previous report, dated June 2004 by Leonard Rice Consulting Water Engineers, Inc. Major enhancements conducted as part of Phase 6 in coordination with the RGDSS Peer Review Team (PRT) include:

1. Extended the end of the study period from 2005 to 2010.
2. Included metered groundwater withdrawal data for 2009 and 2010.
3. Refined sprinkler acreage timeline based on recently completed satellite imagery evaluations.
4. Revised the approach to estimate historical irrigated acreage see section 5.4.
5. Refined the methodology of assigning climate data to structures.
6. Added crop coefficients and crop characteristics for crops that are now being cultivated in the Rio Grande Basin.
7. Refined the methodology for estimating effective precipitation.
8. Refined select ditch system operations after interviews with the ditch companies.
9. Refinements to diversion records simulated through the use of ***.stm** files that combine appropriate water classes to better represent these complicated systems' historical water supplies.
10. The Irrigation Parameter Yearly Data File was revised to include information gathered from additional water user interviews regarding ditch conveyance efficiencies.
11. Enhanced StateCU code to write out additional information in the detailed water budget that is needed to represent crop irrigation water requirement that was not met by irrigation water supplies but can be met by high groundwater simulated in the MODFLOW model.

2. Introduction

The Rio Grande historical crop consumptive use analysis was performed using StateCU, a generic, data driven consumptive use model and graphical user interface. StateCU software is used to estimate historical crop consumptive use based on user input data such as water supply, cropping, and climate data. For the RGDSS, StateCU was used to develop monthly crop consumptive use estimates. For the RGDSS, key information used by StateCU to assess historical crop consumptive use included irrigated acreage, crop types, farming practices, monthly climate data, and diversion records.

A number of subtasks were performed in support of the historical crop consumptive use analysis. Individual technical memoranda describing the approach and results of these subtasks have been included as appendices to this report. In addition, information provided by other RGDSS Contractors and PRT members were used in the preparation of the historical crop consumptive use estimates, and are referenced herein.

StateCU calculates the historical crop consumptive uses in the Rio Grande Basin and the tools used to perform the analysis are documented in the following memoranda related to Phase 6 StateCU and GIS enhancements:

- *RGDSS_P6_StateCU_WellMeters.pdf*: An analysis and evaluation of the Division 3 well measurement program.
- *RGDSS_P6_StateCU_MeterPumpCommands*.pdf: Documents the TSTool commands used to include and distribute metered groundwater withdrawals in the StateCU analysis.
- *RGDSS_P6_StateCU_RevCropsCharacteristics.pdf*. Documents recommendations for the revised crop characteristics incorporated in to the StateCU analysis.
- *RGDSS_P6_GIS_Sprinkler.pdf*: Documents enhancements to the methodology used to compute the sprinkler acreage timeline used for structures within the RGDSS StateCU model.
- *RGDSS_P6_GIS_Parcels.pdf*: Documents enhancements to the irrigated parcel datasets and related datasets used for the RGDSS.
- *RGDSS_P6_StateCU_ClimateStationWeighting.pdf*: Reviews and documents enhancements for climate station weighting.
- *RGDSS_P6_StateCU_AdditionalCrops.pdf*: Provides information on additional crop types.
- *RGDSS_P6_StateCU_Precipitation.pdf:* Details effective precipitation methodology.
- *RGDSS_P6_StateCU_Code.pdf*: Details StateCU code enhancements.

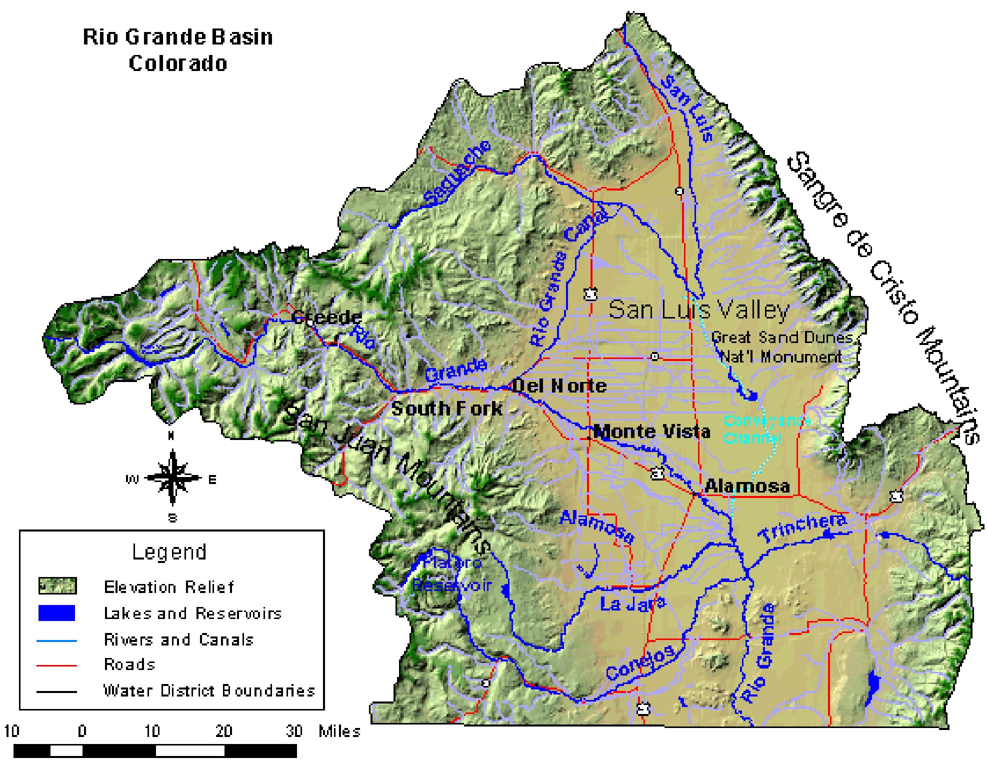
2.1 Basin Description

The Rio Grande Basin (**Figure 1**) is located in south central Colorado and encompasses approximately 7,500 square miles. The valley floor (San Luis Valley) elevation ranges from 7,440 feet in the south to 8,000 feet in the north and is bounded on the west by the San Juan Mountains and on the east by the Sangre de Cristo Mountains. There is an approximate 3,000 square mile area in the northern part of the valley that does not drain on the land surface to the Rio Grande known as the Closed Basin.

2.2 Peer Review Team (PRT) Role

In Phase 6, as in other phases, the PRT provided significant guidance and review during the modeling process. The PRT meetings were open to all interested parties and were attended by DWR staff, water users, engineers, geologists, modelers, and occasional observers. The PRT met 47 times from 2011 to 2015 to review and enhance the Model. The enhancement process, completed by the technical members of the PRT, was iterative with new approaches and enhancements being proposed, reviewed and discussed at a PRT meeting. Once implemented the Model results were then analyzed and reviewed by the PRT, where additional modifications may then be suggested and the enhancement process continued.

Figure 1



2.3 Supporting Subtasks

The following subtasks were performed to determine monthly crop consumptive use in the Rio Grande Basin for the period 1950 through 2010:

- <u>Annual Historical Irrigated Lands and Related Data Time Series Generation.</u> Historical irrigated acreage was estimated for all years in Phase 6 based on irrigated parcel datasets developed for years 1936, 1998, 2002, 2005, 2009, and 2010. The historical acreage with a groundwater supply was assigned an associated groundwater withdrawal volume estimated based on well permit and well water right information. The historical acreage with sprinkler application was developed using sprinkler mapping developed for the Rio Grande Water Conservation District, evaluation of satellite imagery, and sprinkler irrigated parcels from the irrigated parcel datasets. Phase 6 enhancements to the irrigated parcel datasets and sprinkler mapping are provided in Phase 6 RGDSS Groundwater Model Memorandums entitled: *RGDSS_P6_GIS_Parcels.pdf and RGDSS_P6_GIS_Sprinkler.pdf*.

- Estimate Ditch System Efficiencies. Conveyance efficiencies for six of the large ditches were based on prior seepage studies; water users, ditch riders, and water commissioners provided estimated ditch losses for many ditches; the remainders of the ditches' conveyance efficiencies were based upon the length of the ditch and the soil types that it traverses. Maximum sprinkler and flood application efficiencies were estimated based on knowledge of irrigation practices in the basin. The approach and results are provided in a memorandum attached as **Appendix A**.

- Assign Soil Moisture Capacities to Parcels and Structures. Soil moisture capacity estimates were determined for each ditch system or multi-structure ditch system based on Colorado STATSGO mapping and irrigated acreage parcel locations. The approach and results are provided in a memorandum attached as **Appendix B**.

- Select and Fill Key Climate Stations. Key climate stations were selected for the Rio Grande Basin based on their period of record and location. Precipitation, temperature, and frost data gaps were filled as needed to create monthly data for the study period. Documentation of the selection and gap filling of Key climate stations is described in **Appendix C**. The weighting used to assign climate stations to irrigated parcels is described in the Phase 6 RGDSS Groundwater Model Memorandum entitled: *RGDSS_P6_StateCU_ClimateStationWeighting.pdf*

- Calibration of Blaney-Criddle Coefficients. San Luis Valley calibrated crop coefficients for the Blaney-Criddle method were developed through comparisons of potential ET results using the Modified Hargreaves ET method for thirteen years. The approach and results are provided in a memorandum attached as **Appendix D**. The development of calibrated crop coefficients for the Blaney-Criddle method for additional crop types utilized in Phase 6 are described in the RGDSS Phase 6 Memorandum entitled: *RGDSS_P6_StateCU_AdditionalCrops.pdf*

  Revisions to the crop characteristics used to define the growing season for the crops within the StateCU modeling are documented in the RGDSS memorandum (*RGDSS_P6_StateCU_RevCropCharacteristics.pdf*).

2.4 Definitions of Terms

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 Requirements.

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.

Irrigation Water Requirement (IWR): The amount of water required from surface or groundwater diversions to meet crop consumptive needs. Calculated as potential evapotranspiration less effective 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 in this document 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 the StateCU historical consumptive use model effort. Ditch systems are generally defined as key if they have relatively large diversions, have senior water rights, or are important for administration.

Multi-Structure: A group of diversion structures that operate in a similar fashion to satisfy a common demand.

Groundwater Only Structure: A group of irrigated parcels without a surface water source. Groundwater only lands are typically aggregated based on location; e.g. those that fall within the same Response Area.

HydroBase: The State of Colorado's central relational database that houses real-time, historic, and geographic data related to water resources in Colorado (data includes: diversion records, streamflow records, climate data, diversion structure information, well structure information, etc.). HydroBase is used as the primary data source in the CDSS efforts.

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

3. General Approach and Conventions

The Rio Grande historical crop consumptive use analysis was performed using StateCU (Version 13.08, December, 2011), a generic data driven consumptive use model and graphical user interface. The StateCU model is used to develop monthly consumptive use estimates.

The StateCU computer code originated at the United States' Bureau of Reclamation (USBR) and has undergone substantial enhancements while being applied to the Colorado River Decision Support System and the Rio Grande Decision Support System. The StateCU Documentation *(StateCU_Program_Documentation.pdf)* provides a complete description of the model and its capabilities.

3.1 StateCU Approach

To perform the historical crop consumptive use analysis, within the irrigated acreage GIS coverage numerous parameters are identified for each parcel including: crop type, irrigation type, and any surface water and groundwater structures that serve that parcel. The general methodology used to estimate historical consumptive use for the Rio Grande Basin is as follows (See the StateCU Documentation for a more complete description of the calculation methods):

1. A Rio Grande Basin scenario was developed that includes the agricultural consumptive use within Water Division 3. For each structure their associated acreage, crop type, water supply, and irrigation method(s) were estimated.
2. Climate stations were assigned to each structure based on a spatial intersection in GIS of climate station Thiessen polygon areas and ditch service areas, headgate locations, or Response Area boundaries.
3. The Potential ET was determined using the SCS Modified Blaney-Criddle consumptive use methodology outlined in the SCS publication Irrigation Water Requirements Technical Release No. 21 (TR-21) with locally calibrated crop coefficients. The irrigation water requirement was determined by reducing this Potential ET by the effective rainfall determined using the USBR method reduced to exclude ineffective misting events. The effective rainfall method utilized in Phase 6 is described in the Phase 6 RGDSS Groundwater Model Memorandum entitled: *RGDSS_P6_StateCU_Precipitation.pdf*
4. Water supply-limited consumptive use was determined by including diversion records, conveyance efficiencies, application efficiencies, soil moisture interactions, and supplemental groundwater supplies. With rare exceptions, groundwater withdrawals in the basin were not measured prior to 2009. Therefore, groundwater withdrawals prior to 2009 were estimated in the Initial StateCU Run described in Section 4.1. For most ditch systems, StateCU determined water supply-limited consumptive use and groundwater withdrawal in the following general sequence, termed the **"mutual ditch"** approach:

   - Surface water was applied to meet irrigation water requirements for all land under the ditch system. If excess surface water still remained, it was stored in the soil moisture reservoir up to the full reservoir capacity, at which point the remaining surface water was returned to the system.

- If the irrigation water requirement was not satisfied, water stored in the soil moisture reservoir was used to meet remaining irrigation water requirements.
- If the irrigation water requirement was still not satisfied, groundwater was first applied to meet remaining irrigation water requirements for sprinkler irrigated lands identified as having a groundwater source, up to the maximum permitted or decreed groundwater withdrawal volume. If groundwater withdrawal volume was not exceeded, groundwater was then applied to meet remaining irrigation water requirements for flood irrigated lands identified as having a groundwater source, up to the remaining groundwater withdrawal volume.
- If the irrigation water requirement was satisfied and there was remaining metered groundwater withdrawal, it was stored in the soil moisture reservoir up to the full reservoir capacity, at which point the remaining metered groundwater withdrawn was returned to the system.

Based on information from water users and administrators, the following large ditch systems, some of which have recharge decrees, were identified as preferentially using groundwater through their sprinklers and applying surface water on lands without sprinklers:

- Rio Grande Canal (2000812)
- Farmers Union Canal (2000631)
- Prairie Ditch (2000798 modeled as 20MS20)
- San Luis Valley Canal Company (2000829)
- Billings Ditch (2000546) - Water Court Case 2013CW3016 confirmed the historical practice of recharging diverted surface water while withdrawing groundwater to meet the crop demands within the service area.
- Rio Grande Lariat Ditch (2000816 modeled as 20MS21) – Historically this ditch has recharged diverted surface water while withdrawing groundwater to meet the crop demands within the service area. However, recharging their surface water was not a decreed use and the Division Engineer took action against this ditch causing the irrigation practice to change in 2012 to the typical "mutual ditch" approach.

StateCU determined water supply-limited consumptive use and groundwater withdrawals for these six ditch systems in the following general sequence, termed the “mutual ditch with groundwater sprinkler first" approach.

- Surface water is allocated to all acreage under a ditch system. Acreage served by surface water only or with groundwater using flood irrigation apply their share of surface water to meet irrigation water requirements. Note that lands with groundwater served by sprinklers do not apply their share of surface water to meet irrigation water requirements at this step. Instead surface water for this sprinkler irrigated acreage is made available for recharge.
- Groundwater is withdrawn to meet irrigation water requirement on sprinkler irrigated acreage identified as having a groundwater source using the maximum sprinkler efficiency, limited by acreage-prorated groundwater withdrawal volume.
- Groundwater is withdrawn to meet any remaining irrigation water requirement on flood irrigated lands identified as having a groundwater source using the maximum flood efficiency, limited by acreage-prorated groundwater withdrawal volume.

In Phase 6, four StateCU runs are included in the process:

- Initial StateCU Run
- Season of Use (SoU) StateCU Run
- Factor Meter Season of Use StateCU Run
- No Pumping (NoQ) or Impact StateCU Run

These runs are discussed in detail in **Section 4** StateCU Model Process.

3.2 File Directory Convention

To assist in the file organization and maintenance of official State data, the files associated with a historical consumptive use analysis will install to the default subdirectory *\cdss\data\[analyis_description]*. For the Phase 6 RGDSS modeling dataset, the *analyis_description* folder is "**Ground_Water_Rules_Div_3_2014_Modeling_Files"**. This version of the model was initiated for the groundwater rulemaking process and utilizes the base file name "r**g2012**" because the data set was initially started in 2012. Other official State historical consumptive use data *analyis_descriptions* include directories for the South Platte River Basin (i.e. **sp2008**), Upper Colorado River Basin (i.e**. co2007**), etc. Note that these directory conventions are not a requirement of the model, simply a data management convention for official State datasets.

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 5.0** StateCU Input Data Description.

3.4 Data Centered StateCU Model Development

A majority of the Phase 6 StateCU input files have been generated from HydroBase (Version HydroBase_CO_20140114) data using the data management interfaces StateDMI (Version 3.11.01 (2010-08-11)) and TSTool (Versions 9.09.00 (2010-09-30) and 10.18.00 (2013-03-03)). A description of these tools as applied to StateCU is included in **Section 5** StateCU Input Data Description.

4. StateCU Model Process

The following sections provide a description of the StateCU Model process including the iteration processes between the StateCU, StateFate, and the Groundwater Model (GWModel). The StateCU model process is comprised of four different steps and summarized below:

- Initial StateCU Run
- Season of Use (SoU) StateCU Run
- Factor Meter Season of Use StateCU Run
- No Pumping (NoQ) or Impact StateCU Run

4.1 Initial StateCU Run

The Initial StateCU Run is the first step in the StateCU modeling process. In the first step in the process, groundwater withdrawals are allowed to satisfy the remaining IWR.

StateCU estimates the groundwater withdrawal, for all structures without long term metered data, based on the remaining IWR and available groundwater withdrawal volume. The groundwater withdrawals satisfy the remaining IWR after surface water and tail/drain water supplies are applied. The groundwater withdrawal may, in a few instances, be limited to the available groundwater withdrawal volume specified in the Irrigation Parameter Yearly Data File (**rg2012.ipy**).

There are limited long term metered data for wells in the SLV. The initial StateCU run uses the historical groundwater withdrawal file **(rg2012.pvh)** created with long term groundwater withdrawal records that are available. In this case, data is available for one well known as the Mumm well and the data were obtained from the Alamosa National Wildlife Refuge *(Source: Mike Blenden)*. The groundwater withdrawal file (**rg2012.pvh)** contains half of the recorded groundwater withdrawals from the Mumm well in the StateCU analysis due to the service areas of two ditches overlapping the parcels served by the Mumm well. This is the only well for one of the structures (20MS06 – Alamosa Refuge) and can be explicitly represented in the file. The other ditch service area (2000587 – Costilla Ditch) includes other wells that do not have historical meter records, therefore the groundwater withdrawals associated with the Costilla Ditch cannot be explicitly modeled in this step. For the other structures with wells the historical groundwater withdrawal data back to 1950 are not available and therefore cannot be explicitly included in this file.

The Monthly Drain File **(rg2012_FactorSoUMeter.Xdi)** used in the initial StateCU run is obtained from a previous run of the Groundwater Model in order to minimize the iteration time of the StateCU modeling process. If this file is not available it may take many iterations for the tail/drain water to converge. This file is created by StateFate by reading the StateCU output file **(rg2012.4WB)** and reading the Drain file **(*.drn)** from the GWModel. A detailed description of StateFate program and its interaction with the StateCU and GWModel is provided in the RGDSS memorandum for the StateFate (*RGDSS_P6_Statefate.pdf*) and the StateCU and StateFate model process is described in the flowchart shown in **Figure 2**.

The Initial StateCU Run uses the StateCU Response File **rg2012.rcu** and the input data files listed in

Table 4.1. The Initial StateCU Run outputs several files including the StateCU Binary Output File **(rg2012.BD1)** which provides historical groundwater withdrawal estimates that are used in the subsequent StateCU steps. A detailed description of the StateCU Binary Output File **(rg2012.BD1)** is given in **Section 6** of this document.

Table 4.1: StateCU Response File (rg2012.rcu[1]) for the Initial StateCU Run

File Type/Name	Input Data File and Directory
CUControl	…\StateCU\rg2012.ccu
ClimateStation	…\ClimateCU\rg2012.cli
MeanTemperature_Monthly	…\ClimateCU\rg2012.tem
Precipitation_Monthly	…\ClimateCU\rg2012.pcp
FrostDate_Yearly	…\ClimateCU\rg2012.fd
CropCharacteristic	…\Crop\rg2012.cch
Blaney-Criddle_CropCoefficient	…\Crop\rg2012.kbc
Structure	…\LocationCU\rg2012.str
CropDistribution_Yearly	…\Crop\rg2012.cds
Diversion_Historic_Monthly	…\Diversions\rg2012.ddh
IrrigationParameter_Yearly	…\LocationCU\rg2012.ipy
Well_Historic_Monthly	…\Wells\rg2012.pvh[2]
Drain_Historic_Monthly	…\StateFate\rg2012_FactorSoUMeter.Xdi[3]
#GeographicInformation	…\StateCU\Rg2012.gis[4]

4.2 Season of Use (SoU) StateCU Run

The Season of Use (SoU) StateCU Run is the second step in the StateCU modeling process. In this step, groundwater withdrawals are allowed to satisfy the remaining IWR, while being limited to seasons of use for select regions based on user supplied information.

Water users in Water District 21 expressed that most groundwater users west of Hwy-285 do not use their wells until July if surface water is available, while users east of Highway 285 do not use their wells after the fourth of July to allow for lands to dry out for haying. Water users in Water District 25 explained that they only operate their wells between May 1 and September 15 due to the typical late and early frosts.

The StateCU Binary Output File **(rg2012.BD1)** produced by the Initial StateCU Run is processed by a TSTool command file (**rg2012_SoU.pvh.TSTool)** using the Season of Use criteria in order to create a new groundwater withdrawal file (**rg2012_SoU.pvh)** for the Season of Use StateCU run. Pre-July estimated historical groundwater withdrawals are set to zero for Water District 21 structures west of Hwy-285 (except for 2100503 – Alamosa Creek Canal and 2100601 – Terrace Main Canal) when monthly surface water diversions are at least 25% of the historical average diversions. Estimated groundwater

[1] *The file directory for the Response file (***.rcu**): is …\StateCU*
[2] *This Ground Water Pumping File (**rg2012.pvh**) is based on the historical data from the Mumm well in the first StateCU run*
[3] *The ***.Xdi** file is taken from a previous Groundwater Model run*
[4] *The ***.gis** file is not utilized in the StateCU runs but is maintained as a placeholder if future users choose to display GIS data in the StateCU GUI*

withdrawals are set to zero for Water District 21 structures east of Hwy-285 for months other than April, May, and June. Water District 25 estimated groundwater withdrawals for months other than May through September 15 (estimated groundwater withdrawal is halved in September) are set to zero.

The StateCU Response File **rg2012_SoU.rcu** and the input data files listed in **Table 4.2** are required for the second StateCU run. The input data files **(Table 4.2)** used in the second step of the StateCU process are identical to the initial StateCU run except for the Ground Water Pumping File **(rg2012_SoU.pvh)** that is produced using the season of use criteria to estimate the groundwater withdrawn. The StateCU model output includes the Water Budget (by Structure) Output File **(rg2012_SoU.dwb)**, which is utilized to create the Ground Water Pumping File in the third step of the StateCU modeling process.

Table 4.2: StateCU Response File (rg2012_SoU.rcu) for the 2nd StateCU Run

File Type/Name	Input Data File and Directory
CUControl	…\StateCU\rg2012.ccu
ClimateStation	…\ClimateCU\rg2012.cli
MeanTemperature_Monthly	…\ClimateCU\rg2012.tem
Precipitation_Monthly	…\ClimateCU\rg2012.pcp
FrostDate_Yearly	…\ClimateCU\rg2012.fd
CropCharacteristic	…\Crop\rg2012.cch
Blaney-Criddle_CropCoefficient	…\Crop\rg2012.kbc
Structure	…\LocationCU\rg2012.str
CropDistribution_Yearly	…\Crop\rg2012.cds
Diversion_Historic_Monthly	…\Diversions\rg2012.ddh
IrrigationParameter_Yearly	…\LocationCU\rg2012.ipy
Well_Historic_Monthly	…\Wells\rg2012_SoU.pvh[5]
Drain_Historic_Monthly	…\StateFate\rg2012_FactorSoUMeter.Xdi
#GeographicInformation	…\StateCU*Rg2012.gis*

4.3 Factor Meter Season of Use StateCU Run

The Factor Meter Season of Use StateCU Run is the third step in the StateCU modeling process. In this step, the estimated groundwater withdrawals of the Season of Use (SoU) StateCU Run are compared against overlapping years of metered withdrawals to generate a calibration factor (ratio) used to scale estimated historical groundwater withdrawals by region when meter records are not available. In this step, groundwater withdrawals are scaled estimates limited to seasons of use or metered volumes.

Information from the Water Budget (by Structure) Output File **(rg2012_SoU.dwb)** produced in the second StateCU model run is imported into a Microsoft Excel spreadsheet (**Summary.xlsx**). In this spreadsheet, estimated groundwater withdrawals and metered records are compared for the years 2009 and 2010 by ditch in order to calculate average factors (ratios) by Water District. The individual and combined Water District factors calculated in the **Summary.xlsx** file are incorporated manually into the TSTool command file **(rg2012_FactorSoUMeter.pvh.TSTool)**.

[5] *This Ground Water Pumping File (**rg2012_SoU.pvh**) is the only input data file adjusted based on the water user supplied information (Season of Use) in the second StateCU run*

The TSTool command file (**rg2012_FactorSoUMeter.pvh.TSTool)** used in the third StateCU run is identical to the TSTool command file in the second run but in addition it multiplies the structure groundwater withdrawals by the meter factors from the **Summary.xlsx** file and replaces the year 2009 and 2010 data with the metered data from the **MeteredPumping.stm** file, which is generated from well meter diversion records stored in HydroBase. Annual metered groundwater withdrawal data for the years 2009 and 2010 are distributed monthly by the estimated groundwater withdrawal for those years by the TSTool command file (**rg2012_FactorSoUMeter.pvh.TSTool)**. The steps to replace StateCU estimated groundwater withdrawals with metered data are discussed in more detail in the RGDSS Memorandum for Commands to Include and Distribute Metered Pumping in StateCU Analysis (*RGDSS_P6_StateCU_MeterPumpCommands.pdf*).

The Factor Meter Season of Use StateCU Run uses a third StateCU Response File (**rg2012_FactorSoUMeter.rcu)** and the input data files listed in **Table 4.3**. The input data files include the Ground Water Pumping File (**rg2012_FactorSoUMeter.pvh)** in which metered data is implemented.

The StateCU model output includes a Detailed Structure Water Budget by Land Category File **(rg2012_FactorSoUMeter.4WB)** that is used as an input file to the StateFate program. The StateFate program reads the **4WB** file and the Drain file written by the **mksum** postprocessor to MODFLOW to determine how much surface water needs to be routed. Based on the routing information, the program then determines the fate of that water. Water that is routed to another ditch is included in the Monthly Drain File (**Xdi)**, water that is routed to a drain is included in the **Xdr** file, water routed to a surface stream is included in the **Xst** file, and water that is routed to groundwater recharge is included in the **Xgw** file as shown in **Figure 2**. StateFate is discussed in detail in the memorandum named *RGDSS_P6_StateFate.pdf*.

Table 4.3: StateCU Response File (rg2012_FactorSoUMeter.rcu) for Third StateCU Run

File Type/Name	Input Data File and Directory
CUControl	…\StateCU\rg2012.ccu
ClimateStation	…\ClimateCU\rg2012.cli
MeanTemperature_Monthly	…\ClimateCU\rg2012.tem
Precipitation_Monthly	…\ClimateCU\rg2012.pcp
FrostDate_Yearly	…\ClimateCU\rg2012.fd
CropCharacteristic	…\Crop\rg2012.cch
Blaney-Criddle_CropCoefficient	…\Crop\rg2012.kbc
Structure	…\LocationCU\rg2012.str
CropDistribution_Yearly	…\Crop\rg2012.cds
Diversion_Historic_Monthly	…\Diversions\rg2012.ddh
IrrigationParameter_Yearly	…\LocationCU\rg2012.ipy
Well_Historic_Monthly	…\Wells\rg2012_FactorSoUMeter.pvh[6]
Drain_Historic_Monthly	…\StateFate\rg2012_FactorSoUMeter.Xdi
#GeographicInformation	…\StateCU*Rg2012.gis*

[6] *The Ground Water Pumping File (**rg2012_FActorSoUMeter.pvh**) is the only input data file adjusted based on the metered pumping data in the third StateCU run*

The new Monthly Drain File (**rg2012_FactorSoUMeter.Xdi)** created by the StateFate program is used as input to rerun the StateCU model from the initial step of the StateCU model process (**Figure 2**) to determine the changes to the water budget as a result of additional surface water supplies. The rerun of the initial StateCU changes the output which subsequently affects the second and third StateCU model runs. Therefore, StateCU and StateFate are run iteratively following the loop shown in **Figure 2** until the results from StateCU converges (*RGDSS_P6_Statefate.pdf*).

The new Monthly Drain File (**rg2012_FactorSoUMeter.Xdi)** is also used in the fourth step of the StateCU modeling process as an input file to the No Pumping (NoQ) or Impact StateCU Run. The description of the Monthly Drain File is given in **Section 5.0.**

4.4 StateCU Model Process Summary

The StateCU model process flowchart in **Figure 2** below shows the three steps in the StateCU modeling process for the historical run including the iterative process between the StateCU, StateFate, and GWModel.

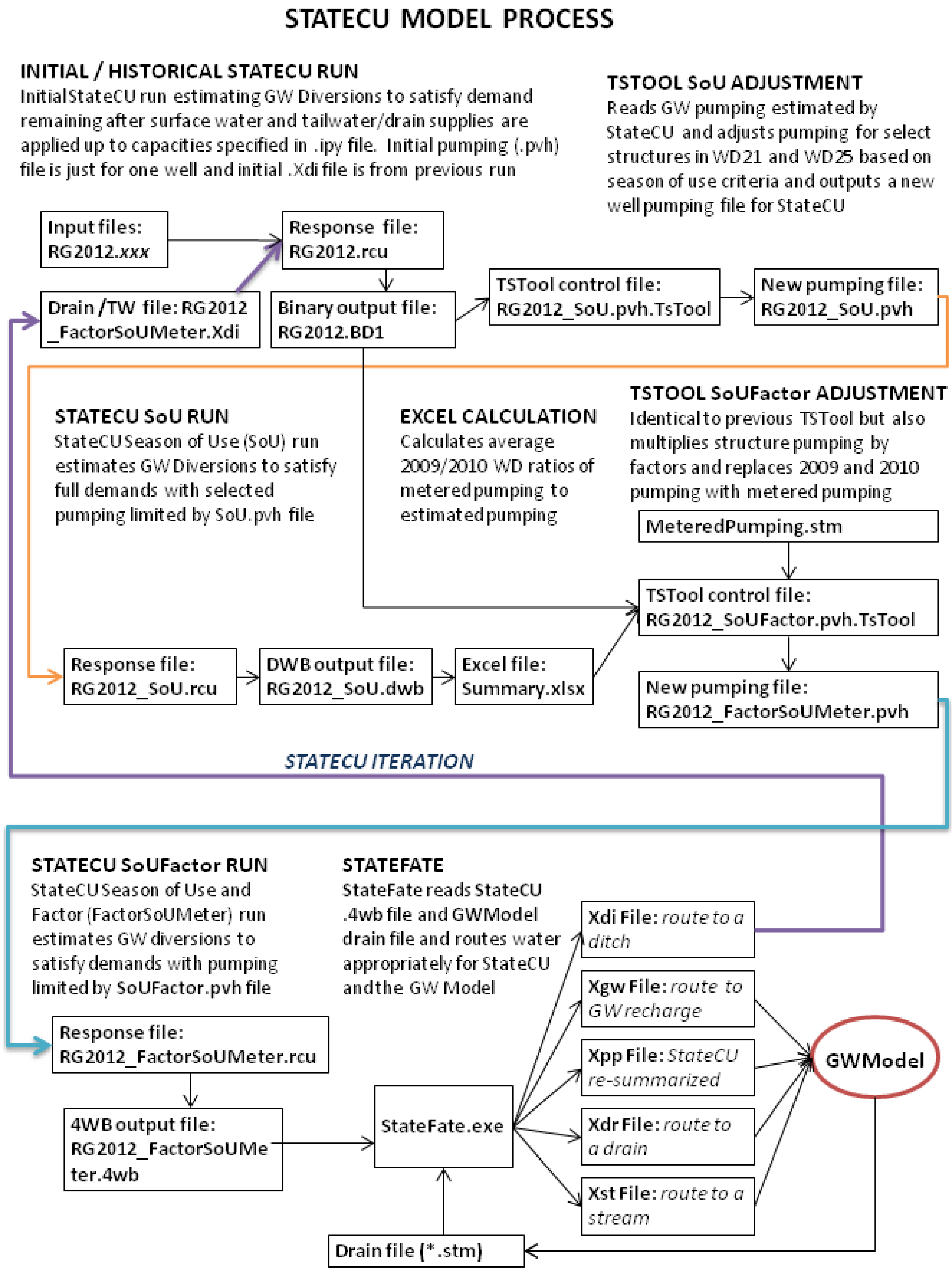


Figure 2: StateCU Model Process Flowchart

4.5 No Pumping (NoQ) or Impact StateCU Run and Process Summary

The No Pumping (NoQ) or Impact StateCU Run estimates the water budget for a scenario where groundwater withdrawals are set to zero.

The No Pumping (NoQ) or Impact StateCU Run is separate from and follows the iterative process of the previous StateCU runs. The StateCU run for no pumping scenario utilizes the StateCU Response File (**rg2012_NoQ.rcu**) and the input data files listed in **Table 4.4**. The input data files **(Table 4.4)** used in the StateCU no pumping run are identical to the third StateCU run except for the Irrigation Parameter Yearly Data File and the Ground Water Pumping File. The groundwater withdrawal volumes are set to zero and the groundwater use mode (GMode) are set to 2 for all structures in the Irrigation Parameter Yearly Data File **(rg2012_NoQ.ipy)**. The Ground Water Pumping File is commented out (indicated by the "#" at the beginning of the line) and is therefore ignored.

The results from the NoQ StateCU run are summarized in a **4WB** output file (**rg2012_NoQ.4WB**). The StateFate program reads the **4WB** output file (**rg2012_NoQ.4WB**) and the Drain file (***.drn**) written by the **mksum** postprocessor to GWModel. The flowchart provided in **Figure 3** shows the NoQ StateCU run and the interaction with the StateFate and GWModel.

Table 4.4: StateCU Response File (rg2012_NoQ.rcu) for NoQ StateCU Run

File Type/Name	Input Data File and Directory
CUControl	…\StateCU\rg2012.ccu
ClimateStation	…\ClimateCU\rg2012.cli
MeanTemperature_Monthly	…\ClimateCU\rg2012.tem
Precipitation_Monthly	…\ClimateCU\rg2012.pcp
FrostDate_Yearly	…\ClimateCU\rg2012.fd
CropCharacteristic	…\Crop\rg2012.cch
Blaney-Criddle_CropCoefficient	…\Crop\rg2012.kbc
Structure	…\LocationCU\rg2012.str
CropDistribution_Yearly	…\Crop\rg2012.cds
Diversion_Historic_Monthly	…\Diversions\rg2012.ddh
IrrigationParameter_Yearly	…\LocationCU\rg2012_NoQ.ipy[7]
#Well_Historic_Monthly	…\Wells\rg2012_FactorSoUMeter.pvh[8]
Drain_Historic_Monthly	…\StateFate\rg2012_FactorSoUMeter.Xdi[9]
#GeographicInformation	…\StateCU*Rg2012.gis*

[7] *Pumping volume in the Annual Irrigation Parameter file (***.ipy**) set to zero and GMode set to 2 for all structures*
[8] *Ground Water Pumping File (***.pvh**) is commented out and therefore not utilized in the no pumping scenario run*
[9] *A new Monthly Drain file created after the StateCU and StateFate iterative process*

StateCU No Pumping Model Process

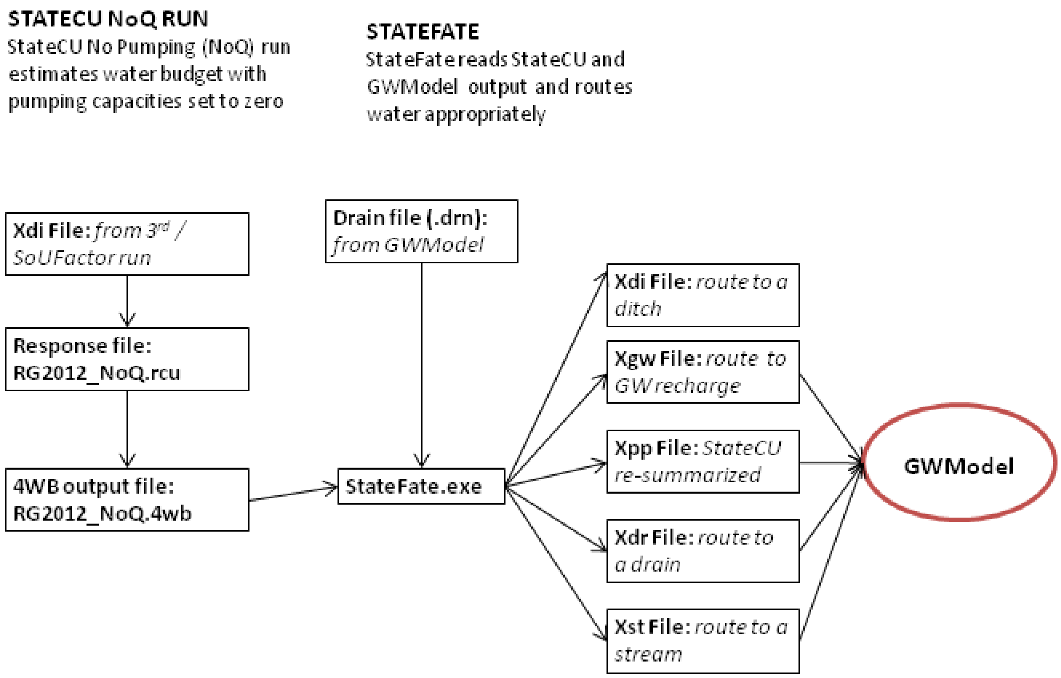


Figure 3: StateCU No Pumping Model Process Flowchart

5. StateCU Input Data Description

This section provides the description of input files, the sources of data contained in the input files, and the command files used to create the input files in the StateCU analyses. The data sources for the input files are primarily from HydroBase. Other sources, typically user supplied data, are compiled in Excel spreadsheets or other formats that the command files can read. It is important that all sources of data and information used in the input files be updated prior to use for the generation of new StateCU input files. Detailed information regarding the file contents and formats can be found in the StateCU Documentation.

5.1 StateCU Response File (*.rcu)

The StateCU Response File (***.rcu**) is a hand edited file that contains the list of input data files required to run the StateCU model. The input files can be listed in any order but the file names should be identified by the appropriate defined file description as it is case sensitive. The StateCU Response File should include all potential input file types, although only a subset of those input files may be required depending on the StateCU analysis scenario. A list of the StateCU Response Files utilized to complete the StateCU model process is below and the description of the process is above in Section 4. Note that the specific file extension is a requirement for the StateCU Response File (***.rcu**) in order for the StateCU software to recognize it as the scenario response file. The list of filenames in the StateCU Response File must be identified by a defined file description, although the number of input files may vary depending on the type of scenario to be simulated.

- Rg2012.rcu
- Rg2012_SoU.rcu
- Rg2012_FactorSoUMeter.rcu
- Rg2012_NoQ.rcu

5.2 Model Control File (rg2012.ccu)

The Model Control File (***.ccu**) is used to define overall parameters of the StateCU model. The options in the Model Control File can be revised through the StateCU Graphical User Interface (GUI) or edited by hand as it was for this dataset**.** The Model Control File contains the following information used in the historical consumptive use analysis:

- Period of simulation from the beginning to ending year: actual simulation period of record for the analysis is set to 1950 through 2010.
- Consumptive use analysis method: the SCS Modified Blaney-Criddle method as described in USDA-SCS TR-21 is used and set to “1”.
- Effective monthly precipitation method: the USBR Effective Precipitation method is used and set to “2”.
- Scenario type: the structure scenario was used and set to “1”.
- Water supply option: the water supply option considers groundwater and set to “4”.
- Input summary output option: The input summary switch was set to "1" indicating the detailed input summary was generated.

- Soil moisture: detailed soil moisture accounting is considered and set to “1”.
- Initial soil moisture: the initial soil moisture reservoir was set to 20 percent of full reservoir capacity at the beginning of the analysis period (1950). The 20 percent initial soil moisture content applies to all structures modeled in the StateCU analysis and set to “0.20 0.0 0.0”.
- Use of soil moisture by priority: this option was not used, the soil moisture was used by proration and set to “0”.
- Winter carry-over precipitation percent: This defines the amount of non-irrigation season precipitation that is available for storage in the soil moisture reservoir. Winter carry-over precipitation was set to 0 for the Rio Grande analysis. Based on winter conditions in the San Luis Valley, it is believed that most winter precipitation does not contribute to soil moisture storage, but instead is sublimated or evaporated. Flag set to “0”.
- Output summary options: The output summary switch was set to "15" indicating that in addition to typical output, a Detailed Structure Water Budget by Land Category **(*.4wb**) for all structures is generated and additional totals are included in the StateCU Binary Output File (***.bd1**).
- Sub-irrigated crops: The number of sub-irrigated crops to output additional information for. In Phase 6 the crops that have additional information included in the output files are grass pasture and alfalfa. The additional output for these crops includes groundwater use irrigation method (flood and sprinkler), consumptive use shortage, and irrigation water requirement. Flag set to “2” followed on successive lines by “GRASS_PASTURE.CCRG” and “ALFALFA.CCRG”.
- StateMod formatted output files: The switch was set to “1” so as to generate StateMod formatted irrigation water requirement, average monthly surface water system efficiency, groundwater withdrawals, and monthly groundwater application efficiency output files on a calendar year basis.
- Diversion priority: This identifies how priorities are assigned to diversions and set to “3”. However, this option is not implemented when the water supply option is set to “4”.
- Senior/Junior administration number break point: This identifies the administration number that defines the senior water rights from the junior water rights and set to “0”. However, this option is not implemented when the water supply option is set to “4”.
- Monthly Drain File consideration: The Monthly Drain File switch was set to “1” indicating the analysis should include drain/return flow information.
- Filling missing data: Monthly data has already been filled in the input files, therefore no additional filling is required. Flag set to “0”.

5.3 Structure Location File (rg2012.str)

The Structure Location File provides the list of structures used in the StateCU analysis. The file contains physical information and structure-specific information that does not vary over time including the structure ID and name; location information; available soil capacity; and assignments of climate stations to use in the analysis. Location information includes the latitude, county, and hydrologic unit code (HUC) for each structure.

The Phase 6 Structure Location File (**rg2012.str**) used in the historical consumptive use analysis was created using a StateDMI command file (**rg2012.str.StateDMI**). The command file uses the structure list (**rg-wdid.csv**) and extracts information from HydroBase on diversion structures location information, soil capacity information from the file **rg2012.awc**, and climate weight assignments from the file **rg-wts.csv** to create the Structure Location File (**rg2012.str**) for use in the StateCU analysis. Below are the descriptions of the files utilized to create the Structure Location File.

- Individual structure list **(rg-wdid.csv):** Contains the list of key diversion structures, multi-structures, and groundwater only structures generated from analyzing available data in HydroBase and previous structure lists in the **structure list comparison.xlsx** file. This file is located in the following folder "…\Diversions\Development Excel Files".
- Available water content **(rg2014.awc):** AWC is calculated using the CDSS Toolbox add-in to ArcGIS to provide StateDGI information from the 1936, 1998, and 2005 Irrigated Acreage and the STATSGO AWC/Soils Coverage and the results are analyzed in the **AWC_Calculations.xlsx** file. This file is located in the following folder "…\LocationCU\Development Excel Files". The AWC are calculated separately in the spreadsheet file (**AWC_Calculations.xlsx**) for individual structures, multi-structures, and groundwater only structures. Those values are transferred into the AWC file (**rg2012.awc**).
- Climate weights **(rgdss.wts.csv**): This file contains the climate stations weight for all structures in the StateCU analysis based on the nine key climate stations discussed in **Section 5.9**. The data in this file is processed in the Excel spreadsheet "**Climate Weights.xlsx**". This file is located in the following folder "…\LocationCU\Development Excel Files". The process to develop climate station weights based on the Thiessen polygon method is described in the RGDSS memorandum prepared for Climate Station Weighting (*RGDSS_P6_StateCU_ClimateStationWeighting.pdf*).

5.4 Crop Distribution File (rg2012.cds)

The Crop Distribution File (**rg2012.cds**) contains acreage and associated crop percentages for each key diversion structure, multi-structure, and groundwater only structure for every year in the analysis period from 1950 to 2010. The Phase 6 Structure Location File used in the historical StateCU analysis was created using HydroBase data and a StateDMI command file (**rg2012_CDS.StateDMI**). The StateDMI command file (**rg2012_CDS.StateDMI**) requires the following files to create the Crop Distribution File (**rg2012.cds**).

  - Structure Location File (**rg2012.str)**: The Structure Location File is discussed in detail in **Section 5.3**.
  - Multi-Structure File (**rg-ms.csv**): This file provides the list of structures that are represented by the multi-structures and is generated from the **structure list comparison.xlsx** files.
  - Groundwater Only Aggregated Area Files (**agg_gw.csv**)**:** These files contain information regarding the parcels and acreages associated with groundwater only structures for the years with irrigated parcel datasets. The years with irrigated parcel datasets are 1936, 1998, 2002, 2005, 2009, and 2010.

- Well Right File (**rg2012.wer**): This file is used to define acreage for groundwater only structures in the Crop Distribution File based on when the water rights for the wells associated with the parcels were appropriated or permitted. The well right file (**rg2012.wer**) is generated from an Excel file (**Well Rights Adjustment.xlsx**) which processes information pulled from HydroBase using three StateDMI command files along with additional data from HydroBase including volumetric limitations and meter test information related to flowing rates for artesian wells, additional details below.
  - The well decree or permit file (**rg2012_Well_Decree_or_Permit.wer**) is created by the StateDMI command file (**rg2012_Well_Decree_or_Permit.wer.StateDMI**). This **.wer** file contains well production rates based on the well's water rights or permitted flow rate if the well does not have water rights and includes alternate point of diversion water rights.
  - The absolute well rate file (rg2012_Well_Rate_Abs.wer) is created by the StateDMI command file (**rg2012_Well_Rate_Abs.wer.StateDMI**). This ***.wer** file contains well production rates based only on the well's water rights.
  - The well apex (**rg2012_Well_Apex.wer**): this file is the third **.wer** file created by StateDMI command file (**rg2012_Well_Apex.wer.StateDMI**). This ***.wer** file contains well production rates based on the well's alternate point of diversion water rights.
  - The Excel spreadsheet file "**Well Rights Adjustment.xlsx"** further analyzes the information generated by the above three ***.wer** files and determines each well's absolute water rights, alternate point water rights, and permitted flow rates. This file also utilizes volumetric limitations that were stored in HydroBase and flowing wells rates at the time of their meter tests.

  To generate the * **.wer** files the StateDMI command files **(*.wer.StateDMI**) also utilized the individual structure file (**rg-wdid.csv**), multi-structure file (**rg-ms.csv**), and 1936, 1998, 2002, 2005, 2009, 2010 groundwater only land files (**agg_gw.csv**) discussed above.

For key diversion structures, multi-structures, and groundwater only structures, historically irrigated acreages were determined from years with irrigated parcel datasets (1936, 1998, 2002, 2005, 2009, and 2010). Annual acreage of irrigated crops were determined as: 1) linear interpolation between 1936 and 1998, 2) repeat 1998 acreages forward through 2001, 3) repeat 2005 acreages between 2003 and 2005, and 4) linear interpolation between 2005 and 2009. As mentioned above, annual acreage of irrigated crops for groundwater only structures were determined using the Well Rights File.

Total irrigated acreages for the Phase 6 dataset are presented in **Table 5.1** based on crop type for years with available data. The details for the irrigated parcel datasets are discussed in RGDSS memorandum for Enhancement of Irrigated Parcel Datasets (*RGDSS_P6_GIS_Parcels.pdf*). In the datasets prior to RGDSS Phase 6, five primary crops were identified in the irrigated parcel datasets for estimation of crop water requirements within the StateCU model. These primary crops were alfalfa, grass pasture, small grains, potatoes, and vegetables. In Phase 6, additional crop types were included and are identified as new alfalfa, cover crops, fall winter wheat, and bluegrass as described in the RGDSS memorandum (*RGDSS_P6_StateCU_AdditionalCrops.pdf)*.

Table 5.1: Phase 6 Irrigated Acreage by Crop Type for Years with Datasets

Attribute	**RGDSS Phase 6 (acres)**					
	1936	**1998**	**2002**	**2005**	**2009**	**2010**
Crop Type						
Potatoes	46,045	77,524	73,005	64,366	59,840	63,732
Small Grains	117,554	108,432	82,821	78,326	113,550	99,416
Vegetables	11,509	8,282	5,701	5,509	1,768	1,367
Alfalfa	107,762	127,475	146,840	146,726	94,318	134,009
Grass Pasture	284,292	249,504	115,624	200,992	240,049	205,242
New Alfalfa	0	12,241	0	12,482	13,644	9,311
Cover Crop	0	1,605	0	6,077	8,509	2,411
Wheat Fall	0	394	0	2,670	247	62
Bluegrass	0	0	0	0	206	83
Total	567,161	585,457	423,991	517,148	532,130	515,633

5.5 Irrigation Parameter Yearly Data File (*.ipy)

The Irrigation Parameter Yearly Data File (***.ipy**) contains yearly structure information required to run StateCU model simulations, including the following:

- Surface water conveyance efficiencies
- Maximum flood irrigation application efficiencies
- Maximum sprinkler irrigation application efficiencies
- Acreage with surface water only supply, flood irrigation
- Acreage with surface water only supply, sprinkler irrigation
- Acreage with only or supplemental groundwater supply, flood irrigation
- Acreage with only or supplemental groundwater supply, sprinkler irrigation
- Maximum groundwater withdrawal volume (AF per month)
- Groundwater use mode (groundwater primary or secondary source)
- Total acres irrigated

The Phase 6 Irrigation Parameter Yearly Data File used in the historical StateCU analysis is created by a StateDMI command file (**rg2012_ipy.StateDMI**) utilizing HydroBase and other input files discussed below**.** The conveyance efficiency accounts for losses between the river headgate and the farm headgate, including losses through canals, ditches and laterals. The maximum flood and sprinkler irrigation efficiencies account for application losses between the farm headgate and/ or well and the crops. Note that conveyance and maximum application efficiency input data are typically 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 water supply in excess of crop requirements. The StateDMI command file (**rg2012_ipy.StateDMI**) relied on the following input files to create the Irrigation Parameter Yearly Data File (**rg2012.ipy**).

- Structure Location File (**rg2012.str)**: The Structure Location File is described in detail in **Section 5.3**.
- Multi-Structure File (**rg-ms.csv**): This file is described above in **Section 5.4**.
- Groundwater Only Aggregated Area Files (**agg_gw.csv):** These files are described above in **Section 5.4**.
- Conveyance Efficiency File (**SurfDelEff.csv**) and Application Efficiency: The conveyance efficiency file (**SurfDelEff.csv**) is used to set the maximum conveyance efficiency for all structures in the StateCU analysis. The values contained in this file are not stored in HydroBase. The conveyance efficiency for some ditches have been defined from studies or information provided by water users, ditch riders, and water commissioners. The conveyance efficiencies for the remaining ditches are estimated using a methodology based on permeability, soil type, and ditch characteristics for the structures. The calculation of conveyance efficiency is performed using the information contained in an Excel spreadsheet file (**ConveyanceEfficiency.xlsm**). The maximum application efficiency for flood and sprinkler irrigation is set in the StateDMI command file to 60% and 80%, respectively. The application efficiencies for several ditches are modified within the StateDMI command file based on additional information. A detailed description of the conveyance and application efficiencies and updates are provided in **Appendix A –** Rio Grande Historic Crop Consumptive Use–Ditch System Efficiencies.
- The Well Right File **(rg2012.wer**): This file is used to set the maximum groundwater withdrawal volume for structures based on the well rights that were appropriated/ permitted for each year. The details for the well right file (**rg2012.wer**) development are discussed in **Section 5.4**.
- Crop Distribution File (**rg2012.cds**): This file is read to set the crop pattern total acreage as the total acreage so as to ensure consistency between StateCU input files.
- Irrigated land category file (**rg2012.sprink**): This file provides the annual acreage for each structure under the four land categories: surface water only supply, flood irrigation; surface water only supply, sprinkler irrigation; only or supplemental groundwater supply, flood irrigation; only or supplemental groundwater supply, sprinkler irrigation. The data is generated using mapping of sprinkler areas over time. The processing is done using the Matlab script **sprinkleripy.m** that compiles the sprinkler acreage timeline information and calculates structure acreages given an initial Irrigation Parameter Yearly Data File. Acreages for years 1998, 2002, 2005, and years after and including 2009 are not included so as to utilize the acreages accessed from HydroBase from the irrigated

parcel datasets. The steps and data used are described in more detail in the RGDSS Memorandum for the Sprinkler Acreage Timeline (*RGDSS_P6_GIS_Sprinkler.pdf*).

The groundwater use mode determines how surface water and groundwater will be used to satisfy irrigation water requirements. The default setting is the "mutual ditch" approach (GWMode = 2) and for several canals the groundwater use mode is set to "mutual ditch with groundwater sprinkler first" (GWMode=3), for a detailed description see **Section 3.1**.

A no pumping Irrigation Parameter Yearly Data File (**rg2012_NoQ.ipy**) is required for the No Pumping (NoQ) or Impact StateCU Run and is created by the same StateDMI command file (**rg2012_ipy.StateDMI**). The file (**rg2012_NoQ.ipy**) contains similar information to the historical Irrigation Parameter Yearly Data File (**rg2012.ipy**). The difference in the no pumping scenario is the maximum groundwater withdrawal volumes are set to zero and the groundwater use mode values are set to "mutual ditch" (GWMode=2) for all structures. In turn, no groundwater withdrawals are simulated and surface water is used on both flood and sprinkler irrigated acreage.

5.6 Historical Direct Diversion File (rg2012.ddh)

The Historical Direct Diversion File provides surface water supply information required to estimate supply-limited consumptive use. The Phase 6 Historical Direct Diversion File (**rg2012.ddh**) is created using the data from HydroBase employing the StateDMI command file (**rg2012_DDH.StateDMI**). The Historical Direct Diversion File contains diversions for structures in the upper Rio Grande Basin in Colorado for the period of 1950 - 2010. The StateDMI command file utilizes the files described below:

- Individual structure list **(rg-wdid.csv):** This file is described above in **Section 5.3**.
- Multi-Structure File (**rg-ms.csv**): This file is described above in **Section 5.4**.
- Pattern file (**rg2012.pat**): This file characterizes dry, average, and wet year conditions for eight key streamflow gages given the 25^{th} and 75^{th} percentiles of the historical mean monthly flows for the period of 1950 - 2010. The TSTool command file (**rg2012.pat.TSTool**) is used to create the pattern file (**rg2012.pat**). Missing diversion data, if any, were filled utilizing the pattern file and the gage assigned to the Water District where the structure is located.
- Historical ditch diversion files (***.stm**): Forty individual historical ditch diversion files (***.stm**) are generated utilizing forty corresponding TSTool command files (***.stm.commands.TSTool**) for structures where the standard use of total diversions through the headgate is not appropriate. The additional processing is typically needed to limit the historical diversion records to specific water classes related to irrigation operations or to combine diversion records for structures that serve the same lands historically. Some of these TSTool command files rely on other source of data that are included in the dataset, please refer to the TSTool command files for these data requirements.

5.7 Ground Water Pumping Files (*.pvh)

The historical groundwater withdrawal file provides groundwater supply information for use in the StateCU process. The groundwater withdrawal files can contain metered records when available and estimated groundwater withdrawals using results from earlier steps in the StateCU modeling process when not available. The three historical Ground Water Pumping Files created and utilized in the StateCU modeling process are:

1. Ground Water Pumping File (**rg2012.pvh**): This file is described above in **Section 4.1**.
2. Ground Water Pumping File (**rg2012_SoU.pvh**): This file is described above in **Section 4.2.**
3. Ground Water Pumping File (**rg2012_FactorMeterSoU.pvh**): This file is described above in **Section 4.3.**

5.8 Monthly Drain File (Rg2012_FactorSoUMeter.Xdi)

The Monthly Drain File provides return flow and drain supply information for structures where water is available and can be directly re-used to irrigate lands (i.e. water used prior to returning to rivers). These water supplies are not included in the Historical Direct Diversion File **(*.ddh**) as they accrue to a ditch below the river headgate and measuring device. The StateFate program is used to create the Monthly Drain File **(*.Xdi**) as discussed in RGDSS memorandum for StateFate (*RGDSS_P6_StateFate.pdf*).

5.9 Climate files

5.9.1 Climate Station Information File (rg2012.cli)

The Climate Station Information File (**rg2012.cli**) provides climate station information for key climate stations used in the StateCU analysis, including the station identification number, latitude, elevation, county, HUC, and station name. **Table 6.1** shows the list of key climate stations utilized in the StateCU analysis. These key climate stations are used for assignment of climate stations weighing to structures in Division 3 employing the Thiessen polygon method. The climate stations weighting is described in the RGDSS memorandum prepared for Climate Station Weighting (*RGDSS_P6_StateCU_ClimateStationWeighting.pdf*).

Table 6.1: Key Climate Stations used in the StateCU Analysis

CLIMATE STATION	STATION ID	COUNTY
ALAMOSA SLV RGNL	USW00023061	ALAMOSA
BLANCA	USC00050776	COSTILLA
CENTER 4 SSW	USC00051458	SAGUACHE
DEL NORTE 2 E	USC00052184	RIO GRANDE
HERMIT 7 ESE	USC00053951	MINERAL
MANASSA	USC00055322	CONEJOS
MONTE VISTA	USC00055706	RIO GRANDE
GREAT SAND DUNES N M	USC00053541	ALAMOSA
SAGUACHE	USC00057337	SAGUACHE

The details and list of these stations are discussed in the RGDSS memorandum for Rio Grande Historic Crop Consumptive Use – Climate Data (**Appendix C -** Filling of Key Climate Station Data). Based on the list of climate stations and location information from HydroBase, the StateDMI command file (**rg2012.cli.StateDMI**) extracts location information and creates the Climate Station Information File (**rg2012.cli**) for use in the StateCU analysis.

5.9.2 Climate Data Files (rg2012.tem, rg2012.pcp, rg2012.fd)

The historical climate data time series for mean temperature, precipitation, and frost dates on a calendar year basis are required for use in the StateCU analysis. The climate data files for the nine climate stations used in the StateCU analysis in Phase 6 are developed accessing information from HydroBase utilizing TSTool command files. A detailed description of the climate data are discussed in the RGDSS memorandum for Rio Grande Historic Crop Consumptive Use – Climate Data (**Appendix C -** Filling of Key Climate Station Data). The summary of climate input data files used in the StateCU analysis are described below:

- Monthly Temperature File (**rg2012.tem**): The TSTool command file (**rg2012.tem.TSTool**) is used to create the Monthly Temperature File (**rg2012.tem**) for use in the StateCU analysis. The TSTool command file extracts mean monthly temperature data for 1950 to 2010 from HydroBase for stations in the Climate Station Information File (**rg2012.cli**).
- Monthly Precipitation File (**rg2012.pcp**): The TSTool command file (**rg2012_pcp.TSTool**) is used to create the Monthly Precipitation File (**rg2012.pcp**) for use in the StateCU analysis. The daily time step precipitation data from 1950 to 2010 are read from HydroBase for stations in the Climate Station Information File (**rg2012.cli**) and precipitation events less than 0.05 inches are set to zero inches. Data are converted from a daily to a monthly time step and missing data are filled using a pattern file (**rg2012_pcp.pat**) based on dry, average and wet months for the years 1950 to 2010. The USBR methodology is applied within StateCU to calculate effective precipitation. This methodology is discussed in more detail in the Phase 6 RGDSS memorandum for Effective Precipitation Methodology (*RGDSS_P6_StateCU_Precipitation.pdf*).
- Frost Date File (**rg2012.fd**): The TSTool command file (**rg2012.fd.TSTool**) is used to create the Frost Date File (**rg2012.fd**) for use in the StateCU analysis for stations in the Climate Station Information File (**rg2012.cli**). Available frost date data is read from HydroBase for years 1950 to 2010. The TSTool command file also reads minimum daily temperatures from HydroBase, fills missing temperature data, recalculates frost dates, and uses that data to fill missing frost date data.

5.10 Blaney-Criddle Crop Coefficient and Crop Characteristic Files

The primary crop types in the RGDSS StateCU model are alfalfa, grass pasture, small grains, potatoes, and vegetables. Crop types added in Phase 6 are new alfalfa, cover crops, fall winter wheat, and bluegrass. The calibration of Blaney-Criddle crop coefficients for most of the primary crop types is discussed in the Rio Grande Historic Crop Consumptive Use – Calibration of Blaney-Criddle Coefficients (**Appendix D** - Calibration of Blaney-Criddle Coefficients) memorandum. Crop parameters for some of these crops were modified in Phase 6 as detailed in the StateCU memorandum for Crop Irrigation Requirements (*RGDSS_P6_StateCU_RevCropCharacteristics.pdf*). Development of crop coefficients and parameters for additional Phase 6 crops is discussed in the RGDSS Memorandum for Additional Crops (*RGDSS_P6_AdditionalCrops.pdf*). For some of the crops that represent a minor fraction of the irrigated acreage, standard TR-21 (vegetables and fall winter wheat) or Pochop (bluegrass) crop coefficient and parameters were used. The following crop specific files are used in the StateCU analysis:

- Blaney-Criddle Crop Coefficient File (**rg2012.kbc**): This file provides crop coefficients for use with the Modified Blaney-Criddle method to determine crop water requirements for the primary and additional crop types for the StateCU analysis. The file is created using the StateDMI command file (**rg2012_kbc.StateDMI)** based on the crop coefficient data in HydroBase.
- Crop Characteristic File (**rg2012.cch**): This file contains information on planting and harvest dates, days to full cover, length of growing season, beginning and ending temperatures or frost conditions, and rooting depths of the crop types utilized in the StateCU analysis. The Phase 6 Crop Characteristics File is created using the StateDMI command file (**rg2012_cch.StateDMI)** based on the crop characteristics information in HydroBase.

Table 5.2 summarizes the crop coefficients and growing season characteristics for the crops used in the StateCU analysis.

Table 5.2: Crop Coefficients and Growing Season Characteristics

Crop Type	Source Crop Coefficient	Beginning Temp. (°F) or planting date	Ending Temperature (°F)	Season (Days)
Alfalfa	Calibrated (CCRG)	43	43	365
Grass Pasture	Calibrated (CCRG)	43	43	365
Potatoes	Calibrated (CCRG)	plant 5/8	32 (frost)	120
Small Grains	Calibrated (CCRG)	43	32 (frost)	130
Vegetables	TR21	55	45	146
New Alfalfa	Calibrated (CCRG)	plant 6/15	43	200
Cover Crop	Derived	50	28 (frost)	120
Fall Winter Wheat	TR21	plant 9/1	45	122
Bluegrass	StateCU - Pochop	50	28 (frost)	365

6. StateCU Common Output Files

The StateCU model outputs several files at different stages of the StateCU model process including the common files— StateCU Binary Output File (***.bd1**), Water Budget (by Structure) Output File (***.dwb**), and Detailed Structure Water Budget by Land Category File (***.4WB**). Description of these common output files generated and utilized during the StateCU modeling process are discussed below. The description of StateCU output files including the common output files are described in more detail in the documentation prepared for the StateCU program (*StateCU_Program_Documentation.pdf*).

- **StateCU Binary Output File (*.bd1)**

The StateCU Binary Output File **(*.bd1)** is created every time a StateCU model run is carried out. The StateCU Binary Output File (*.**bd1**) includes information by structure depending on the level of analysis carried out as defined in the Model Control File (***.ccu**). Depending on the StateCU analysis carried out, the binary output file includes input data as well as potential consumptive use, effective precipitation, irrigation water requirement, water supply, soil storage, total crop consumptive use, and other parameters in the water budget. The StateCU Binary Output File **(*.bd1**) parameter lists and descriptions are provided in the StateCU Program Documentation (Section A-2). Output from the binary file can be viewed through the StateCU GUI using the Time Series Data Tool, or through TSTool. To access the binary file data in TSTool, open the TSTool application, select 'StateCUB' as the input type, and navigate to the *.bd1 file through the standard 'Open File' window.

- **Water Budget (by Structure) Output File** (***.dwb**)

The Water Budget (by Structure) Output File **(*.DWB**) is an output file from each StateCU model run. The file (***.dwb**) is generated when the output file option (typout) is set to level 3, 4, 5, 13, 14, or 15 in the Model Control File (**rg2012.ccu**). The **DWB** output file contains additional information depending on the level of water supply limited analysis. Details of the **DWB** file and list of parameters available in the **DWB** output file, and information on the Model Control File options are provided in the StateCU Program Documentation (*StateCU_Program_Documentation.pdf*).

- **Detailed Structure Water Budget by Land Category File (*.4WB)**

The Detailed Structure Water Budget by Land Category File **(*.4WB**) is an output file that provides the detailed information outlined in the Water Budget (by Structure) Output File (***.dwb)** broken out by land category. The four land categories are:

- Acreage with surface water only supply, flood irrigation
- Acreage with surface water only supply, sprinkler irrigation
- Acreage with only or supplemental groundwater supply, flood irrigation
- Acreage with only or supplemental groundwater supply, sprinkler irrigation

The StateCU code was modified in Phase 6 to be able to output the detailed information for all structures into the **4WB** file and is further discussed in the RGDSS Memorandum *RGDSS_P6_StateCU_Code.pdf*. Previous versions of the StateCU code would only output a **4WB** file for an individual structure specified in the Model Control File (***.ccu**). The file (**4WB**) is generated when the output file option (typeout) is set to level 4, 5, 14, or 15 in the Model Control File (**rg2012.ccu**). The **4WB** file provides more details than the **DWB** file, which are needed by the StateFate program. A detailed description of the **4WB** file is discussed in StateCU Program Documentation (*StateCU_Program_Documentation.pdf*).

7. References

Wilson, Erin, M., June 2004. *Historic Crop Consumptive Use Analysis, Rio Grande Decision Support System*. Leonard Rice Consulting Water Engineers, Inc. Available from the CWCB CDSS website http://cwcbweblink.state.co.us/WebLink/CustomSearchMin.aspx?SearchName=DSSDocsTaskMemo&dbid=0

RGDSS Phase 6 Memorandum: StateFate Documentation - *RGDSS_P6_Statefate.pdf*, November 2015

RGDSS Phase 6 Memorandum: Climate Station weighting — *RGDSS_P6_StateCU_ClimateStationWeighting.pdf*,

RGDSS Phase 6 Memorandum: StateCU code enhancements - *RGDSS_P6_StateCU_Code.pdf*,

RGDSS Phase 6 Memorandum: Additional Crop Types — *RGDSS_P6_StateCU_AddtionalCrops.pdf*, May 2016

RGDSS Phase 6 Memorandum: Effective Precipitation Methodology — *RGDSS_P6_StateCU_Precipitation.pdf*, Agro Engineering, July 2012

RGDSS Phase 6 Memorandum: Evaluation of Division 3 Well Measurement Program — *RGDSS_P6_StateCU_WellMeters.pdf*, Leonard Rice Engineering, May 2012

RGDSS Phase 6 Memorandum: Command to Include and Distribute Metered Pumping in StateCU Analysis — *RGDSS_P6_StateCU_MeterPumpCommands.pdf*, February, 2011

RGDSS Phase 6 Memorandum: StateCU Crop Irrigation Requirements — *RGDSS_P6_StateCU_RevCropCharacteristics*.pdf, Agro Engineering, March, 2011

CDSS: StateCU Documentation — *StateCU_Program_Documentation.pdf*, September 2008.

APPENDICES

Appendix A: Rio Grande historic Crop Consumptive Use —Ditch System Efficiencies
Appendix B: Rio Grande historic Crop Consumptive Use —Soil Moisture Capacities
Appendix C: Rio Grande historic Crop Consumptive Use — Climate Data
Appendix D: Rio Grande historic Crop Consumptive Use —Calibration of Blaney-Criddle Coefficients

APPENDICES

Appendix A - Rio Grande Historic Crop Consumptive Use - Ditch System Efficiencies

The Ditch System Efficiencies were based on the memorandum dated June 1, 2004 from Ross Bethel and Erin Wilson of Leonard Rice Consulting Water Engineers. This memorandum was originally included as Attachment B to the following report:

> Wilson, Erin, June 2004, Historic Crop Consumptive Use Analysis, Rio Grande Decision Support System, Final Report by Leonard Rice Water Consulting Engineers.

This original memorandum is provided at the end of this appendix. The footnotes in this original memorandum are from the original Historic Crop Consumptive Use Analysis Report and do not match the footnote formatting in this Phase 6 memorandum.

Changes made since this memorandum are outlined below.

Revisions to Appendix A Memorandum

The 2004 memorandum recommended conveyance efficiencies for seven large ditches based on seepage studies. Conveyance efficiencies for remaining canals and ditches were based on ditch length and soil types.

The conveyance efficiency recommended in the 2004 memorandum for one of the large ditches (the Empire Canal) has been revised due to additional interviews. The recommended efficiency for another large ditch (The Monte Vista Canal) is retained in the historical time period but is changed after 1992 due to the increased losses observed after the lining of the Terrace Main Canal; the efficiencies of the Terrace Main Canal and Alamosa Creek Canals are also modified after 1992 to reflect this lining. Conveyance efficiencies for a number of other ditches are also set based on estimates of efficiencies or ditch losses that were provided by water users, ditch riders, and water commissioners.

The following table (Table App A Revisions 1) details surface water ditches for which the conveyance efficiency is set based on additional information rather than using the methodology based on ditch length and soil types.

The 2004 memorandum also recommended a maximum application efficiency of 60% for flood irrigation of 80% for sprinkler irrigation. The maximum flood application efficiency is modified from these values for seven ditches. The revised efficiencies for these ditches along with the justifications for the revisions are presented in Table App A Revisions 2.

Table App A Revisions 1. RGDSS Ditches with Set Conveyance Efficiencies

NAME	WDID	Eff.	Source
Rio Grande Canal	2000812	0.65	Appendix B 2004 CU Report - Ditch System Efficiencies, June 1, 2004
Farmers Union Canal	2000631	0.62	Appendix B 2004 CU Report - Ditch System Efficiencies, June 1, 2004
San Luis Valley Canal	2000829	0.63	Appendix B 2004 CU Report - Ditch System Efficiencies, June 1, 2004
Prairie Ditch	20MS20	0.78	Appendix B 2004 CU Report - Ditch System Efficiencies, June 1, 2004
Excelsior Ditch	2000627	0.78	Appendix B 2004 CU Report - Ditch System Efficiencies, June 1, 2004
Empire Canal	20MS02	0.60	Ditch comp. interview 4/18/13, better represents delivery system loss
Monte Vista Canal	20MS10	0.68	Appendix B 2004 CU Rep., 55% after 1993 lining of Terrace Main
Terrace Main Canal	2100601	0.40	60% ditch loss prior to 1993 and 10% thereafter due to lining the canal
Alamosa Creek Canal	2100503	0.40	60% ditch loss prior to 1993 and 10% thereafter due to lining the canal
Park Green Ditch	2000782	0.75	Water Commissioner estimated at 75% conveyance efficiency
Schuch Schmidt Ditch	2000833	0.50	Water Commissioner (past owner) estimated 50% conveyance eff.
El Viego Ditch	2100520	0.80	Water Commissioner estimated at 80% conveyance efficiency
Miller DivSys	21MS04	0.90	Water Commissioner estimated at 90% conveyance efficiency
Richfield Canal	2200616	0.70	Prior 50%, Water Commissioner est. at 80%, NDVI analysis est. 70%
Beckwith Ditch	3500551	0.90	Water Commissioner estimated at 90% conveyance efficiency
Ephraim Ditch	2200541	0.90	Water Commissioner estimated at 90% conveyance efficiency
Sanford Ditch	2200627	0.90	Water Commissioner estimated at 90% conveyance efficiency
Frank Mondragon D1	2400545	0.95	Seepage ditch that intercepts return flows
Frank Mondragon D2	2400604	0.95	Seepage ditch that intercepts return flows
Albert And Vigil D	2400509	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Alfonso Ditch	2400510	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Pando D	2400511	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Antonio Valdez D	2400512	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Antonio Sanchez D	2400513	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Canon D 1	2400519	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Canon Valle D	2400520	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Clarita Vigil D	2400528	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Gabino Atencio D	2400546	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Gabriel Medina D 1	2400547	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Gabriel Medina D 2	2400548	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Guadalupe Sanchez D	2400550	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Jose Lobato D	2400557	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Jose M Sanchez D	2400558	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Julio Gold D	2400559	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Lobato D 1	2400564	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Lobato D 2	2400565	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Ramon Lucero D	2400575	0.90	WD 24 - Structure on upper tributary; small conveyance losses (~10%)
Rio Grande Lariat D sys	20MS21	0.50	Ditch company interview 4/18/2013
Morganville D	2100564	0.75	Ditch company interview 4/18/2013
Rio Grande San Luis D	2000817	0.80	Ditch company interview 4/18/2013
Rio Grande PiedraV sys	20MS23	0.78	Ditch company interview 4/18/2013
Manassa D No 3 Divsys	22MS07	0.73	Ditch company interview 4/18/2013

Table App A Revisions 1. RGDSS Ditches with Revised Maximum Application Efficiencies

Ditch	WDID	Max. App Efficiency		Justification
		Flood	Sprinkler	
Billings Ditch	2000546	0.25		25% due to the senior 9.3 cfs under the ditch being applied to about 1/4 of the total acreage under the ditch where all of this land is flood irrigated and significantly over supplied.
Monte Vista Canal Diversion System	20MS10	0.50		50% due to wild flood on the Monte Vista Refuge and a disproportionate share distribution with 25% ownership by the Refuge
Rio Grande San Luis Ditch	2000817	0.55	0.75	55% flood and 75% sprinkler due to a disproportionate share distribution with 50% ownership on 20-25% of acreage
Rio Grande Piedra Valley Diversion System	20MS23	0.55	0.75	55% flood and 75% sprinkler due to a disproportionate share distribution with a bulk of the shares on the southern end of the system
George Ball Diversion System	26MS05	0.50		Set maximum flood application efficiencies to 50% to reflect wild flood
Oklahoma Co. Diversion System	26MS01	0.50		Set maximum flood application efficiencies to 50% to reflect wild flood
Quartet	2600650	0.50		Set maximum flood application efficiencies to 50% to reflect wild flood

RGDSS Memorandum
Final

To: Ray Bennett, Ray Alvarado, Andy Moore

From: LRCWE, Ross Bethel and Erin Wilson

Subject: Rio Grande Historic Crop Consumptive Use - Ditch System Efficiencies

Date: June 1, 2004

Introduction

This memorandum describes the approach and results obtained under Task 3.8 – Estimate Ditch System Efficiencies. This task includes an estimation of both ditch system and application (on-farm) efficiencies likely to be experienced in the Rio Grande Basin, plus a recommendation on efficiencies to use for the historic consumptive use analyses. It has been updated from the June 2002 version to reflect refinements to maximum flood irrigation efficiency, based on recommendation from peer review.

Factors that affect conveyance efficiencies include:

- Frequency and duration of diversions (i.e. beginning of diversion season versus late summer)
- Underlying soil characteristics
- Canal cross-section
- Canal length
- Location of water table relative to the canal
- Canal flow

Factors that affect application efficiencies include:

- Irrigation practice (i.e. sprinkler, flood)
- Crop types

The StateCU model uses estimated conveyance efficiencies to determine the amount of water delivered to the farm for application on the crops. The maximum application efficiency is used to estimate the maximum water available to meet crop consumptive use demands. StateCU calculates the actual application efficiency by dividing the water delivered to the farm by the crop consumptive use demand.

Approach

The following approach was taken to determine the likely range of efficiencies experienced in the Rio Grande Basin. Conveyance system efficiencies and maximum application efficiencies were investigated separately as described below.

Conveyance System Efficiencies

A commonly used methodology for estimating conveyance efficiency was published by the SCS in the National Engineering Handbook 15-2, (Part 623-2), Irrigation Water Requirements, 1993. This methodology predicts conveyance efficiency when the following information is available or can be estimated:

- Soil type (or soil permeability)
- Ditch length
- Wetted perimeter
- Number of days water is in the ditch
- Diversion flow rate

Several other methods have been developed that use the same basic information. These methods are appropriate for estimating monthly or annual efficiencies for an individual ditch system when the above information is known. However, this methodology is not appropriate for use in the RGDSS basin-wide analysis because ditch configuration, required for wetted perimeter, is not known. The data-centered approach used for the historic crop consumptive use analysis requires information to be developed or estimated basin-wide using available data from GIS coverages or Hydrobase.

There is limited efficiency information available for the large canal systems in the San Luis Valley. This available information was used to develop a simplified approach to estimating likely efficiencies for other ditch systems using available GIS coverages and data stored in HydroBase, as follows:

1. Develop a list of questions relating to system efficiencies for the Surface Water Contractor to use in their interviews with water administrators and ditch companies. Extract the following information from the resulting User Interview Notes:
   - Conveyance Loss information from the large ditch companies
   - Corresponding main canal lengths
2. Measure main canal lengths not available from the User Interview Notes or from the ArcView GIS canal coverage developed for the RGDSS project
3. Obtain main canal capacities from Hydrobase
4. Estimate an average available soil moisture content (AWC) and soil type to represent each main canal from the Soil AWC GIS layer prepared for the RGDSS project
5. Investigate relationships between percent canal loss and canal length
6. Investigate relationships between percent canal loss and soil characteristics
7. Investigate relationships between percent canal loss and canal capacity
8. Use appropriate relationships, if they exist, to estimate canal losses by soil type, ditch size, or proximity to the river

Maximum Application Efficiencies

1. Develop a list of questions relating to irrigation practices for the Surface Water Contractor to use in their interviews with water administrators and ditch companies.
2. Extract the following information from the resulting User Interview Notes:

- Irrigation practices as percent of irrigated acreage per ditch system or water district
- Application efficiency per type of irrigation practice

3. Review published data on on-farm irrigation efficiencies in the San Luis Valley and other areas
4. Contact AGRO engineering principals to gather information from their previous studies and field experience
5. Suggest appropriate maximum application efficiencies to use based on irrigation methods

Results – Conveyance Efficiencies

The large ditch companies, shown in Table 1, were interviewed by the Surface Water Contractors. In some cases, the contact for the ditch company was able to indicate a percentage of flow loss experienced along the main canal, portions of the main canal, or throughout the ditch system. As indicated in the table footnote, either the length of the main canal was provided by the ditch company, was measured from USGS County maps showing the major ditches, or was extracted from the RGDSS GIS canal coverage. Canal lengths provided in the User Interview Notes were verified from the USGS mapping. Main canal capacities are those reported in Hydrobase. The average soil available water content beneath the main canal was determined from the Rio Grande Soil AWC GIS mapping.

Canals in the Rio Grande are estimated to flow through the lower soil layer. Permeability for this layer was determined for each NRCS soil polygon using the methodology described in Appendix C for the average available water content. The average permeability beneath the main canal was determined from the resulting GIS mapping.

In 1972, the results of a gain/loss study were published in the Colorado Water Resources Basic-Data Release No. 22 – Hydrologic Data for the San Luis Valley, Colorado. This report included flow measurements taken at various locations along the Empire Canal, the Rio Grande Canal, and the Farmers Union Canal.

The Empire Canal results were not considered, because only a portion of the canal was measured. Flow measurements for the Rio Grande Canal were taken after the first month of irrigation at points along the main canal. The measured 31 percent loss was used in our analyses, as footnoted on Table 1, because no information was provided during the user interviews regarding later season losses on the Rio Grande Canal.

Flow measurements were also taken after the first month of irrigation at points along Farmers Union Canal. The measured 32 percent loss was also used in our analyses, as no more recent information was provided during the user interviews.

Table 1
Large Ditch Information

Ditch System	Main Canal Length (miles)	Main Canal Capacity (cfs)	Estimated Losses (Percent of Diversion)		Percent Loss per Mile		Soil Available Water Content (AWC)
			First Month of Irrigation	After First Month	First Month of Irrigation	After First Month	
Rio Grande	34[1)]	1900	50	31[2)]	1.47	1.06	0.114
Farmers Union	27[1)]	910	60	32[2)]	2.22	1.19	0.074
San Luis Valley	19[1)]	400	45	35	2.37	1.84	0.104
Prairie	28	380	30	20	1.07	0.71	0.074
Excelsior	13	120	30	20	2.31	1.54	0.121
Empire	24	550	Not provided	25		1.04	0.106
Monte Vista	27	380	40	30	1.48	1.11	0.126
Average	24.6	663	42.5	28.3	1.82	1.21	0.103

1) Canal Lengths determined from USGS County Maps
2) From Colorado Water Resources Basic-Data Release 22 – Hydrologic Data for the San Luis Valley, Colorado

Conveyance Loss versus Main Canal Length

Most of the ditch company representatives provided loss percentages for the beginning of the irrigation season, when losses tend to be higher due to ditch wetting, and for later in the irrigation season. Based on past experience, we have associated the beginning losses with the first month of diversions. Figure 1 shows the provided ditch losses in percent versus the main canal length for the first month of irrigation. Figure 2 shows the provided ditch losses in percent versus main canal length for subsequent months.

An attempted relationship between percent loss and main canal length resulted in low correlation coefficients values (r^2) for both time periods, however the trend shows that losses increase with increased canal length. As expected, the average loss per mile is greater during the first month of irrigation – 1.82 versus 1.21.

Figure 1
Percent Loss versus Canal Length
First Month of Irrigation

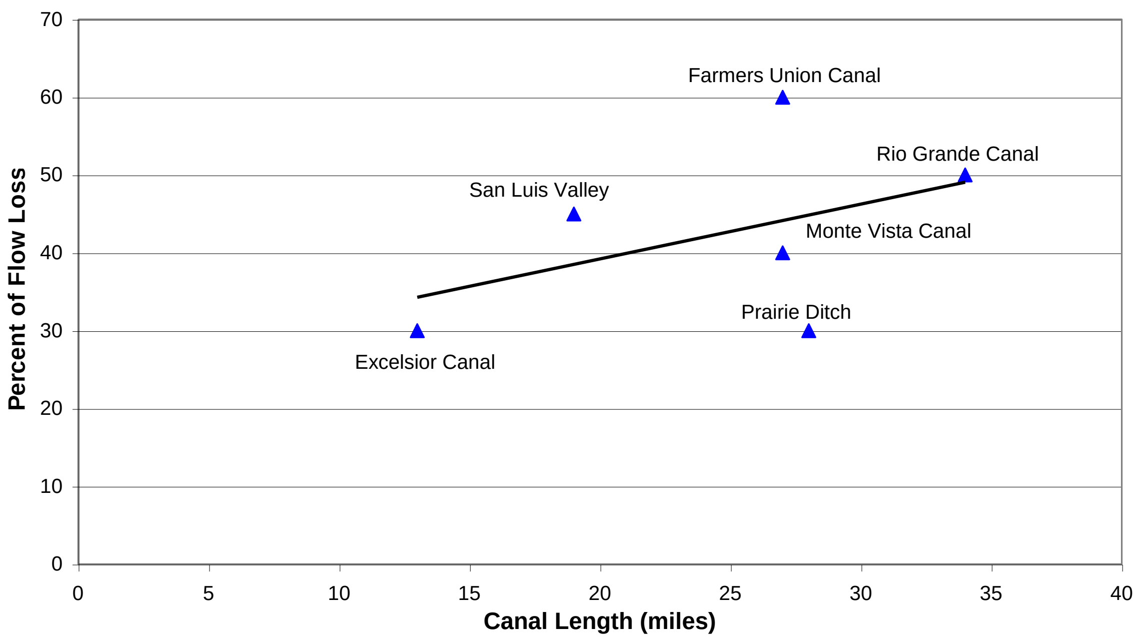
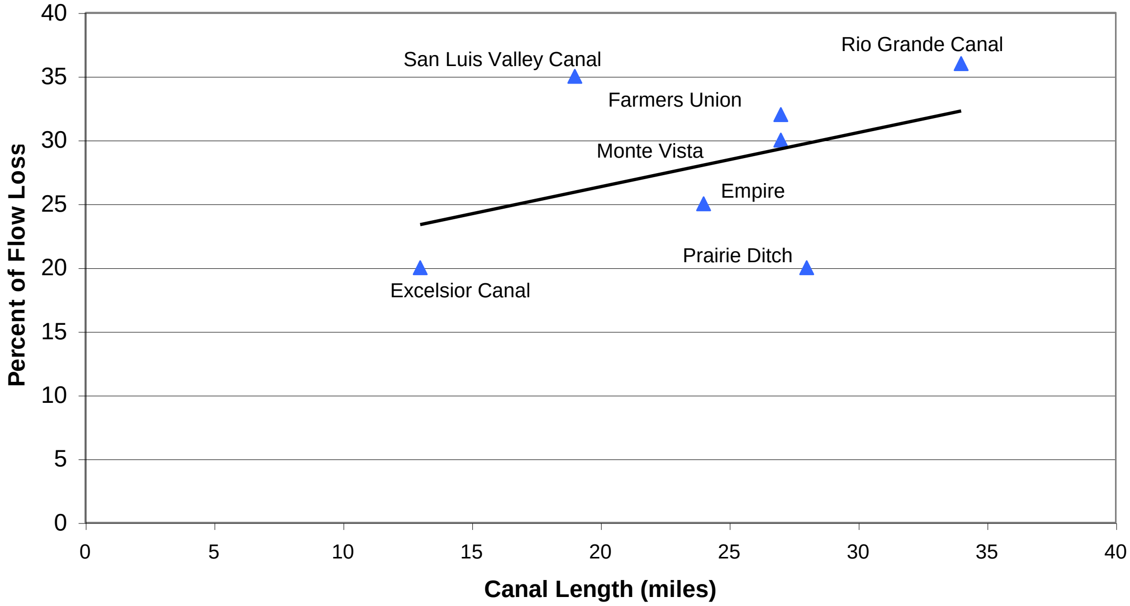


Figure 2
Percent Loss versus Canal Length
After First Month of Irrigation



Conveyance Loss versus Canal Capacity

In some instances, it was unclear whether the ditch system losses provided by the ditch companies were for the main canal only, or included parts of the lateral delivery system. In addition, some of the main canals become laterals and, therefore, there was uncertainty involved with measuring the main canal lengths. Canal capacity often provides a good basis for estimating conveyance loss, as it can be representative of overall system size as well as the wetted perimeter. Figures 3 and 4 show conveyance loss versus ditch capacity during the first month of irrigation and subsequent months, respectively.

The graphs show that larger capacity ditches generally have greater ditch losses, but the r^2 values are still too low to use as a basis to predict canal loss. In addition, canal capacities store in HydroBase are decreed ditch capacities, and may not accurately represent the actual ditch configuration.

Figure 3
Conveyance Loss versus Ditch Capacity
First Month of Irrigation

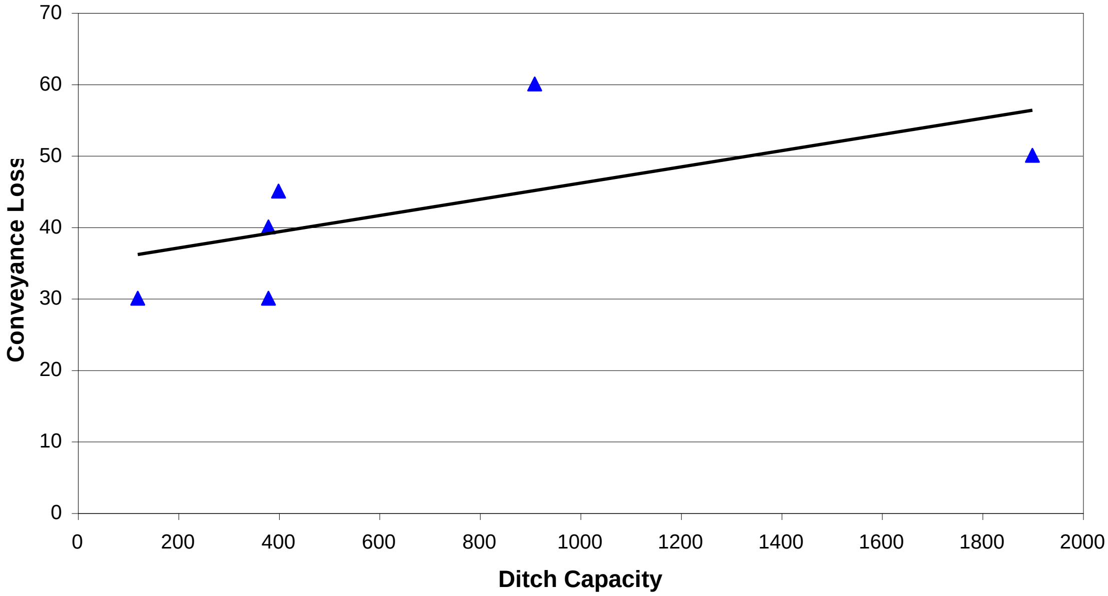
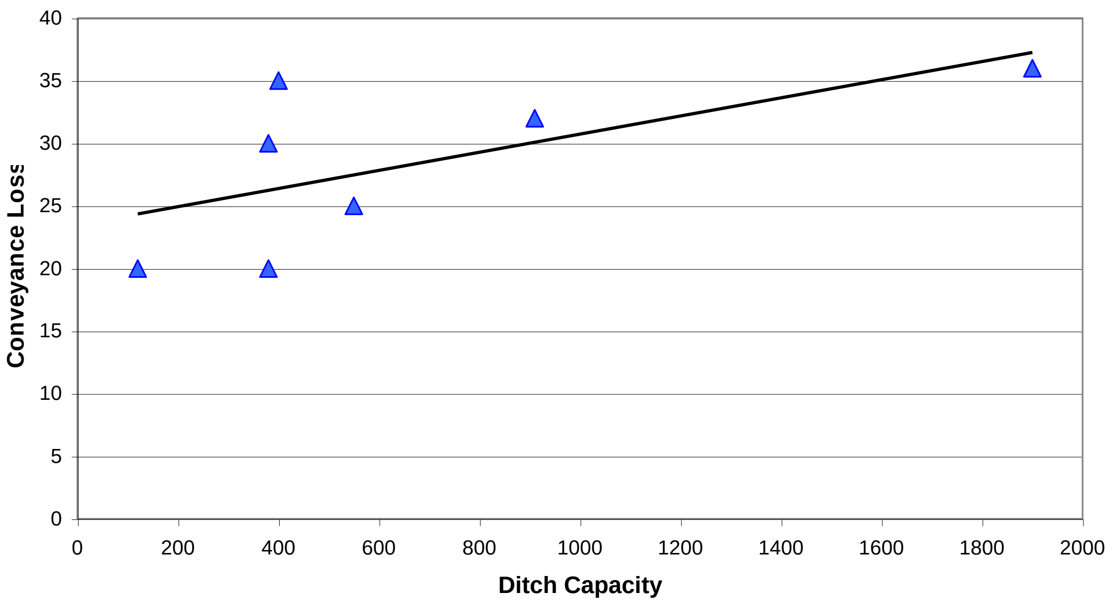


Figure 4
Conveyance Loss versus Ditch Capacity
After First Month of Irrigation



Conveyance Loss versus Soil Moisture Parameters

Average soil moisture holding capacities (AWC) for each ditch system were estimated based on the Soil AWC GIS layer prepared for the RGDSS project. A strong relationship between canal loss per mile and AWC was not apparent for either time period of interest, as shown in Figures 5 and 6. Therefore, relationships between canal loss and average AWC could not be used to predict canal losses by water district in the San Luis Valley.

Figure 5
Percent Loss per Ditch Mile versus Soil Available Water Content
First Month of Irrigation

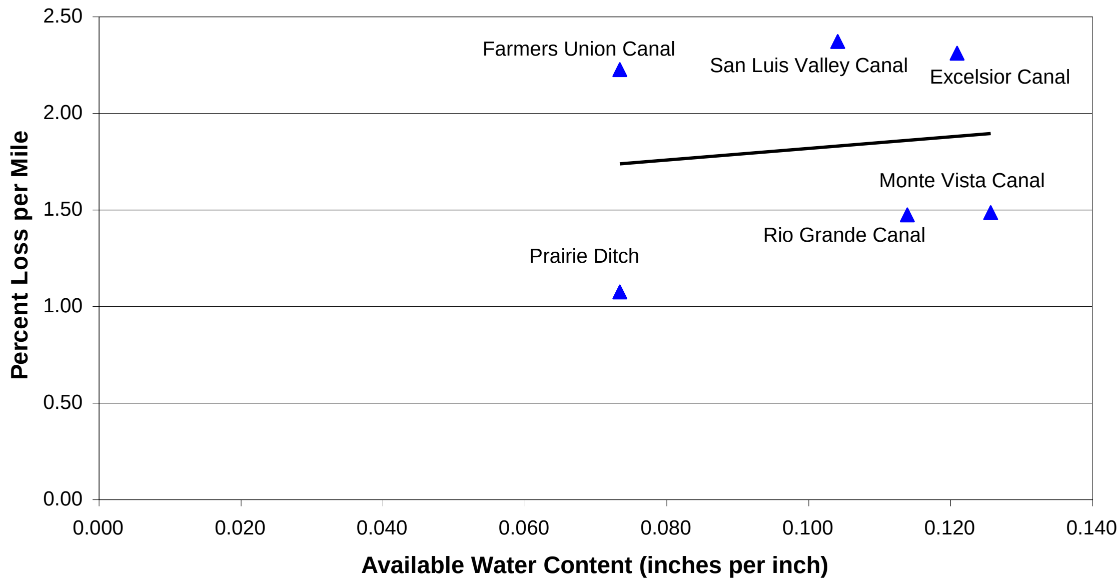
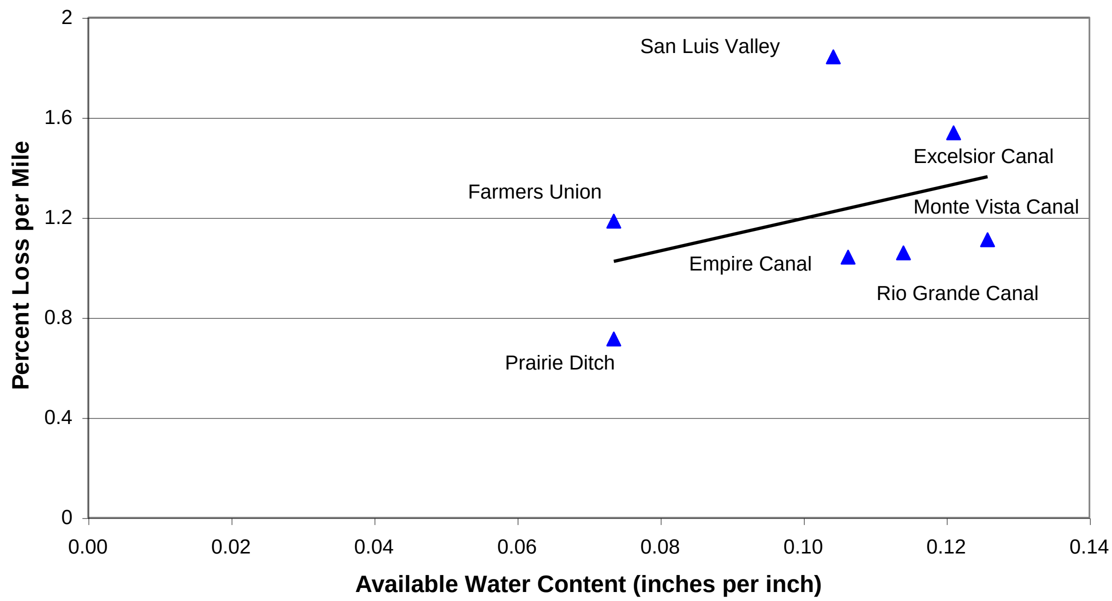


Figure 6
Percent Loss per Ditch Mile versus Soil Available Water Content
After First Month of Irrigation



Average permeability of the lower soil layer for each ditch system was estimated based on the NRCS Colorado based STATSGO mapping using the methodologies described in Appendix C. A good relationship was found between canal loss per mile in the first month and lower soil layer permeability, as shown in Figure 7. Figure 8 also shows that ditches flowing through soil with higher permeability have larger losses. Note that when comparing geologic and soil parameters, an r^2 value greater than 0.5 is considered good.

Figure 7
Percent Loss per Ditch Mile versus Average Permeability
First Month of Irrigation

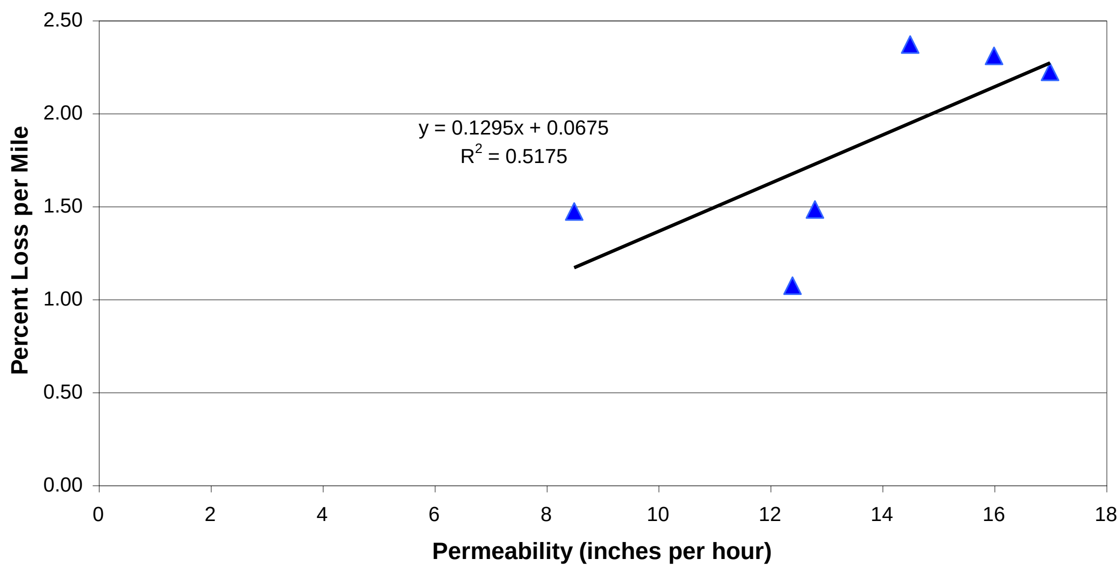
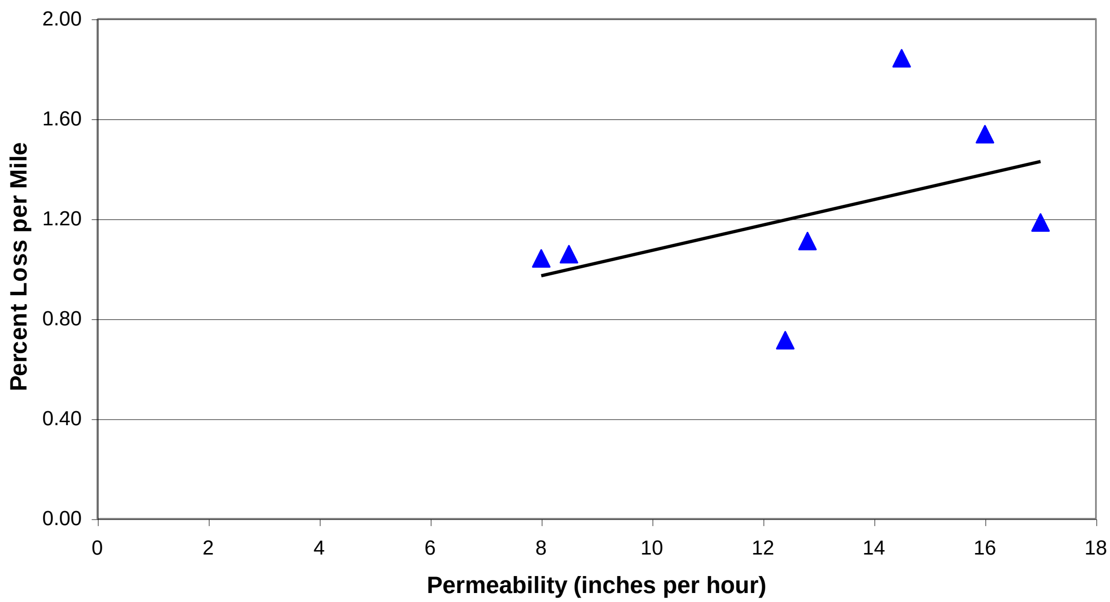


Figure 8
Percent Loss per Ditch Mile versus Average Permeability
After First Month of Irrigation



Recommendations - Conveyance Efficiencies

As shown in Table 1, conveyance losses for the large ditch systems during the first month of irrigation range from 30 to 60 percent, with an average near 40 percent. The conveyance losses later in the irrigation season range from 20 to 35 percent, with an average near 30 percent. The growing season in the San Luis Valley generally extends for about five months, from mid April through mid September. Therefore, the first month of irrigation is approximately 20 percent of the entire irrigation season.

StateCU currently uses one annual conveyance efficiency estimate for each ditch system. For the six ditch systems shown in Table 1 with estimated losses for both the first month of irrigation and subsequent months, the annual conveyance loss was estimated by the following equation:

Annual Loss (%) = (0.20 * % First Month Loss) + (0.80 * % After First Month Loss)

Conveyance Efficiency (%) = 100 - Annual Loss (%)

Estimated first month losses for the Empire Canal were not available. The Empire Canal second month losses were similar to the Prairie and Excelsior ditches, therefore, a conveyance efficiency of 75 percent is recommended. Table 2 shows the recommended conveyance efficiencies for the large Water District 20 ditch systems.

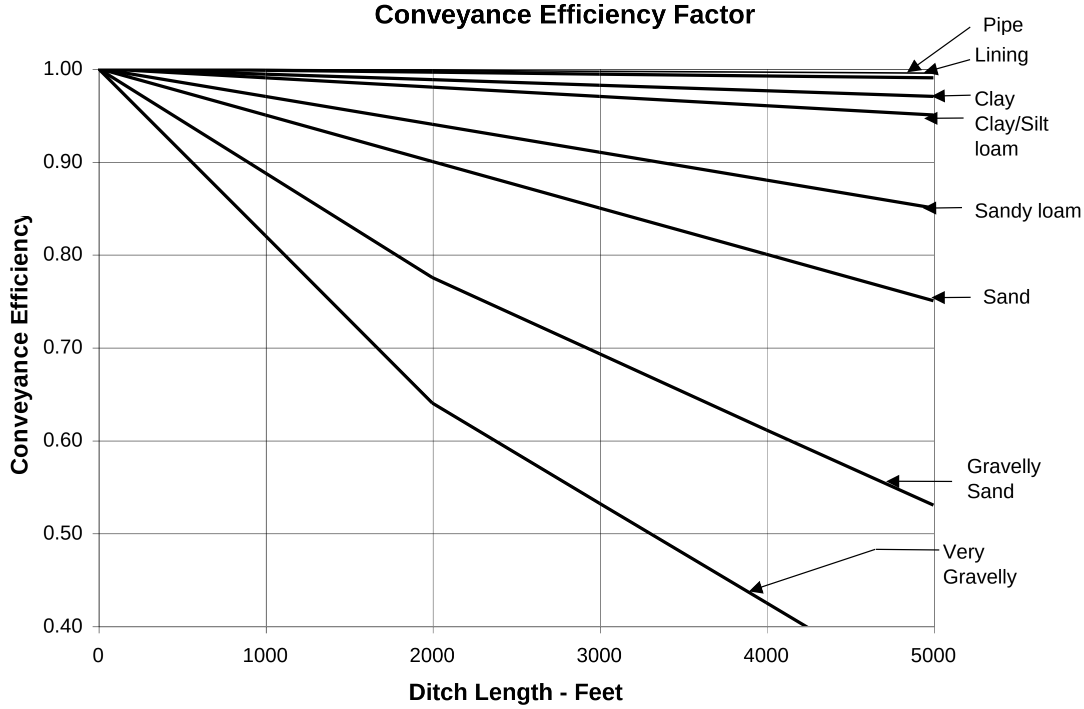
Table 2
Recommended Conveyance Efficiencies for Large Water District 20 Ditches

Ditch System	Conveyance Efficiencies
Rio Grande	65 %
Farmers Union	62 %
San Luis Valley	63 %
Prairie	78 %
Excelsior	78 %
Empire	75 %
Monte Vista	68 %

As noted above, methodologies that require detailed information regarding wetted perimeter and flow velocities are not appropriate for use in the RGDSS basin-wide analysis because this information is generally not known. The data-centered approach used for the historic crop consumptive use analysis requires information to be developed or estimated basin-wide using available data from GIS coverages or Hydrobase.

Information regarding conveyance efficiency is only available for the larger ditches in the basin, therefore, a method is required to estimate conveyance efficiency for shorter, smaller capacity ditches. The NRCS has developed conveyance efficiency curves that can be used to estimate ditch efficiency based on soil type and canal loss – information that is available or can be developed from GIS coverages for the Rio Grande basin for ditches less than one mile in length. These curves are appropriate for use when more detailed information on wetted perimeter and flow rate is not available. Figure 9 shows the curves, published by the NRCS in the Farm Irrigation Rating Index (FIRI) – A method for planning, evaluating, and improving irrigation management, June 1991.

Figure 9
Conveyance Efficiency Factor



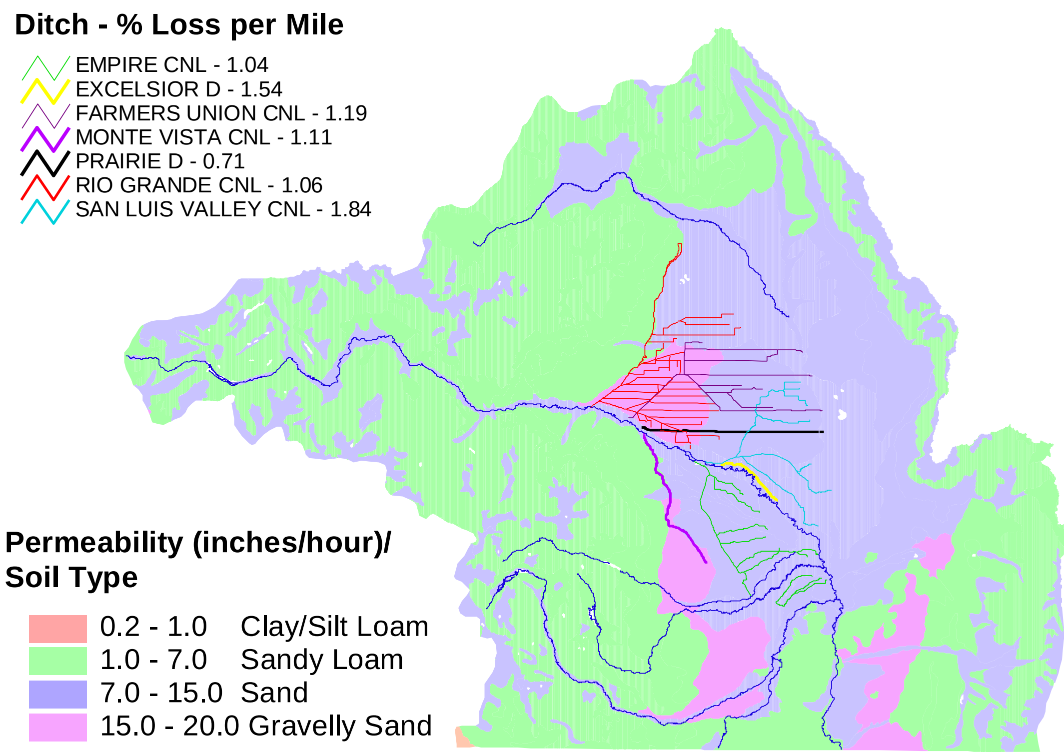
The NRCS STATSGO soil mapping was reviewed to determine the relationship between permeability in the lower soil layer and soil description so the curves shown in Figure 9 could be used. Table 3 shows the general relationship for the Rio Grande between soil description and permeability. Other soil types are not present in the irrigated portion of the basin.

Table 3
Relationship between Soil Classification and Permeability

Soil Description	Permeability (inches/hour)
Clay/Silt Loam	0.2 – 1.0
Sandy Loam	1.0 – 7.0
Sand	7.0 – 15.0
Gravelly-Sand	15.0 – 20.0

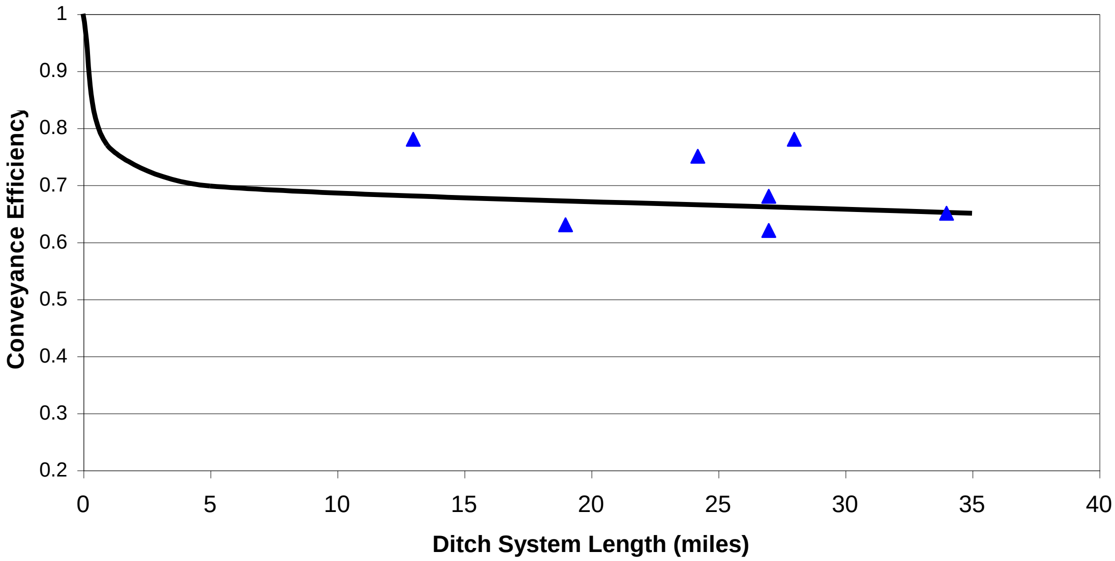
Figure 10 shows the soil permeability and soil descriptions in the Rio Grande basin and the location of the large ditches. As shown, most of the San Luis Valley ditches flow through soil described as sand.

Figure 10
Permeability and Soil Type in the Rio Grande Basin



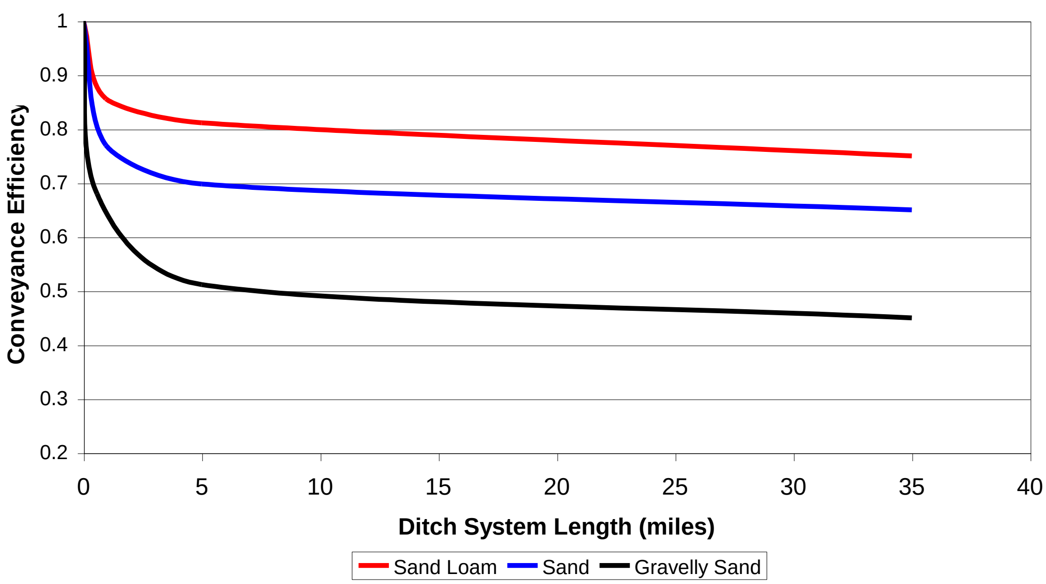
The curves shown in Figure 9 were developed for ditch systems less than one mile in length. However, that only represents about one quarter of the total ditch systems in the basin. Therefore, the curves were extended based on the canal loss information for the larger ditches discussed above. Figure 11 shows the NRCS conveyance efficiency curve up to one mile in length, and an estimated curve based on available ditch data for up to 35 miles in length for ditches flowing through sand. Figures 12 shows the estimated ditch loss curves used for the three soil types found in the San Luis Valley.

Figure 11
Conveyance Efficiency Function for Sand
(Permeability between 7.0 and 15.0 inches per hour)



0 to 1 mile - Based on NRCS Conveyance Efficiency Curve (FIRI)
1 to 35 miles - Based on reported efficiencies for large ditches in the Rio Grande

Figure 12
Conveyance Efficiency Curves



0 to 1 mile - Based on NRCS Conveyance Efficiency Curve (FIRI)
1 to 35 miles - Based on reported efficiencies for large ditches in the Rio Grande

Canal lengths and soil description for ditch systems were extracted from the ArcView canal and soils coverage developed for the RGDSS project. The canal GIS coverage did not have information for 75 explicitly modeled ditch systems. These 75 structures, along with the 44 aggregated surface water structures represented in the model, were assigned a conveyance efficiency of 80 percent. It is estimated that the missing ditches are smaller and irrigate within a short distance from the river.

Table 4 shows the results of this analysis and the number of ditches that are represented in each efficiency category.

Table 4
Conveyance Efficiencies and Corresponding Number of Ditches

Efficiency	Number of Ditches
> 90 %	15
80 to 90 %	61
70 to 80 %	257
60 to 70 %	47
< 60%	27
Total	407

There has not been a trend towards improving or lining canals and laterals in an attempt to decrease conveyance losses in the San Luis Valley. Canal losses, and the resulting aquifer recharge, are considered beneficial by most of the ditch systems, since many irrigators depend on ground water to meet crop requirements. Therefore, the recommended conveyance efficiencies are appropriate for the period considered in the RGDSS project. In addition, the range of conveyance efficiencies is consistent with our knowledge of conveyance efficiencies in areas outside of the Rio Grande basin.

Results – Maximum Application Efficiencies

As mentioned in the introduction, application efficiencies are dependent on irrigation methods, which may vary with crop type. In addition, irrigation methods have changed considerably during the period considered in the RGDSS project**.**

A conference call was held with Kirk Thompson and Leroy Salazar of Agro Engineering, Inc. to discuss application efficiency studies and general knowledge of on-farm efficiencies within the San Luis Valley. Specific information included irrigation methods for the large ditch systems and by water district, estimated on-farm efficiencies for each method, and, if applicable, timing of installation of sprinkler systems. They indicated that "flood" irrigated lands within the basin include uncontrolled, overland flood irrigation as well as border irrigation systems.

The user interview memorandums were reviewed for the local water commissioners' estimates of irrigation methods used in their districts, and estimates of application efficiencies. According to Agro Engineering, efficiency estimates can vary both by irrigation methods and by crop types. Agro Engineering suggested a range of likely maximum application efficiencies for flood irrigation and sprinkler techniques shown in Table 5.

Table 5
Range of Maximum Application Efficiencies per Irrigation Method

Irrigation Method	On-farm Efficiencies
Border, Furrow, and Flood Irrigation	30 - 70 %
Center Pivot/Lateral Sprinklers	70 - 80 %

This information is consistent with efficiency percents presented by Duane D. Klamm and John S. Brenner in the 1995 Evapotranspiration and Irrigation Efficiency Seminar sponsored by the American Consulting Engineers Council of Colorado and the Colorado Division of Water Resources. They proposed a range of 50 to 60 percent application efficiency for flood irrigation, 60 to 80 percent for border irrigation, 75 percent for furrow irrigation, and 75 to 85 percent for sprinkler irrigation.

Recommendations – Maximum Application Efficiencies

The StateCU model uses maximum application efficiencies to estimate the amount of irrigation water delivered to the farm that is available to meet crop consumptive use demands. The actual application efficiency is calculated within the model, and may be considerably less than the maximum application efficiency. The total acreage and the acreage of sprinkler irrigated lands under each ditch system, by year, is input to the StateCU model. The maximum application efficiency is determined by weighting the flood irrigated acreage and associated efficiency with the sprinkler irrigated acreage and associated efficiency.

Alan Davey of Davis Engineering provided sprinkler extend maps for 14 years (1975 through 1980, 1982 through 1984, 1989, 1991, 1993, 1996 and 1998), prepared for the Rio Grande Water Conservation District. These maps were digitized and linked to ditch service areas using the GIS ditch service area mapping developed by Agro Engineering. This provided the sprinkler-irrigated acreage over time for use in the StateCU historic consumptive use analysis.

Notes from a meeting held with Ralph Curtis in March, 1987, during the Rio Grande Water Supply Study, Phase I, performed by LRCWE in 1990, indicated that at that time, the conservancy district assumed an on-farm efficiency for sprinkler systems of 65 to 80 percent. He also indicated that installation of sprinklers began in 1969. According to Agro Engineering, most of the sprinklers in the valley were installed between 1970 and 1980. Prior to that time, almost all farms used flood irrigation methods.

Although actual application efficiency can vary with crop type, a consistent maximum application efficiency is recommended throughout the basin based on irrigation method. Table 6 shows the recommended maximum application efficiencies for use in the consumptive use analysis.

Table 6
Recommended Maximum Application Efficiencies

Flood Irrigation	Sprinkler Irrigation
60 %	80 %

Information from Other Sources - Checks

The CSU extension office in Alamosa, as well as county NRCS offices throughout the San Luis Valley, were contacted to determine if they have been involved with, or knew of any, canal loss studies performed on Rio Grande diversion canals. They were not aware of any studies. A literature review was performed to gather additional information regarding conveyance efficiencies in the San Luis Valley, as well as elsewhere. The information gathered was used to check the conclusions suggested in this memorandum for reasonableness. The following summarizes this effort.

- The 1976 report Crop Consumptive Irrigation Requirements and Irrigation Efficiency Coefficients for the United States, published by the USDA and the SCS, suggested an average conveyance efficiency for the San Luis Valley of 68 percent in 1975. This report did not attempt to distinguish between early season and later season efficiencies. The 68 percent fall in the range of the suggested conveyance efficiencies for the large ditches. The report indicated that conveyance efficiency in the San Luis Valley would likely increase to 75 percent by the year 2000, as canals would be improved or lined. As discussed previously, this has not necessarily been the trend, as aquifer recharge along the canal systems is generally considered to be a benefit, particularly in the Close Basin.

  This report also indicated that the average application efficiency for 1975 was 54 percent. This efficiency is in the range for flood irrigation efficiency, which is expected because the extensive changeover to sprinkler systems was still on going through the 1970s. The report predicted the application efficiency would increase to 60 percent by the year 2000, as more farms moved toward sprinkler irrigation.

- During the Rio Grande Water Supply Study, Phase I, performed by LRCWE in 1990, a table was obtained from a report done by Zorich-Erker Engineering, Inc. The report (actual title unknown) outlined work they had performed during an investigation of the recharge of the confined and unconfined aquifers in the Closed Basin of the San Luis Valley in 1977. They provided a table of Estimated Annual Recharge to Unconfined Aquifer (Closed Basin) that showed canal losses. A footnote to the table indicated that canal loss figures were "estimated on the basis of the canal loss figures developed for the Farmers Union Canal, with adjustments made for difference soil conditions, amount of water carried and length of canal". This resulted in the following conveyance efficiency figures:

  - Farmers Union Canal 71%

- Prairie Ditch 65%
- Rio Grande Canal 56%
- San Luis Valley Canal 75%

Although these efficiencies do not necessarily match the efficiencies indicated by the ditch companies during the user interview process; they fall well within the range of recommended conveyance efficiencies for the large ditches.

Application efficiencies used by the consultant in their analysis were as follows:

- Farmers Union Canal 50%
- Prairie Ditch 52%
- Rio Grande Canal 61%
- San Luis Valley Canal 63%

Note that these are actual application efficiencies, not maximum efficiencies required for the consumptive use analysis. However, these application efficiency estimates are within the range for 1977 when flood irrigation was being replaced with sprinklers.

- The 1978 report Water and Related Land Resources – Rio Grande Basin Colorado, published by the USDA and the CWCB, indicated that "All consumptive use and irrigation requirement calculations are based on 29 percent efficiency (including conveyance and farm losses)". This estimate is within the suggested range of system efficiencies. It is closer to the minimum efficiencies, which is expected because the extensive changeover to sprinkler systems was still on going through the 1970s.

- The 1987 report "San Luis Valley Confined Aquifer Study", by HRS, indicated a 50 percent efficiency for the Rio Grande Canal. This figure includes conveyance and application losses. This is close to the recommended maximum overall efficiency for the Rio Grande Canal, as the majority of the canal is sprinkler irrigated.

Comments and Concerns

Historic water supply-limited consumptive use estimates are relatively sensitive to both conveyance efficiency and maximum application efficiency. Analyses were simulated to determine the level of sensitivity for the recent period from 1990 through 1997. When the input files for the RGDSS historic consumptive use simulation were revised to reflect conveyance efficiencies 5 percent higher than the efficiencies recommended in this memorandum (for instance from 80 percent to 85 percent), the resultant water supply-limited consumptive use from surface water basin-wide increased by 5 percent. When the conveyance efficiencies were decreased by 5 percent, the consumptive use from surface water decreased by 6 percent.

Similarly, when the recommended maximum application efficiencies for flood and sprinkler use were increased to 65 percent and 85 percent respectively, the water supply-limited consumptive use from surface water increased 6 percent. When the flood and sprinkler use efficiencies were decreased to 55 percent and 75 percent respectively, the consumptive use from surface water decreased by 6 percent.

We believe the recommended conveyance efficiencies are appropriate for use in analyses performed as part of the RGDSS project. However, ditch loss data was only available for large ditch systems. In addition, the GIS canal coverage does not include all the ditch systems, and some ditches include main canal plus laterals while others only include the main canal only. If more information becomes available through further investigations, ditch-specific conveyance efficiencies may be more accurately determined based on:

- More complete ditch length coverage
- Information on depth to underlying water table
- Location of ditch compared to other ditches (return flow considerations)

Appendix B - Rio Grande Historic Crop Consumptive Use -Soil Moisture Capacities

Soil Moisture Capacity information was based on the memorandum dated June 5, 2005 from Ross Bethel and Erin Wilson of Leonard Rice Consulting Water Engineers. This memorandum was originally included as Attachment C to the following report:

> Wilson, Erin, June 2004, Historic Crop Consumptive Use Analysis, Rio Grande Decision Support System, Final Report by Leonard Rice Water Consulting Engineers.

This original memorandum is provided at the end of this appendix. The footnotes in this original memorandum are from the original Historic Crop Consumptive Use Analysis Report and do not match the footnote formatting in this Phase 6 memorandum.

Changes made since this memorandum are outlined below

Revisions to Appendix B Memorandum

Since the development of the 2004 memorandum, there have been improvements to ArcGIS, the development of the CDSS Toolbox add-on to ArcGIS, the development of StateDGI, and development of additional irrigated lands coverages. The capabilities of these software enhancements have streamlined the process described in the attached memorandum and the more recent data have been used. Further, the average soil moisture capacities used for the groundwater only structures have been modified from the County/HUC approach to an area weighted Water District approach. The data is processed in the Excel spreadsheet "**AWC Calculations.xlsx**" file located in the following folder "…\LocationCU\Development Excel Files".

RGDSS Memorandum
Final

To: Ray Bennett, Ray Alvarado, and Andy Moore

From: LRCWE, Ross Bethel and Erin Wilson

Subject: Rio Grande Historic Crop Consumptive Use - Soil Moisture Capacities

Date: June 5, 2000

Introduction

This memorandum describes the approach and results obtained under Task 3.3 – Assign Soil Moisture Capacities to Parcels and Structures. Soil moisture capacities are used by StateCU to determine historic water supply-limited consumptive use.

This task includes:

1. Determining the weighted available water capacity (AWC) values (in inches per inch) for each soil type polygon defined on the Colorado based STATSGO map, and create an associated ArcView theme.
2. Use the ArcView coverage to determine the average available water capacity for irrigated parcels and ditch systems.
3. Prepare the results for use in StateCU.

Approach and Results

Determine the weighted AWC values and create ArcView layer.

The following steps were performed to determine the weighted AWC values and create an associated ArcView theme for use in the RGDSS project.

1. A map of major soil types for the Rio Grande Basin was obtained from the CDSS web site at http:\\cdss.state.co.us. This map was prepared by the RGDSS GIS contractor (HDR Engineering) based on State Soil Geographic (STATSGO) databases of the National Resources Conservation Service (NRCS). This map theme, named "soils", was downloaded as an ArcView GIS shapefile. The associated attribute table for each delineated soil polygon includes a 5-character map unit identifier (field *Muid*). There are 199 polygons (excluding "water" polygons associated with reservoirs and lakes) in the Rio Grande Basin.

2. Additional STATSGO tables of data attributes were obtained from the RGDSS GIS contractor. The originals of these tables as well as the soils map theme were obtained from

the web site at www.ftw.nrcs.usda.gov/statsgo_ftp.html. The three tables and associated fields used in the available water capacity analysis are:

Comp.dbf - This table indicates the percent (field *compct*) of the *Muid* with a specific soil type (field *Muidseqnum*).

Compyld.dbf - This table indicates soil types (field *Muidseqnum*) that are cultivated with crops (field *Cropname*) and yields (fields *Nirryld* and *Irryld*).

Layer.dbf - This table provides minimum (field *Awchl*) and maximum (field *Awch*) water holding capabilities for a depth range (field *Laydepl* to field *laydeph*) of a soil type (field *Muidseqnum*).

3. In ArcView, the tables indicated above were linked to create a new table (named "tlayer") that had information needed to estimate the average water holding capacity in each soil polygon. The following table processing occurred.
   a. The layer.dbf table was linked with the "soils" map attribute table (link field *Muid*), the "soils" polygons selected, and the resultant selected records in the layer.dbf table saved into a new table ("tlayer"). The tlayer table contains records only for soils found in the Rio Grande Basin.
   b. The tlayer table was joined with the "Comp.dbf" table (join field *Muidseqnum*) such that the percent of each soil type in a *Muid* was added to the tlayer table.
   c. A new numerical column (field *include*) was added to the tlayer table to indicate whether a soil type (field *Muidseqnum*) should be included in the available water capacity calculation. This column was completed by the following process.
      - Soil types with names of "Rock Outcrop" or "Rubble Field" were not included (include=0). This was performed using the ArcView query and calculate functions.
      - The tlayer table was linked with the "Compyld" table (link field *Muidseqnum*), Compyld records selected and associated records in the joined table included in the analysis (include=1). Due to the primary purpose of calculating available water capacity for application in crop consumptive use calculations, this process bases the available water capacity for a *Muid* on cultivated lands if they exist in a *Muid*. Of the 26 map units in the Rio Grande Basin, 15 included cultivated soils.
      - For the 11 *Muids* without cultivated lands, the remaining (after exclusion for rock outcrops) soil types were included in the analysis.

4. In Excel, a worksheet ("awc.xls") was prepared to accept the tlayer table created in the previous step. Formulas were added to the worksheet to summarize the average soil water capacity for depth zones of 0-12 inches, 12-24 inches and 24-60 inches in each map unit. An average of the high and low water holding capacities for a given soil type in a given depth range was assumed to be representative of the water holding capacity. Also calculated was an average available water capacity (AWC) in inches per inch for the first 60 inches of soil. A summary table in the worksheet was prepared containing the *Muid* and AWC and saved in text format.

5. In ArcView with the original "soils" map, the text table from the previous step was added and joined to the "soils" map attribute table. The GIS theme was renamed to "AWC" and metadata was prepared to describe the coverage creation and attributes.

Assign Soil Moisture Capacities to Parcels and Structures

The following steps were preformed to assign a soil moisture capacity value to each key structure or aggregate structure modeled in the historic consumptive use analysis.

1. An ArcView project was created with the AWC theme, the irrigated parcel theme, and the ditch service area theme.

2. A script called "modfind" (Attachment 1) was used to determine the intersecting area of the AWC theme and the irrigated parcel theme. The intersected areas were weighted by the soil moisture capacity file and a new weighted soil moisture capacity filed was created in the irrigated parcel theme.

3. The "modfind" script was used to determine the intersection area of the irrigated parcel theme and the ditch service area themes. The intersected areas were weighted by the soil moisture capacity field created in step 2. The resulting weighted soil moisture capacity field was added to the ditch service area theme.

4. Default soil moisture capacities were determined by County/HUC combination in an excel spreadsheet called "lrcweditchdata.xls". The ditch service area theme attribute table from step 3 was copied into a worksheet. The average of the soil moisture capacity field for structures in each County/HUC combination was determined. These average soil moisture capacity values were assigned to aggregate surface and ground water structures and structures not included in the ditch service area theme.

Table 1 shows the average soil moisture capacities, in inches per inch, for each County/HUC combination with irrigated acreage in the Rio Grande Basin. Aggregate structures, or structures with acreage outside of the irrigated parcel theme coverage, were assigned these average soil moisture capacities.

Table 1
Average Soil Moisture Capacity (inches/inch)

HUC	County	Average Soil Moisture Capacity (inches/inch)
13010001	Mineral	0.1255
	Rio Grande	0.1255
13010002	Saguache	0.1771
	Rio Grande	0.1771
	Alamosa	0.1142
	Costilla	0.1130
	Conejos	0.1073
13010003	Saguache	0.0770
	Rio Grande	0.0739
	Alamosa	0.0869
	Costilla	0.0869
13010004	Saguache	0.1226
13010005	Conejos	0.1099
13020101	Costilla	0.0852

Comments and Concerns

The procedure described above is the same as that used to determine the available soil moisture capacity GIS theme for the western slope, as part of the CRDSS project. There are two soil map units that are common between the CRDSS basins and the Rio Grande basin. A comparison was made of the two soil map units to verify techniques and to check the consistency between basins. As shown in Table 2, available moisture capacity for the two common layers are within 6 percent but are not exact. This difference can be attributed fact that while each soil unit (*Muid*) polygon is composed of approximately the same soil types, the percentages of each soil type vary by polygon.

Table 2
CRDSS/RGDSS Soil Moisture Capacity Comparison

Soil Layer Identifier (*Muid*)	RGDSS Soil Moisture Capacity	CRDSS Soil Moisture Capacity	Percent Difference
CO112	0.0557	0.0551	1.1 %
CO411	0.0485	0.0458	5.6 %

Appendix C – Filling of Key Climate Station Data

The filling of key climate station data was based on the memorandum dated October 28, 1999 from Erin Wilson and Janet Willems of Leonard Rice Consulting Water Engineers. This memorandum was originally included as Attachment D to the following report:

> Wilson, Erin, June 2004, Historic Crop Consumptive Use Analysis, Rio Grande Decision Support System, Final Report by Leonard Rice Water Consulting Engineers.

This memorandum is provided at the end of this appendix. The footnotes in this memorandum are from the original Historic Crop Consumptive Use Analysis Report and do not match the formatting in this Phase 6 memorandum.

Changes made since this memorandum are outlined below.

<u>Revisions to Appendix C Memorandum</u>

Since the development of the 1999 memorandum, there have been improvements to TSTool, changes in available climate stations, and additional data included in HydroBase.

The TSTool command files have been updated to use current commands and have been combined so as to simplify the data processing. Three TSTool command files are now used to pull and fill the climate data – temperature data (**rg2012.tem.TSTool**), precipitation data (**rg2012_pcp.TSTool**), and frost date data (**rg2012_pcp.TSTool**).

The Blanca NOAA climate station was discontinued in 2010. The nearby Blanca CoAgMet station has been used to extend the period of record for the discontinued site. The Saguache and Center NOAA climate stations were replaced in 2009. The new stations have been used to extend the period of record for the original sites.

The USBR methodology to calculate effective precipitation, discounting for misting events, has now been implemented in these modeling efforts. These methodologies are discussed in more detail in the Phase 6 RGDSS memorandum for Effective Precipitation Methodology (*RGDSS_P6_StateCU_Precipitation.pdf*). To accommodate this methodology, the precipitation data has been evaluated on a daily basis to remove misting events and then aggregated on a monthly basis.

A couple of enhancements to how missing data are filled have been implemented in the precipitation and frost date files. A dry, average, wet monthly pattern file developed from the Alamosa climate station data is being used to fill missing precipitation data at other climate stations. Daily minimum temperatures have been evaluated to fill missing spring and fall frost date information prior to filling any remaining missing information with long-term averages.

RGDSS Memorandum
Final

To: Ray Bennett, Ray Alvarado, Andy Moore

From: LRCWE, Erin Wilson and Janet Williams

Subject: Rio Grande Historic Crop Consumptive Use – Climate Data

Date: October 28, 1999

Overview

This memorandum presents the approach and results obtained for the Consumptive Use and Water Budget Component Subtask 3.1 – Select and Fill Key Climate Stations.

The estimation of potential crop consumptive use requires climate data for temperature, precipitation and frost dates. For the Rio Grande Historic Crop Consumptive Use Analysis and the Rio Grande Water Resource Planning Model Application, climate data sets were generated through a data centered approach.

General Approach

For the generation of climate data sets for RGDSS modeling, linear regression was used to fill the temperature data sets, and long-term averages were used to fill missing precipitation and frost date data for calendar years 1950 through 1997. The filling processes are described in more detail below.

Filling of Missing Values in the Temperature Data Sets

Linear regression requires dependant (to be filled) and independent (to be used as the basis for filling) data sets. Two weather stations in the Rio Grande Basin were selected for use as primary independent data sets based on their completeness of historic record during the 1950 through 1997 period and their goodness of fit coefficients (r^2) in regressions with the remaining stations. The two stations selected for use as potential primary independent data sets were:

- Alamosa WSO AP (NWS No. 130, 1948-1997) with missing values for 12 months during the 1950-1997 period.
- Del Norte (NWS No. 2184, 1948-1997) with missing values for 43 months during the 1950-1997 period.

Missing data in the Alamosa temperature data set were filled using Del Norte as the independent data set, based on its high correlation coefficient with Alamosa and because there were no missing monthly values between the two stations. The regression between Alamosa and Del Norte was performed using the DMI **tstool**. Regressions were then performed between unfilled temperature series for Alamosa and other stations, and between filled temperature series for

Alamosa and other stations. The best filling basis was determined as reflected by the largest goodness of fit parameter (r^2 – correlation coefficient squared) and the completeness of data for the 1950-1997 period. Regressions were made on all data values as one set rather than performing separate regressions for each month. Table 1 shows the goodness of fit coefficients (r^2) as well as the independent station used for filling.

All temperature station regression command files where combined to create one TSTOOL command file named *rgtempfillallcom*, shown in Exhibit A.

Table 1
Temperature Station Filling Parameters

Station to be Filled		Station used as Basis for Filling		r^2- Goodness of Fit	**tstool** Command File names
Name	NWS No.	Name	NWS No.		
Alamosa WSO AP	130	Del Norte	2184	.9915	Alamosacom
Blanca	776	Alamosafill	130	.9954	Blancacom
Center 4 SSW	1458	Alamosafill	130	.9893	Centercom
Del Norte	2184	Alamosa	130	.9915	Delnortecom
Great Sand Dunes Nat	3541	Alamosafill	130	.9885	Sanddunescom
Hermit 7 ESE	3951	Alamosa	130	.9513	Hermitcom
Manassa	5322	Alamosafill	130	.9914	Manassacom
Monte Vista 2 W	5706	Alamosafill	130	.9889	Montevistacom
Saguache	7337	Alamosafill	130	.9883	Saguachecom

Summaries

Table 2 shows historic summary information for each weather station including the period of record and number of missing temperature, precipitation, and frost date values for the period 1974 through 1996. Table 3 shows the regression equations used to fill temperature stations.

Table 2
Historic Summary of Climate Stations

Climate Station		Historic Period of Record	Number Missing Months 1950-1997		
Name	NWS No.		Temp.	Precip.	Frost Dates
Alamosa	130	1948-1997	12	11	8
Blanca	776	1948-1997	168	14	88
Center 4 SSW	1458	1948-1997	27	14	18
Del Norte	2184	1948-1997	43	16	24
Great Sand Dunes	3541	1950-1997	68	52	40
Hermit 7 ESE	3951	1948-1997	15	19	10
Manassa	5322	1948-1997	210	91	92
Monte Vista 2 W	5706	1948-1997	116	59	62
Saguache	7337	1948-1997	44	41	42

Table 3
Regression Equations used for Temperature Station Filling

Station to be Filled		Station used as Basis for Filling		
Name	NWS No.	Name	NWS No.	Linear Regression Equation
Alamosa	130	Del Norte	2184	1.133725 (Del Norte) – 7.684296
Blanca	776	Alamosafill	130	10.942873 (Alamosafill) + 3.305515
Center 4 SSW	1458	Alamosafill	130	0.961837 (Alamosafill) + 1.365141
Del Norte	2184	Alamosa	130	0.874541 (Alamosa) + 7.087797
Great Sand Dunes	3541	Alamosafill	130	0.896254 (Alamosafill) + 6.608061
Hermit 7 ESE	3951	Alamosa	130	0.928416 (Alamosa) – 4.367228
Manassa	5322	Alamosafill	130	0.921370 (Alamosafill) + 4.214111
Monte Vista 2 W	5706	Alamosafill	130	0.945732 (Alamosafill) + 2.241404
Saguache	7337	Alamosafill	130	0.907345 (Alamosafill) + 4.937711

Results

As shown in Table 1, a good linear correlation was found between temperature stations, therefore linear regression was used to fill missing temperature values in the temperature data set. A linear relationship was not clear for precipitation and frost date data. Figures 1 and 2 show examples of the poor precipitation relationships found between Alamosa and Del Norte climate stations and between Center and Alamosa climate stations. Figures 3 through 6 show examples of the poor spring and fall frost date relationships found between Alamosa and Del Norte climate stations and between Center and Alamosa climate stations, therefore, tstool was used to fill missing precipitation values with average monthly values for the period of record, and fill missing frost date values with average frost date values for the period of record.

Figure 1
Alamosa vs Del Norte Precipitation
1950-1997 April through October Data

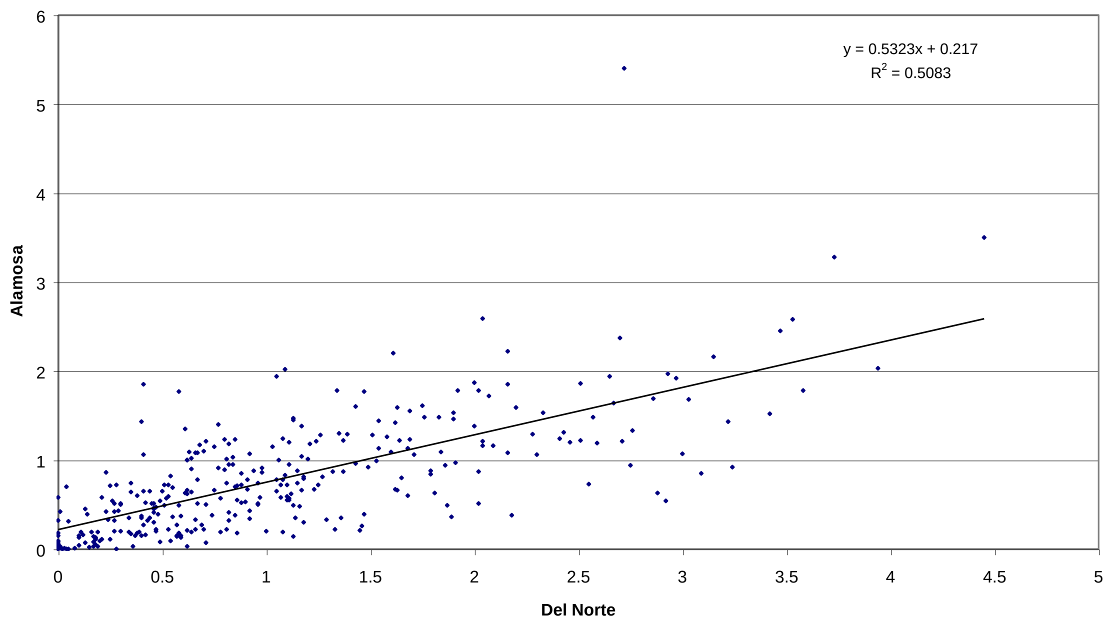


Figure 2
Center vs Alamosa Precipitation
1950-1997 April through October Data

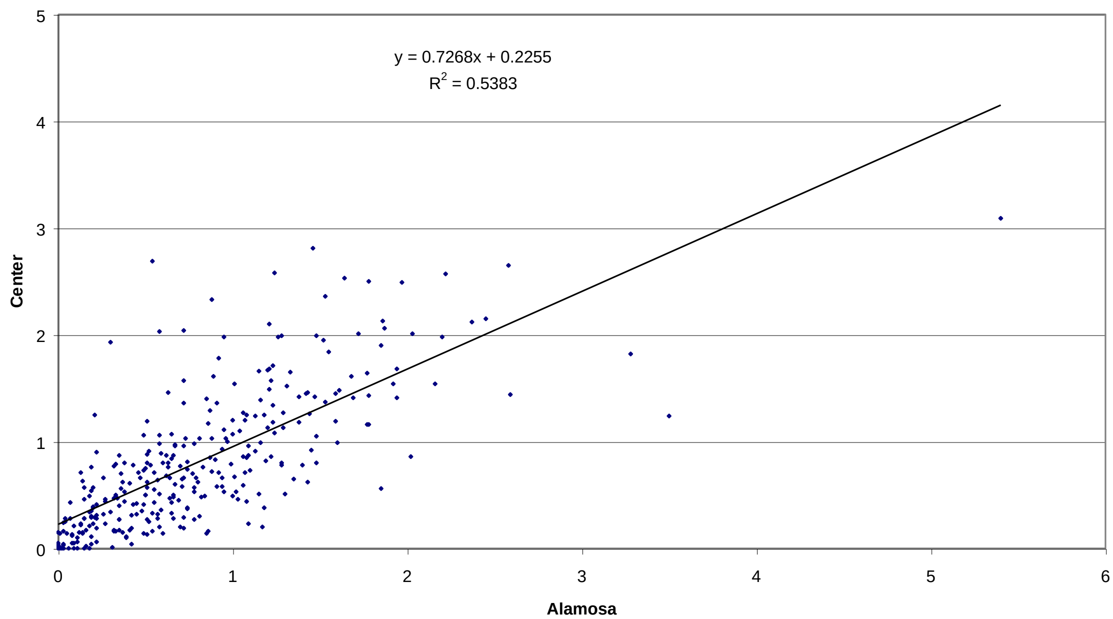


Figure 3
Spring 28 Deg Frost Dates
Alamosa vs Del Norte

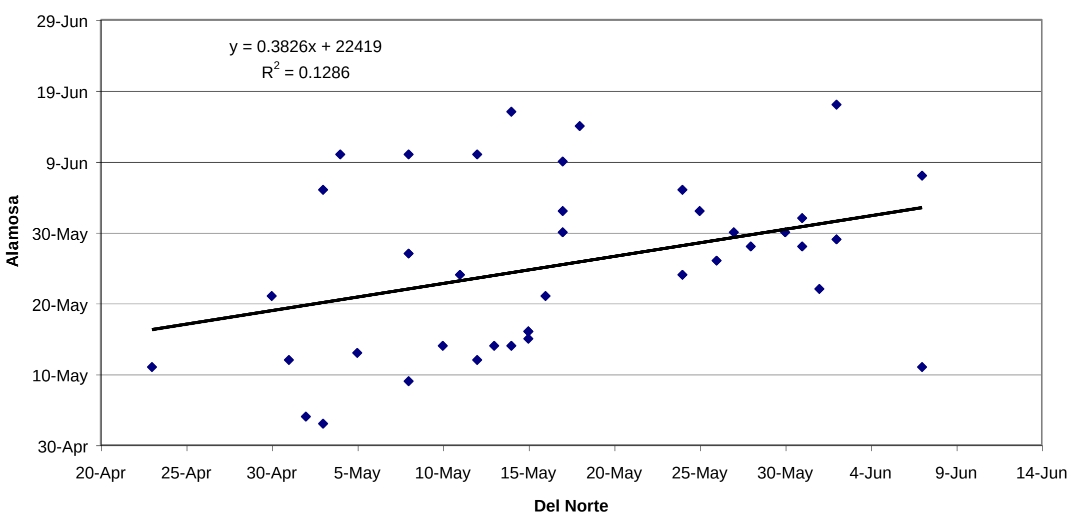


Figure 4
Fall 28 Deg Frost Dates
Alamosa vs Del Norte

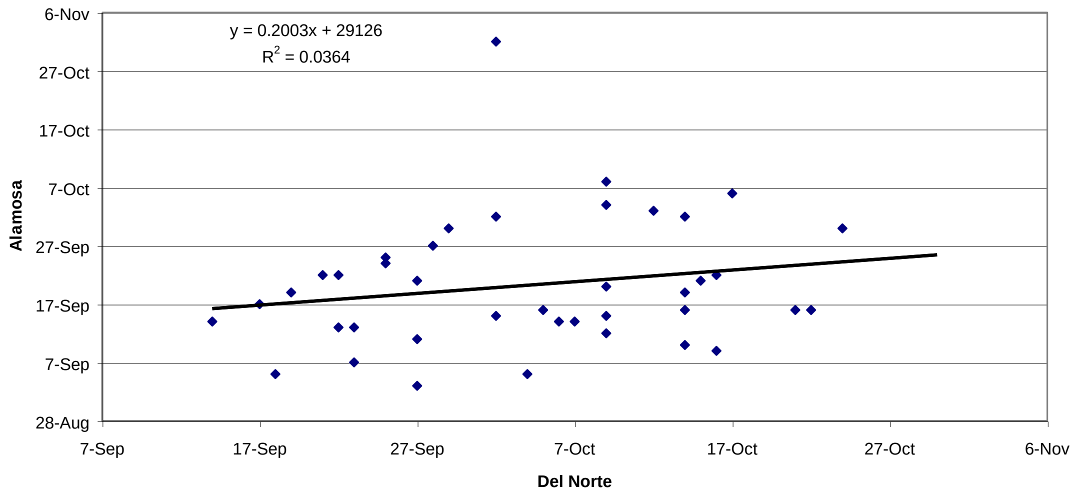


Figure 5
Spring 28 Deg Frost Dates
Center vs Alamosa

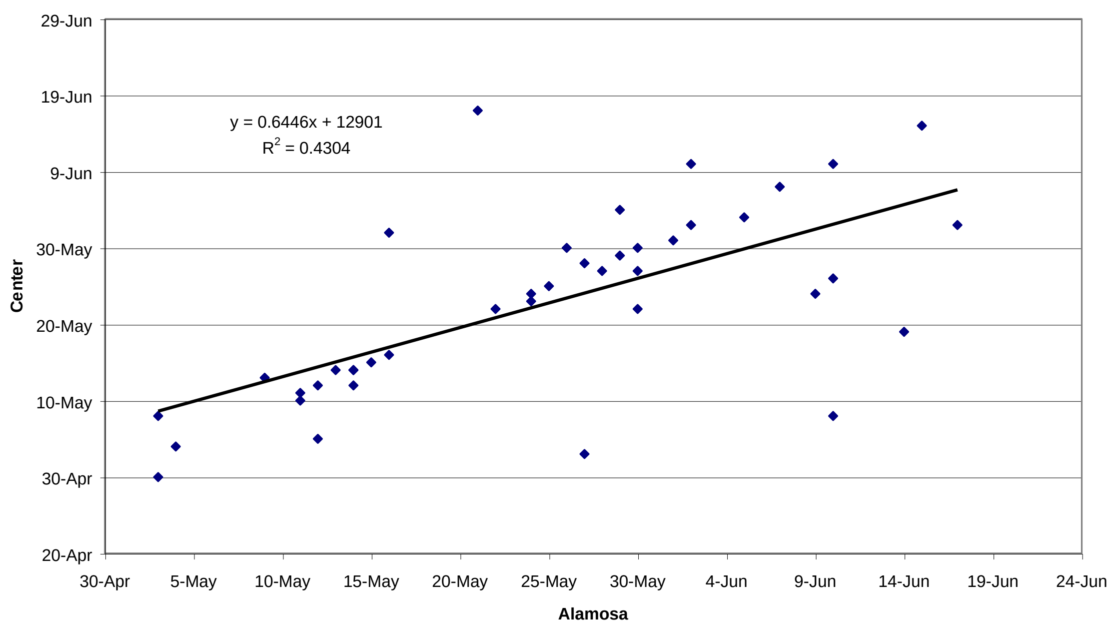


Figure 6
Fall 28 Deg Frost Dates
Center vs Alamosa

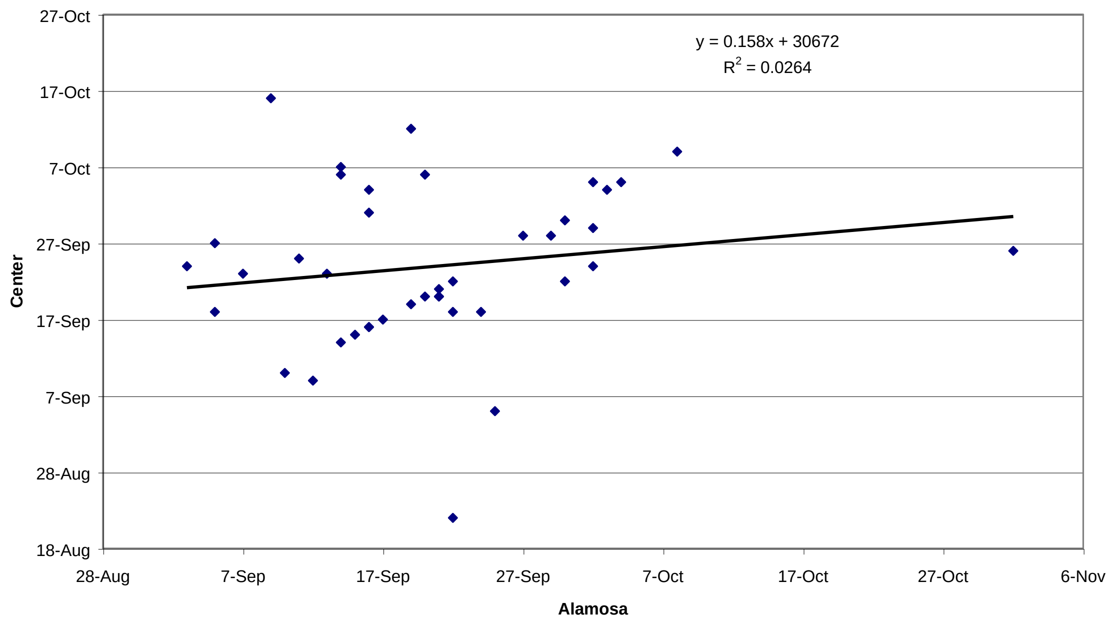


Table 4 shows the average annual temperature, precipitation, and frost dates for the filled data sets for 1950 through 1997. The spreadsheet rgclimfill.xls contains the following information for each climate station:

- Graph illustrating the temperature data correlation between each dependent station and the best-fit independent station
- Matrix of temperature data for 1950 through 1997, with the filled values shaded
- Matrix of precipitation data for 1950 through 1997, with the filled values shaded. Note that the averages shown in these matrices are the average from 1950 through 1997. The missing values were filled using the average over the entire period of record.
- Matrix of complete frost date data for 1950 through 1997, with the filled dates shaded. Note that the averages shown in these matrices are the average from 1950 through 1997. The missing values were filled using the average over the entire period of record.

Table 4
Average Annual Filled Values 1950 to 1997

Climate Station		Average Annual Filled Values 1950 – 1997					
				Frost Dates – Degrees F			
Name	NWS No.	Temperature (Degrees F)	Precipitation (Inches)	Spring 28 Deg	Spring 32 Deg	Fall 32 Deg	Fall 28 Deg
Alamosa	130	41.2	7.19	May 25	Jun 6	Sep 8	Sep 20
Blanca	776	42.2	8.39	May 19	Jun 8	Sep 12	Sep 25
Center 4 SSW	1458	41.0	7.12	May 21	Jun 7	Sep 10	Sep 24
Del Norte	2184	43.2	9.98	May 15	May 30	Sep 23	Oct 4
Great Sand Dunes	3541	43.6	10.96	May 13	May 31	Sep 23	Oct 4
Hermit 7 ESE	3951	33.9	15.24	Jun 27	Jul 7	Aug 2	Aug 21
Manassa	5322	42.2	7.53	May 25	Jun 9	Sep 8	Sep 18
Monte Vista 2 W	5706	41.2	7.49	May 22	June 7	Sep 11	Sep 21
Saguache	7337	42.4	8.50	May 20	Jun 4	Sep 15	Sep 29

Comments and Concerns

None.

Exhibit A – Tstool Command File for Temperature Regression

```
#HeaderRevision 0
#
# File generated by...
# program:   TSTool 3.09.00 (16 Feb 1999) Java
# user:      Janet Williams
# date:      Thu May 13 19:15:31  1999
# host:      host unknown
# directory: D:\CRDSS\bin
# command:   TSTool -home d:\CRDSS -helpindex
#            http://greenmtn.state.co.us/manuals\tstool\tstool_help_index.txt
#            -dbhost localpc -dbmiddleware ODBC_ACCESS -browser
#            C:\PROGRA~1\NETSCAPE\COMMUN~1\PROGRAM\NETSCAPE.EXE -archive_dbhost
#            greenmtn.state.co.us -archive_dbmiddleware Borland
#-------------------------------------------------
01/1948 12/1997
-missing -999.0
-units DFLT
-cy
# perform regress operation on the following
# (1948-1997) ALAMOSA WSO AP  NOAA  MeanTemp  Monthly
# (1948-1997) DEL NORTE  NOAA  MeanTemp  Monthly
regress(0130..TAVG.MONTH.,2184..TAVG.MONTH.)
# perform regress operation on the following
# (1960-1997) BLANCA  NOAA  MeanTemp  Monthly
# (1948-1997) D:\JPW\ClimCorr\alamosafill.stm  StateMod  StateMod  Monthly
regress(0776..TAVG.MONTH.,0130.StateMod..MONTH.D:\JPW\ClimCorr\alamosafill.stm)
# perform regress operation on the following
# (1948-1997) CENTER 4 SSW  NOAA  MeanTemp  Monthly
# (1948-1997) D:\JPW\ClimCorr\alamosafill.stm  StateMod  StateMod  Monthly
regress(1458..TAVG.MONTH.,0130.StateMod..MONTH.D:\JPW\ClimCorr\alamosafill.stm)
# perform regress operation on the following
# (1948-1997) DEL NORTE  NOAA  MeanTemp  Monthly
# (1948-1997) ALAMOSA WSO AP  NOAA  MeanTemp  Monthly
regress(2184..TAVG.MONTH.,0130..TAVG.MONTH.)
# perform regress operation on the following
# (1950-1997) GREAT SAND DUNES NAT  NOAA  MeanTemp  Monthly
# (1948-1997) D:\JPW\ClimCorr\alamosafill.stm  StateMod  StateMod  Monthly
regress(3541..TAVG.MONTH.,0130.StateMod..MONTH.D:\JPW\ClimCorr\alamosafill.stm)
# perform regress operation on the following
# (1948-1997) HERMIT 7 ESE  NOAA  MeanTemp  Monthly
# (1948-1997) ALAMOSA WSO AP  NOAA  MeanTemp  Monthly
regress(3951..TAVG.MONTH.,0130..TAVG.MONTH.)
# perform regress operation on the following
# (1948-1997) MANASSA  NOAA  MeanTemp  Monthly
# (1948-1997) D:\JPW\ClimCorr\alamosafill.stm  StateMod  StateMod  Monthly
regress(5322..TAVG.MONTH.,0130.StateMod..MONTH.D:\JPW\ClimCorr\alamosafill.stm)
# perform regress operation on the following
# (1948-1997) MONTE VISTA 2 W  NOAA  MeanTemp  Monthly
# (1948-1997) D:\JPW\ClimCorr\alamosafill.stm  StateMod  StateMod  Monthly
regress(5706..TAVG.MONTH.,0130.StateMod..MONTH.D:\JPW\ClimCorr\alamosafill.stm)
# perform regress operation on the following
# (1948-1997) SAGUACHE  NOAA  MeanTemp  Monthly
# (1948-1997) D:\JPW\ClimCorr\alamosafill.stm  StateMod  StateMod  Monthly
regress(7337..TAVG.MONTH.,0130.StateMod..MONTH.D:\JPW\ClimCorr\alamosafill.stm)
```

Appendix D - Rio Grande Historic Crop Consumptive Use - Calibration of Blaney-Criddle Coefficients

The Calibration of Blaney – Criddle coefficients was based on the memorandum dated December 19, 1999 from Erin Wilson and Janet Willems of Leonard Rice Consulting Water Engineers. This memorandum was originally included as Attachment F to the following report:

> Wilson, Erin, June 2004, Historic Crop Consumptive Use Analysis, Rio Grande Decision Support System, Final Report by Leonard Rice Water Consulting Engineers.

This memorandum is provided at the end of this appendix. The footnotes in this memorandum are from the original Historic Crop Consumptive Use Analysis Report and do not match the formatting in this Phase 6 memorandum.

Changes made since this memorandum are outlined below.

Revisions to Appendix D Memorandum

Crop parameters for some of these crops were modified in Phase 6 as detailed in the StateCU memorandum for Crop Irrigation Requirements (*RGDSS_P6_StateCU_ETMemo.pdf*). Development of crop coefficients and parameters for additional Phase 6 crops is discussed in the RGDSS Memorandum for Additional Crops (*RGDSS_P6_AdditionalCrops.pdf*).

RGDSS Memorandum
Final

To: Ray Bennett, Ray Alvarado, Andy Moore

From: LRCWE, Erin Wilson and Janet Williams

Subject: Rio Grande Historic Crop Consumptive Use - Calibration of Blaney-Criddle Coefficients

Date: December 19, 1999

Introduction

This memorandum describes the approach and results for Task 2.8 – Calibration of Blaney-Criddle Coefficients. The Modified Hargreaves Evapotranspiration method, developed by Agro Engineering, Incorporated (Agro), uses local crop coefficients to provide what is believed to be a good estimate of crop potential consumptive use in the San Luis Valley. The crop coefficients were developed based on comparisons made with local lysimeter data. The Modified Hargreaves method requires daily climatological data, including solar radiation, wind speed, temperature, and precipitation. However, the availability of solar radiation and wind speed data is limited.

The Blaney-Criddle calculation uses monthly temperature data to determine crop potential consumptive use. Since monthly temperature data is readily available from climate stations in the San Luis Valley, the Blaney-Criddle method was chosen to estimate crop consumptive use for the RGDSS project. Blaney-Criddle crop parameters were revised to yield results more consistent with Modified Hargreaves estimates. Results using these calibrated coefficients are believed to provide a good estimate of actual crop consumptive use in the San Luis Valley.

Approach

The following approach was used to develop local Blaney-Criddle crop coefficients for the San Luis Valley:

- Identify and obtain available climate data
- Identify crops in the San Luis Valley
- Review Agro Engineering's Modified Hargreaves method
- Compare the Modified Hargreaves ET estimates with Blaney-Criddle ET estimates. ET estimates reported herein reflect gross potential consumptive use and, therefore, are not reduced for precipitation.
- Adjust the various crop growing seasons to better represent the growing seasons in the San Luis Valley
- Adjust the Blaney-Criddle crop coefficients to better represent crop ET results predicted using the Modified Hargreaves method

Identify and Obtain Climate Data

Daily climate data required for Modified Hargreaves calculations are available for three stations in the Rio Grande basin. The Center CoAgMet station was chosen for use in the calibration of Blaney-Criddle crop coefficients due to its length of record and central location within the basin. Table 1 shows these stations and the associated period of record.

Table 1
Climate Stations with Solar Radiation and Wind Records

Station Name and Identifier	Period of Record
Center CoAgMet station (CTR01)	1980 to present
Blanca CoAgMet station (BLA01)	1997 to present
Agro Engineering Meteorological Station (AGRO)	1992 to present

Identify Crops in the San Luis Valley

According to Agro Engineering, crops in the San Luis Valley can generally be classified into the following four categories:

- Alfalfa
- Pasture grass
- Pototaoes
- Small Grains

Small grains include both wheat and barley. Vegetables are also grown in the San Luis Valley, however, their acreage is relatively minor when compared to the four crop types shown above.

Modified Hargreaves Evapotranspiration Method

Hargreaves (1975) developed an empirical method for determining reference evapotranspiration (ETo) for an Alta fescue grass crop. This method requires daily temperature and radiation data. Agro modified the original Hargreaves equations to recognize the effects of wind. The resulting Modified Hargreaves equation provided better calibration with local conditions in the San Luis Valley:

$$ETo = (F * Rs * Tavg)/1498.6$$

where **Rs** is the incoming short wave solar radiation in langleys (cal/cm2/day) and **Tavg** is the average daily temperature in degrees Fahrenheit. The 1498.6 term represents the latent heat of vaporization at 55 degrees Fahrenheit multiplied by the density of water. The latent heat of vaporization term converts the solar radiation from langleys to inches of water per day. The following wind function, **F**, was developed for the San Luis Valley:

$$F = \begin{cases} 0.0080 & \text{If } U_2 < 80 \\ 0.0085 & \text{If } 80 \le U_2 \le 120 \\ 0.0090 & \text{If } U_2 > 120 \end{cases}$$

where $\mathbf{U_2}$ represents the wind run at a two meter height in miles per day. The wind function **F** has units of ($^{o}F^{-1}$).

A crop coefficient is used to convert the reference ET into the actual ET used by the crop. The crop coefficients are a function of crop variety, canopy development, and stage of growth. The actual ET is calculated as follows:

$$ET = Kc * ETo$$

where **Kc** is the crop coefficient for a crop growing under conditions of optimum fertility and soil moisture and achieving full production and water use potential. The crop coefficient is calculated as follows:

$$Kc = \begin{cases} K1 & \text{If } D_{plant} \le D \le D_{10\%} \\ K1+(K2-K1) * (D-D_{10\%})/(D_{cover}-D_{10\%}) & \text{If } D_{10\%} < D < D_{cover} \\ K2 & \text{If } D_{cover} \le D \le D_{mature} \\ K2+(K3-K2) * (D-D_{mature})/(D_{harvest}-D_{mature}) & \text{If } D_{mature} \le D \le D_{harvest} \\ K3 & \text{If } D_{harvest} \le D \end{cases}$$

where **D** is the current day of the year, $\mathbf{D_{10\%}}$ is the date of 10 percent cover, $\mathbf{D_{cover}}$ is the date of effective full cover, $\mathbf{D_{mature}}$ is the date of the start of maturity, and $\mathbf{D_{harvest}}$ is the date of harvest. Note that for alfalfa and pasture grass, **D** can exceed the harvest date. **K1**, **K2**, and **K3** are the values of the crop coefficient at 10 percent cover, effective full cover, and harvest respectively.

Agro has developed Modified Hargreaves crop coefficients for several varieties of potatoes, wheat, barley, and alfalfa. Table 2 shows the Modified Hargreaves crop coefficients for a normal year.

Table 2
Crop Coefficients for a Normal Year
Agro Engineering, Inc.

Crop	Variety	Plant Date	Growth Rate – Days to: 10% Cover	80% Cover	Maturity	Harvest	Crop Coefficients K1	K2	K3
Potato	Norkotah	05/05	30	55	85	110	0.20	1.10	0.50
Potato	Norkotah	05/12	30	55	85	110	0.20	1.10	0.50
Potato	Nugget	05/01	32	60	100	125	0.20	1.00	0.75
Potato	Nugget	05/08	32	60	100	125	0.20	1.00	0.75
Potato	Centennial	05/10	40	60	95	115	0.20	1.05	0.75
Potato	Sangre	05/10	30	55	85	110	0.20	1.10	0.75
Barley	Moravian	04/10	20	45	85	120	0.20	1.05	0.20
Barley	Moravian	05/10	15	40	80	115	0.20	1.05	0.20
Wheat	Oslo	04/05	20	45	90	125	0.30	1.05	1.00
Wheat	Oslo	05/01	15	35	85	120	0.30	1.05	1.00
Wheat	Centennial	04/10	25	55	100	140	0.30	1.05	1.00
Wheat	Centennial	05/10	15	40	85	130	0.30	1.05	1.00
Winter Wheat	Tomahawk	Fall	15	20	80	95	0.30	1.05	0.20
Alfalfa	Alfalfa	1 Yr +	10	15	125	170	0.50	1.20	1.00

According to Agro, the Nugget variety of potatoes is the most prominent in the San Luis Valley, therefore the averaged parameters for the two Nugget varieties were used during the crop parameter calibration process. The averaged parameters of the two Moravian varieties of barley and the averaged parameters for the four wheat varieties were used during the crop parameter calibration process.

Alta fescue grass is the reference crop, which is the predominant variety of "pasture grass" grown in the San Luis Valley. ET for pasture grass can be determined using Modified Hargreaves crop coefficients equal to 1.0. To account for the irrigation practices and define the growing season, the percentages shown in Table 3 were applied to the reference ET per Agro recommendations.

Table 3
Percent of Reference ET Used to Estimate Pasture Grass ET

Month(s)	Percent of Reference ET
January through March	0 %
April	25 %
May	65 %
June through September	100 %
October	65 %
November through December	0 %

Modified Hargreaves coefficients have not been determined by Agro for vegetables. Through discussions with Agro, it was decided to use the original TR-21 Blaney-Criddle crop characteristics and crop coefficients to determine ET for vegetables in the San Luis

Valley since vegetable acreage is such a small percent of the total cropped acreage, and local information for use in crop calibration is not available.

Modified Hargreaves and Blaney-Criddle Comparisons

The Modified Hargreaves option in StateCU was used to determine the Modified Hargreaves ET estimates at the Center climate station from 1984 through 1998. Note that ET could not be determined for the years 1981, 1982, 1983, 1991, 1995 and 1996 due to missing daily values during the irrigation season. Therefore, the total number of years used for the calibration process was thirteen.

Monthly average temperature values were determined from the daily temperature data measured at the Center climate station (CTR01) and formatted for use in the StateCU Blaney-Criddle calculations. ET estimates for pasture grass, alfalfa, potatoes, barley, and wheat were determined using both methods. The Blaney-Criddle crop parameters used for this comparison were as published in TR-21. Table 4 summarizes the annual results for both methods and the percent difference compared to Modified Hargreaves results for the period 1984 through 1998.

Table 4
Modified Hargreaves and Blaney-Criddle ET Estimates
1980, 1984-1990, 1992-1994, 1997-1998 Annual Averages

Crop	Modified Hargreaves (inches)	Modified Blaney-Criddle (inches)	Percent Difference
Alfalfa (2 cuttings)	31.2	19.3	38.1 %
Potatoes	16.3	10.7	34.4 %
Barley (Spring Grains)	16.9	13.9	17.8 %
Wheat (Spring Grains)	21.9	13.9	36.5 %
Pasture Grass	29.3	18.3	37.5 %

As shown, the Modified Hargreaves ET estimates are significantly higher than the Blaney-Criddle estimates for the crop types compared. Figures 1 through 5 show the average monthly Blaney-Criddle ET estimates, using TR-21 crop parameters, compared to the Modified Hargreaves average monthly ET estimates for the period 1984 through 1998 using the Center climate station.

Calibrate Blaney-Criddle Crop Parameters

Calibration of Blaney-Criddle crop parameters was accomplished in two steps. First, the average growing season was adjusted to match the season parameters provided by Agro. Next the Blaney-Criddle crop coefficients were adjusted so that average monthly ET values determined using the Blaney-Criddle approach matched reasonably well with average monthly ET values determined using the Modified Hargreaves approach.

For the Blaney-Criddle procedure, the crop growing season is based on frost dates or average temperatures reported in TR-21 for a variety of crops. The maximum length of growing season may override the ending date determined based on frost dates or average temperature. The Modified Hargreaves coefficients are derived based on the average planting date for each crop type in the San Luis Valley.

To match Blaney-Criddle estimates with Agro's season parameters, the average monthly values for the 1984 through 1998 period for both methods were graphed and compared, as shown in Figures 1 through 5. The Blaney-Criddle method uses either mean temperature or frost dates (32 degree F or 28 degree F) to predict the beginning of the growing season, depending on crop type. The end of the growing season is determined based on either the length of growing season or an ending temperature or frost date.

In the cases where the Blaney-Criddle average growing season did not match Agro's estimated average growing season, the beginning and ending temperatures and length of season values were adjusted to values so that results were more consistent with the start and end dates predicted by the Modified Hargreaves method. This iterative process was accomplished by adjusting the StateCU crop characteristics input file until the seasons matched closely.

Table 5 shows the TR-21 beginning and ending temperatures and length of season values and the values determined through the calibration process. Figures 6 and 7 show the results of this step on an average monthly basis for the 1984 through 1998 period using the Center climate station for alfalfa and potatoes. Pasture grass, barley and wheat did not require season adjustments.

Table 5
Season Beginning Temperature, Ending Temperature, and Length
TR-21 and Revised to Reflect Local Conditions

	Beginning Temperature (Degrees Farenheit)		Ending Temperature (Degrees Farenheit)		Length of Season (Days)	
Crop	TR-21	Calibrated	TR-21	Calibrated	TR-21	Calibrated
Alfalfa	50	45	28	28	365	365
Potatoes	60	50	32	32	130	130
Barley	45	45	32	32	130	130
Wheat	45	45	32	32	130	130
Pasture Grass	45	45	45	45	365	365

Note that the TR-21 coefficients for barley and wheat are from the TR-21 spring grain category. Table 6 shows the Modified Hargreaves estimates compared to the Blaney-Criddle estimates with adjusted growing season parameters and the percent difference for Alfalfa and Potatoes.

Table 6
Modified Hargreaves and Blaney-Criddle with Adjusted Growing Season ET Estimates, 1980, 1984-1990, 1992-1994, 1997-1998 Annual Averages

Crop	Modified Hargreaves	Blaney-Criddle w/ adjusted growing season	Percent Difference
Alfalfa	31.2	20.8	33.3 %
Pototatoes	16.3	16.5	1.2 %

After the season beginning temperatures, ending temperatures, and lengths were adjusted, the TR-21 Blaney-Criddle crop coefficients were adjusted so ET estimated by the Blaney-Criddle method would closely match the Modified Hargreaves estimates. The procedure was as follows:

1. The monthly average Modified Hargreaves ET estimates were divided by the monthly average Blaney-Criddle ET estimates.
2. The resulting factor was either applied to the monthly Blaney-Criddle crop coefficients, or converted to factors for percent of growing season and applied to the percent of growing season coefficients.
3. Blaney-Criddle ET calculations were performed again, using StateCU, and the monthly average gross potential consumptive use values were compared to the Modified Hargreaves estimates.
4. If monthly values were still significantly different, the percent difference was applied to the pertinent crop coefficients and ET calculations performed again.

Figures 8 through 12 show the average monthly resulting Blaney-Criddle ET estimates compared to the Modified Hargreaves ET estimates for the period 1984 through 1996 for each crop type using the Center climate station. Tables 7 through 11 shows the TR-21 Blaney-Criddle crop coefficients compared to the calibrated crop coefficients for alfalfa, potatoes, barley, wheat, and pasture grass.

Table 7
TR-21 and Calibrated Crop Coefficients for Alfalfa

Day of the Year	Crop Coefficients	
	TR-21	Calibrated
1	0.600	0.600
15	0.630	0.630
32	0.680	0.680
46	0.730	0.730
60	0.790	0.790
74	0.850	0.850
91	0.920	0.420
105	0.990	0.450
121	1.045	1.950
135	1.090	2.020
152	1.120	1.870
166	1.135	1.890
182	1.130	1.430
196	1.115	1.410
213	1.090	1.570
227	1.065	1.540
244	1.030	1.400
258	0.990	1.360
274	0.950	1.430
288	0.905	1.360
305	0.850	0.850
319	0.790	0.790
335	0.720	0.720
349	0.640	0.640
366	0.600	0.600

Table 8
TR-21 and Calibrated Crop Coefficients for Potatoes

Percent of Growing Season	Crop Coefficients	
	TR-21	Calibrated
0	0.200	0.400
5	0.220	0.440
10	0.250	0.480
15	0.280	0.550
20	0.330	0.610
25	0.400	0.730
30	0.500	0.870
35	0.640	1.030
40	0.790	1.150
45	0.900	1.250
50	0.970	1.340
55	1.010	1.450
60	1.020	1.420
65	1.000	1.380
70	0.940	1.310
75	0.880	1.230
80	0.800	1.490
85	0.730	1.030
90	0.660	0.670
95	0.570	0.400
100	0.490	0.240

Table 9
TR-21 and Calibrated Crop Coefficients for Barley

Percent of Growing Season	Crop Coefficients	
	TR-21	Calibrated
0	0.280	0.150
5	0.350	0.190
10	0.460	0.400
15	0.580	0.620
20	0.710	0.910
25	0.830	1.250
30	0.940	1.210
35	1.040	1.400
40	1.150	1.600
45	1.250	1.800
50	1.310	1.960
55	1.310	2.020
60	1.270	1.520
65	1.180	1.330
70	1.040	1.100
75	0.870	0.860
80	0.690	0.640
85	0.500	0.510
90	0.300	0.300
95	0.130	0.130
100	0.000	0.000

Table 10
TR-21 and Calibrated Crop Coefficients for Wheat

Percent of Growing Season	Crop Coefficients	
	TR-21	Calibrated
0	0.280	0.570
5	0.350	0.700
10	0.460	0.850
15	0.580	1.000
20	0.710	1.150
25	0.830	1.310
30	0.940	1.440
35	1.040	1.540
40	1.150	1.660
45	1.250	1.740
50	1.310	1.770
55	1.310	1.540
60	1.270	1.440
65	1.180	1.290
70	1.040	1.520
75	0.870	1.600
80	0.690	1.870
85	0.500	1.590
90	0.300	1.070
95	0.130	0.460
100	0.000	0.000

Table 11
TR-21 and Calibrated Crop Coefficients for Pasture Grass

Day of the Year	Crop Coefficients	
	TR-21	Calibrated
1	0.480	0.480
15	0.470	0.470
32	0.525	0.525
46	0.575	0.575
60	0.640	0.640
74	0.740	0.740
91	0.815	1.880
105	0.855	1.970
121	0.880	1.210
135	0.900	1.230
152	0.915	1.600
166	0.920	1.610
182	0.925	1.350
196	0.925	1.350
213	0.915	1.310
227	0.905	1.290
244	0.890	1.540
258	0.870	1.500
274	0.840	2.210
288	0.795	2.090
305	0.735	0.735
319	0.670	0.670
335	0.605	0.605
349	0.550	0.550
366	0.480	0.480

During the irrigated lands assessment, it was difficult to distinguish between barley, wheat, and other small grains. These crops were grouped into a “small grains” category. As with barley and wheat, the season beginning average temperature is 45 degrees Farenheit, the season ending frost date is 32 degrees Farenheit, and the growing season is 130 days. The crop coefficients used for this category are an average of the calibrated coefficients for wheat and barley, shown in Table 12.

Table 12
Calibrated Crop Coefficients for Small Grains

Percent of Growing Season	Calibrated Crop Coefficients
0	0.360
5	0.450
10	0.630
15	0.810
20	1.030
25	1.280
30	1.330
35	1.470
40	1.630
45	1.770
50	1.860
55	1.780
60	1.480
65	1.310
70	1.310
75	1.230
80	1.260
85	1.050
90	0.690
95	0.300
100	0.000

Results

As shown in Figures 8 through 12, average monthly values for ET using locally calibrated Blaney-Criddle crop parameters agree closely with the Modified Hargreaves estimates. Figures 13 through 17 show the same results for the period 1984 through 1998 based on the Center climate station. The average annual ET estimates for the 1984 through 1998 time period using the Blaney-Criddle calculations with the calibrated crop parameters are within 0.2 inch of the Modified Hargreaves average annual estimates for the crop types considered, as shown in Table 13. Monthly and annual values for individual years tend to vary more between the two methods because the Blaney-Criddle method depends upon mean temperature for beginning, and in some cases, ending dates. The Modified Hargreaves method (Agro) reported fixed planting dates and season lengths that represent an average for the San Luis Valley.

Table 13
Calibrated Blaney-Criddle and Modified Hargreaves ET Estimates
1980, 1984-1990, 1992-1994, 1997-1998 Annual Averages

Crop	Modified Hargreaves (inches)	Calibrated Blaney-Criddle (inches)	Difference (inches)
Alfalfa (2 cuttings)	31.2	31.0	0.2
Potatoes	16.3	16.5	0.2
Barley (Spring Grains)	16.9	16.9	0.0
Wheat (Spring Grains)	21.9	22.0	0.1
Pasture Grass	29.3	29.1	0.2

Comments and Concerns

None.

Figure 1
Average Monthly Alfalfa ET - Modified Hargreaves and Blaney-Criddle using TR-21 Crop Parameters

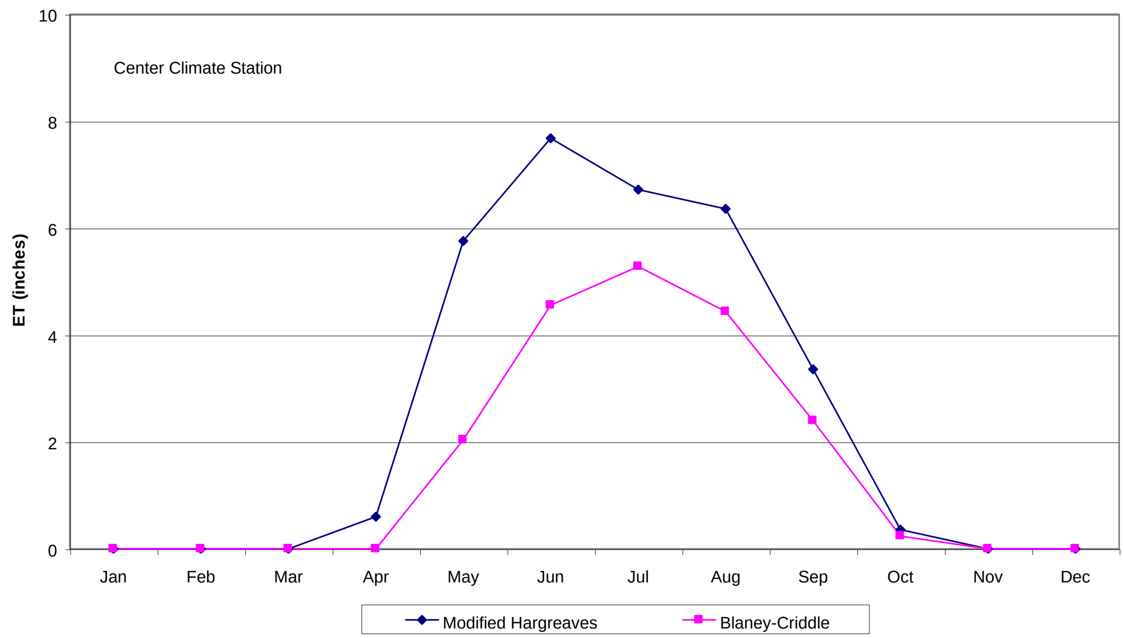


Figure 2
Average Monthly Potato ET - Modified Hargreaves and Blaney-Criddle using TR-21 Crop Parameters

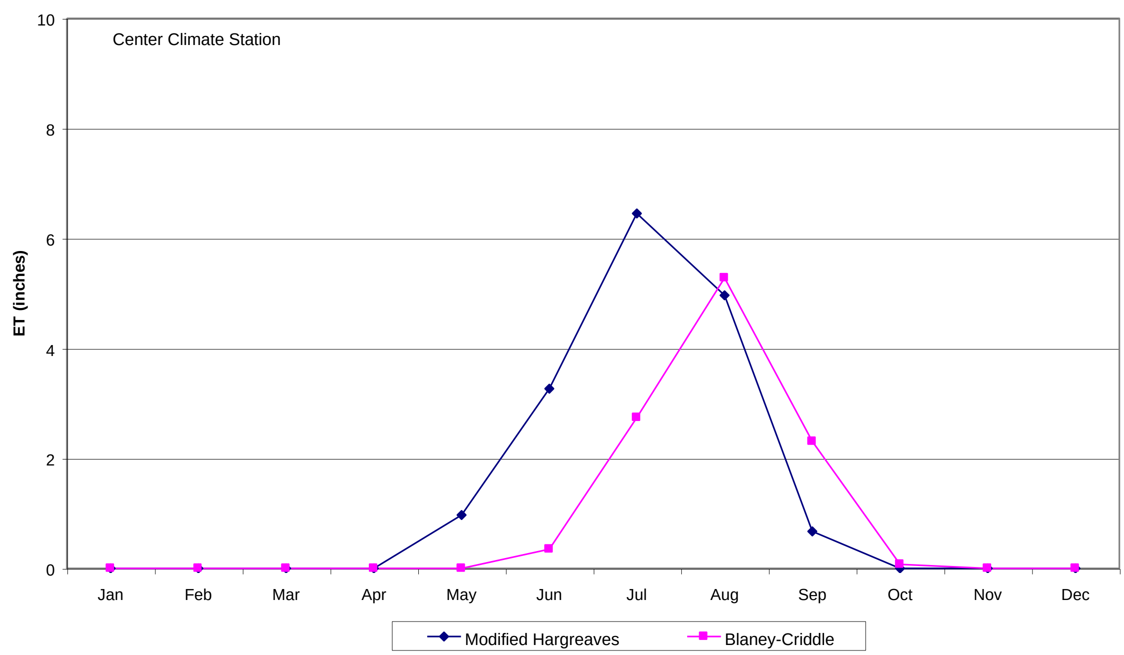


Figure 3
Average Monthly Barley ET - Modified Hargreaves and Blaney-Criddle using TR-21 Crop Parameters

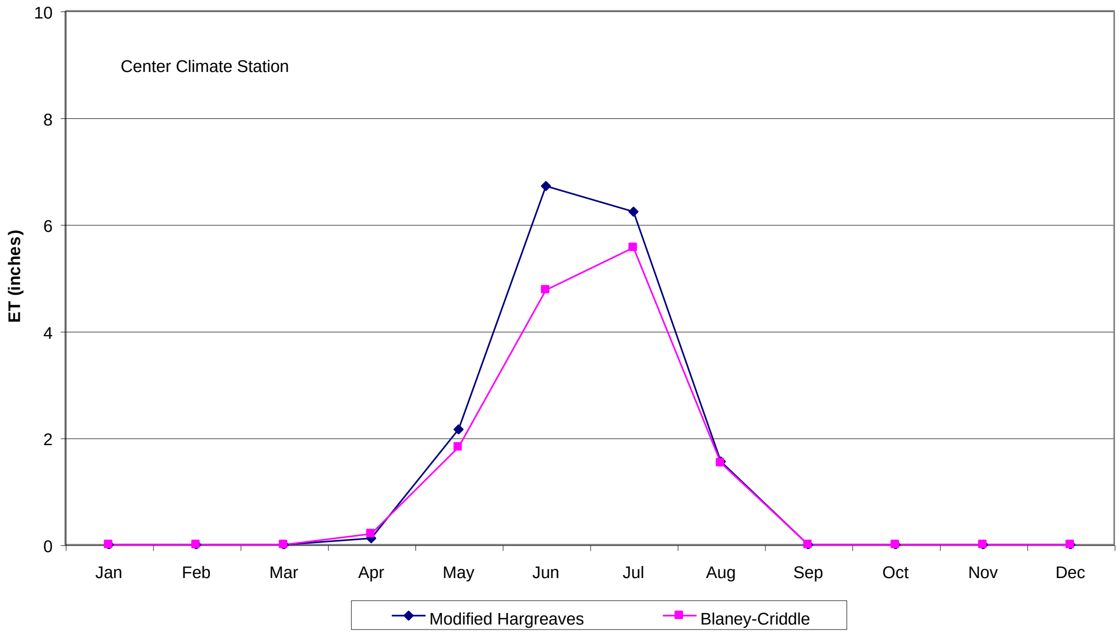


Figure 4
Average Monthly Wheat ET - Modified Hargreaves and Blaney-Criddle using TR-21 Crop Parameters

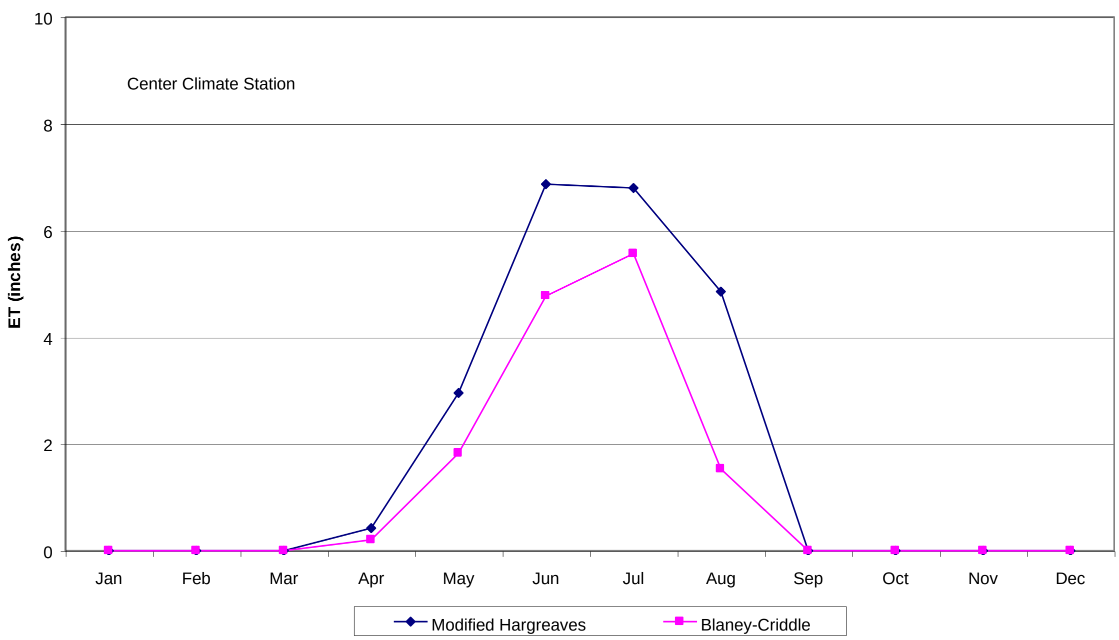


Figure 5
Average Monthly Pasture Grass ET - Modified Hargreaves and Blaney-Criddle using TR-21 Crop Parameters

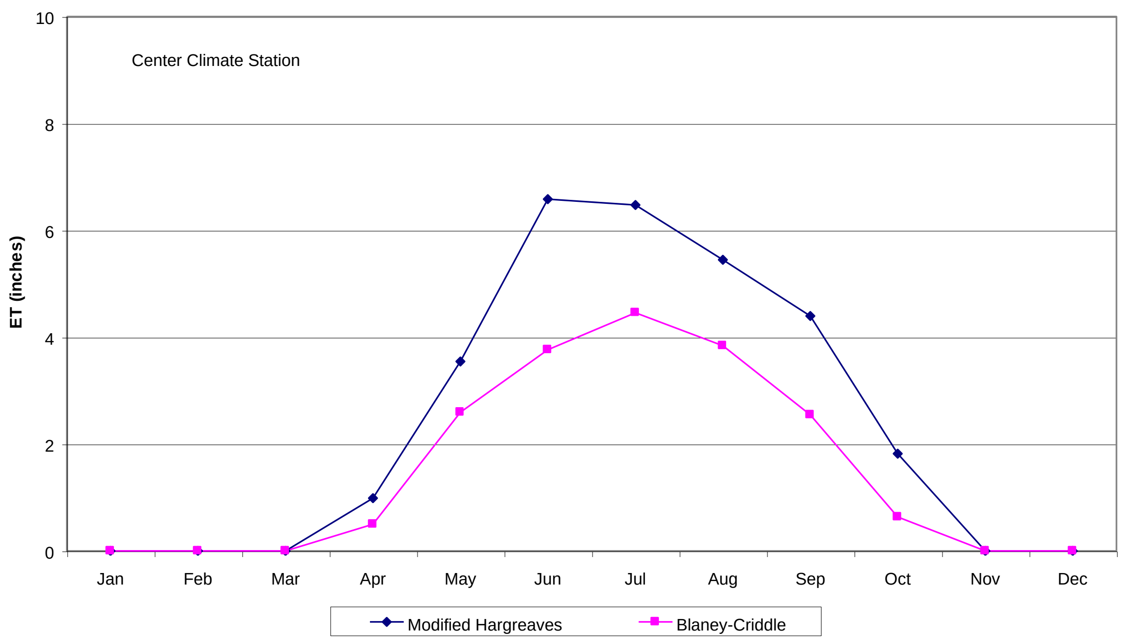


Figure 6
Average Monthly Alfalfa ET - Modified Hargreaves and Blaney-Criddle w/ Revised Season Parameters

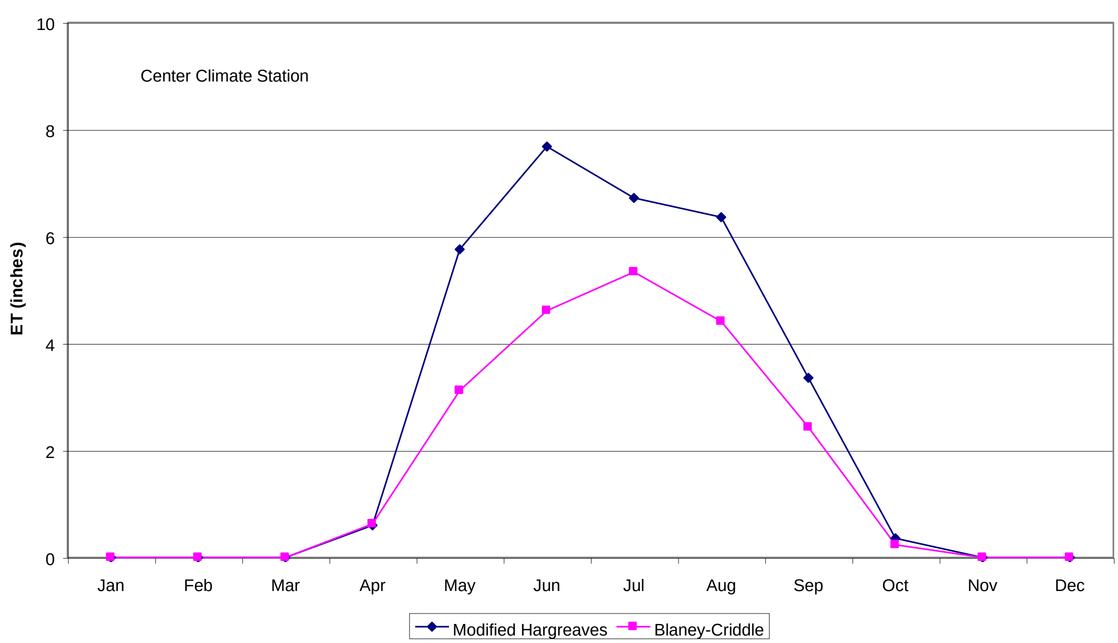


Figure 7
Average Monthly Potato ET - Modified Hargreaves and Blaney-Criddle w/ Revised Season Parameters

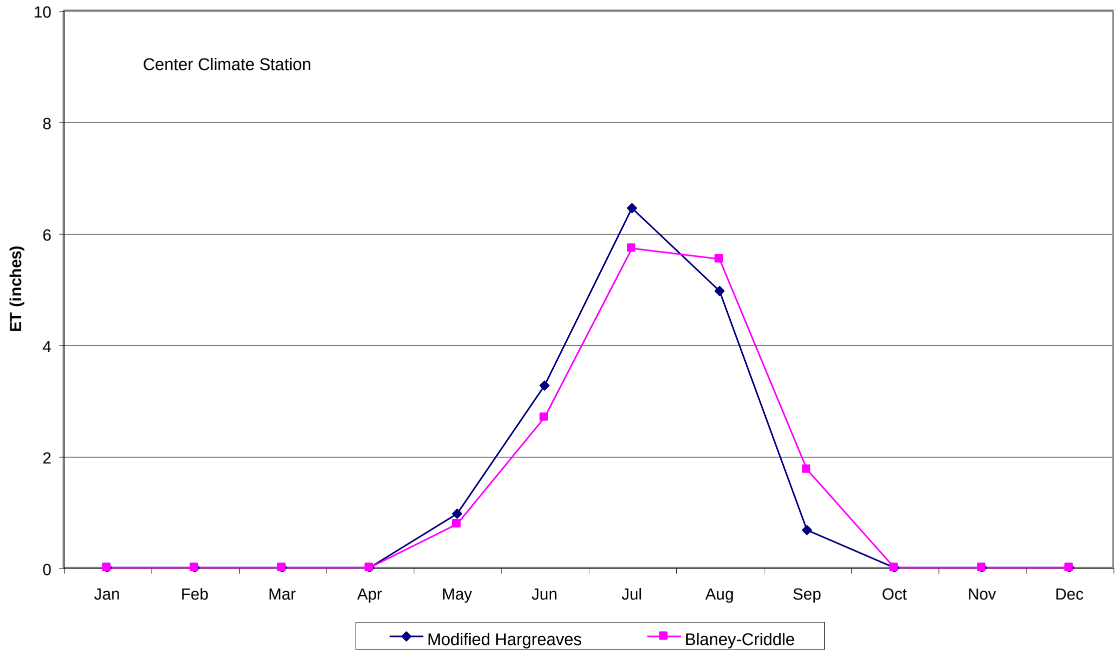


Figure 8
Average Monthly Alfalfa ET - Modified Hargreaves and Blaney-Criddle w/ Adjusted Crop Coefficients

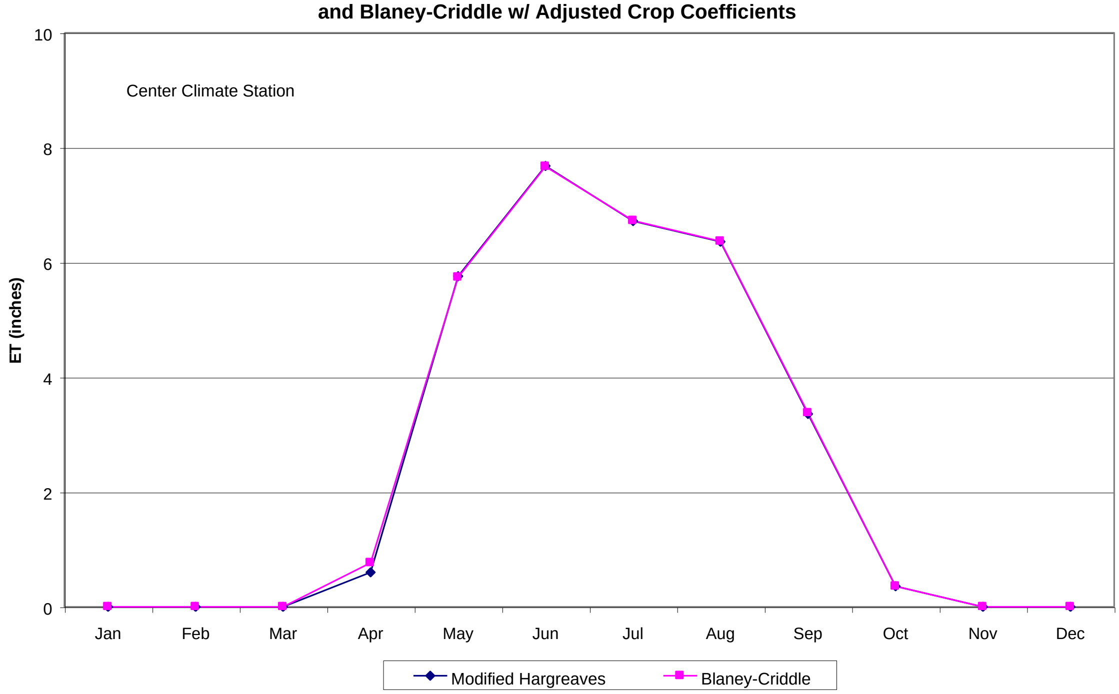


Figure 9
Average Monthly Potato ET - Modified Hargreaves and Blaney-Criddle w/ Adjusted Crop Coefficients

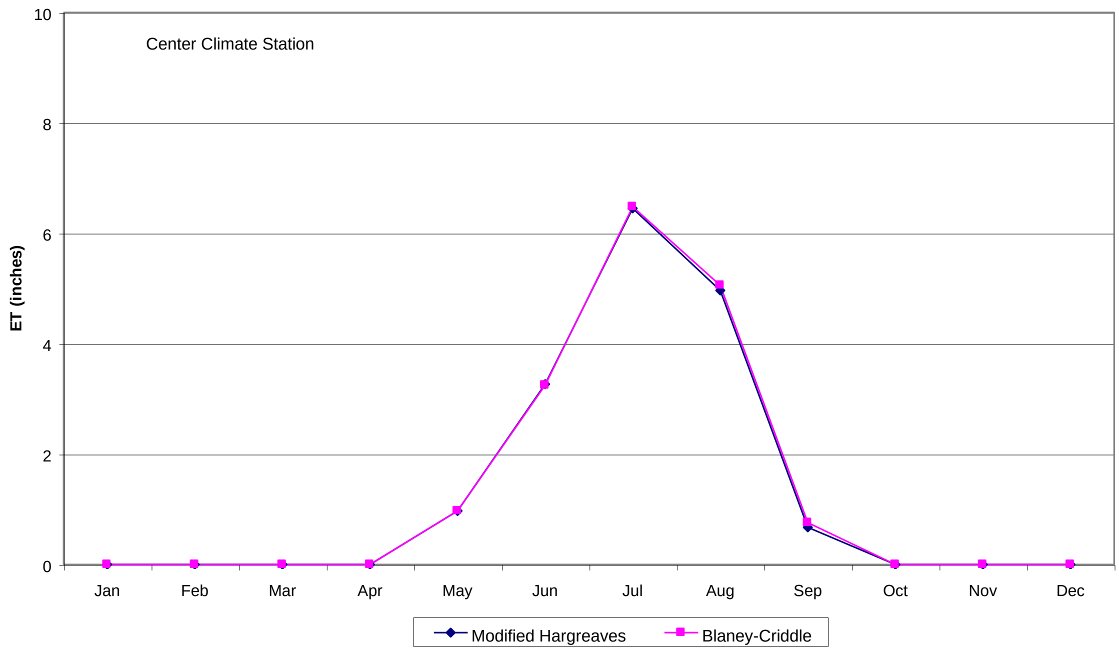


Figure 10
Average Monthly Barley ET - Modified Hargreaves and Blaney-Criddle w/ Adjusted Crop Coefficients

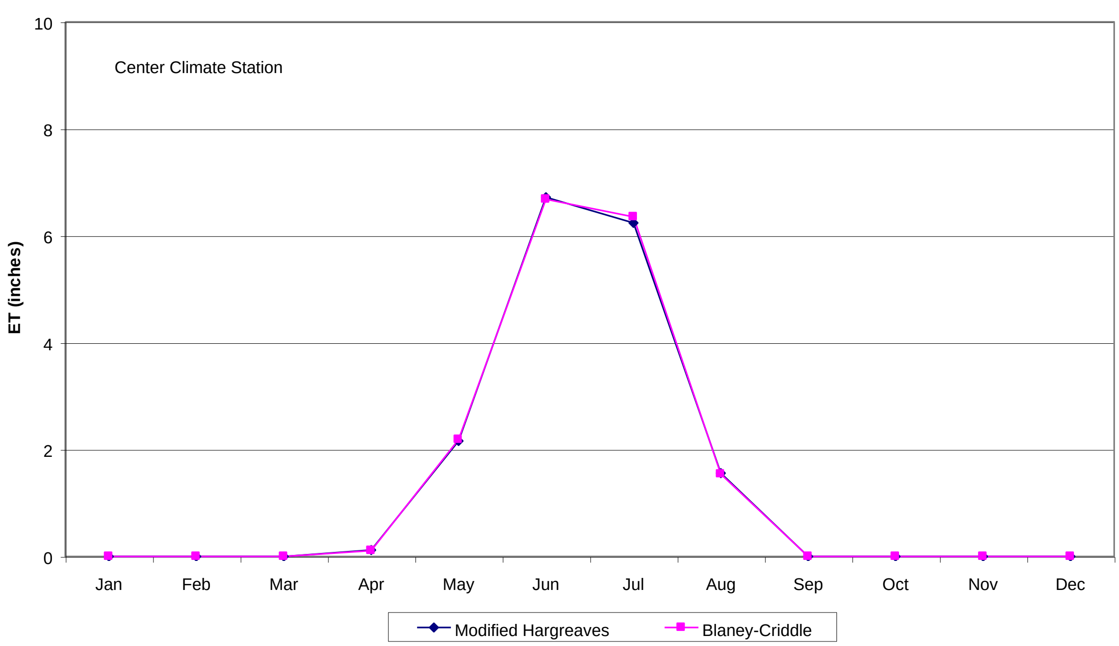


Figure 11
Average Monthly Wheat ET - Modified Hargreaves and Blaney-Criddle w/ Adjusted Crop Coefficients

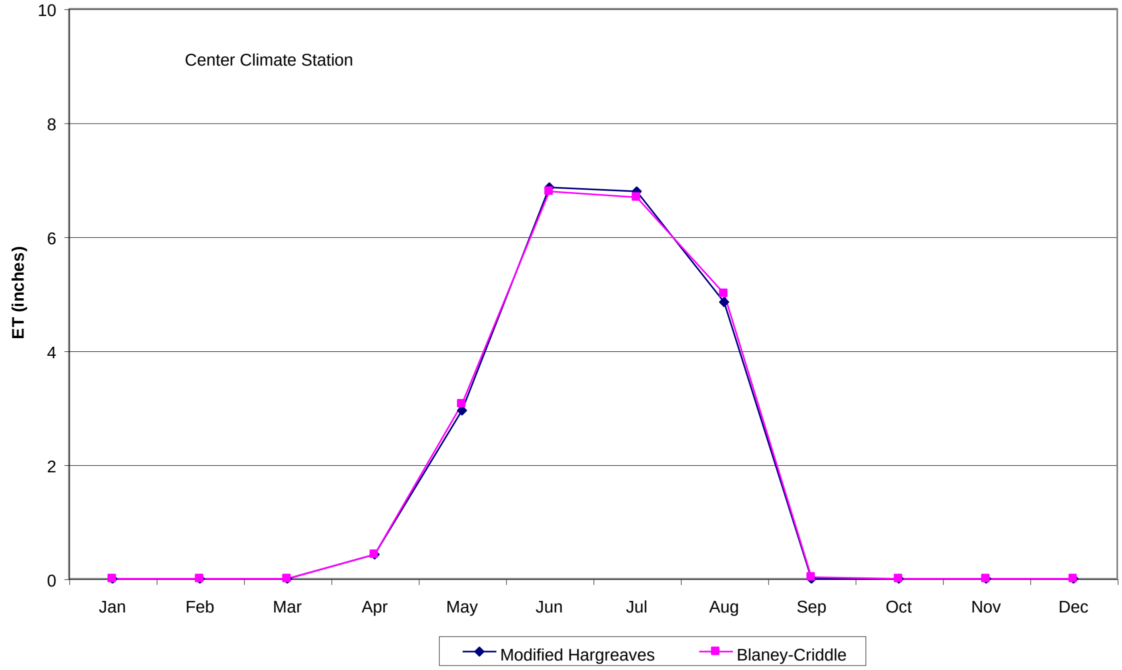


Figure 12
Average Monthly Pasture Grass ET - Modified Hargreaves and Blaney-Criddle w/ Adjusted Crop Coefficients

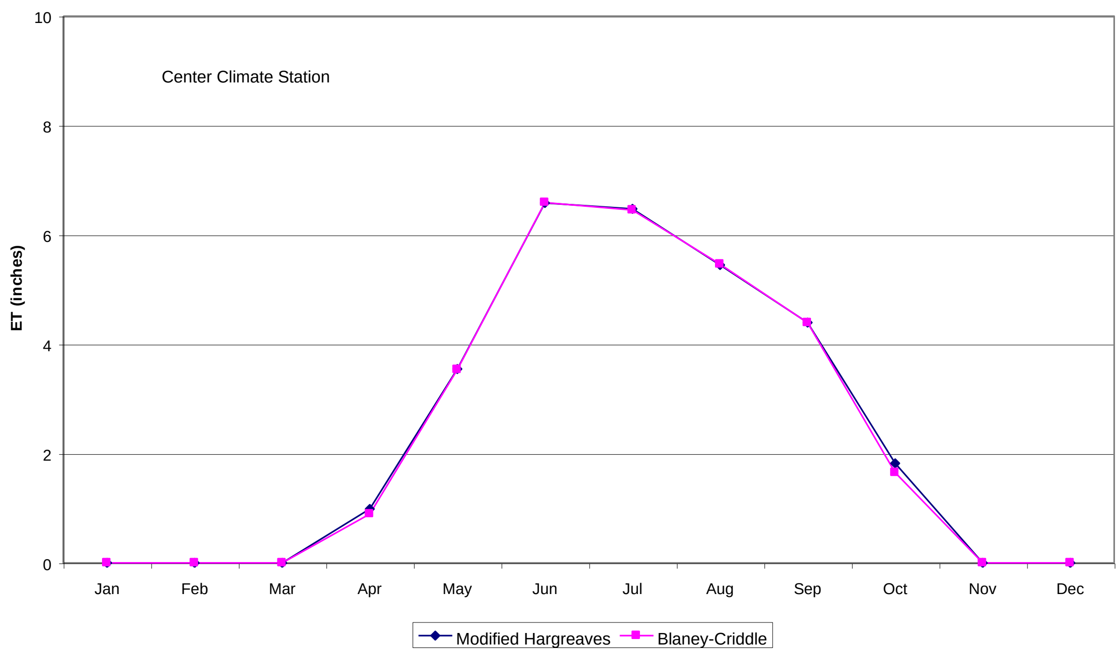


Figure 13
Monthly Alfalfa ET - Modified Hargreaves and Calibrated Blaney-Criddle

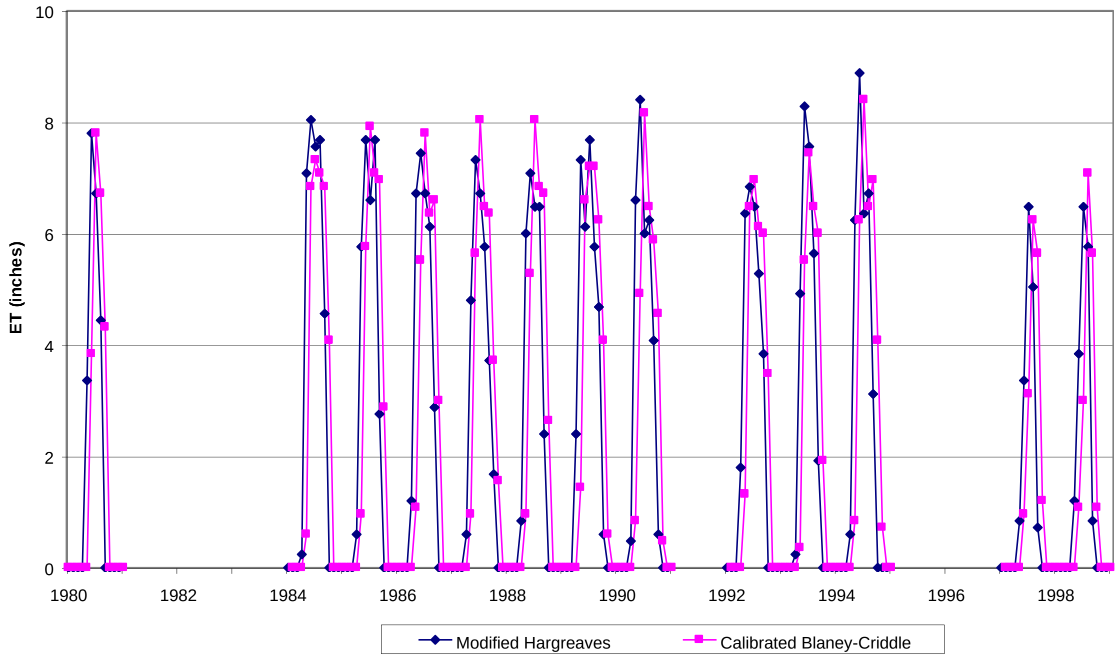


Figure 14
Monthly Potato ET - Modified Hargreaves and Calibrated Blaney-Criddle

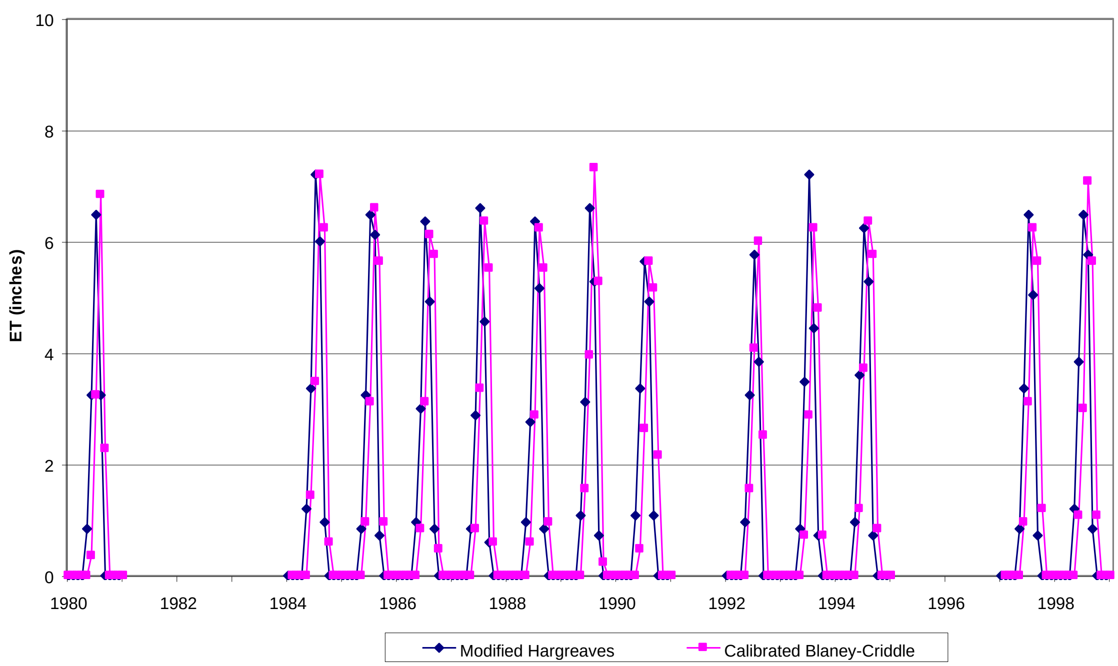


Figure 15
Monthly Barley ET - Modified Hargreaves and Calibrated Blaney-Criddle

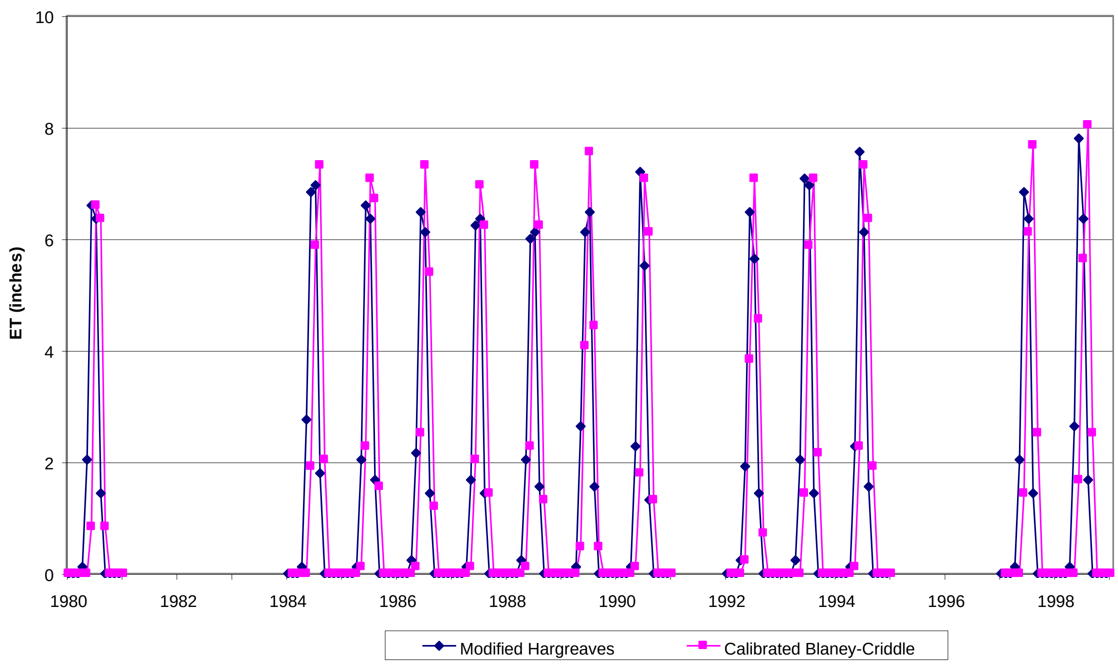


Figure 16
Monthly Wheat ET - Modified Hargreaves and Calibrated Blaney-Criddle

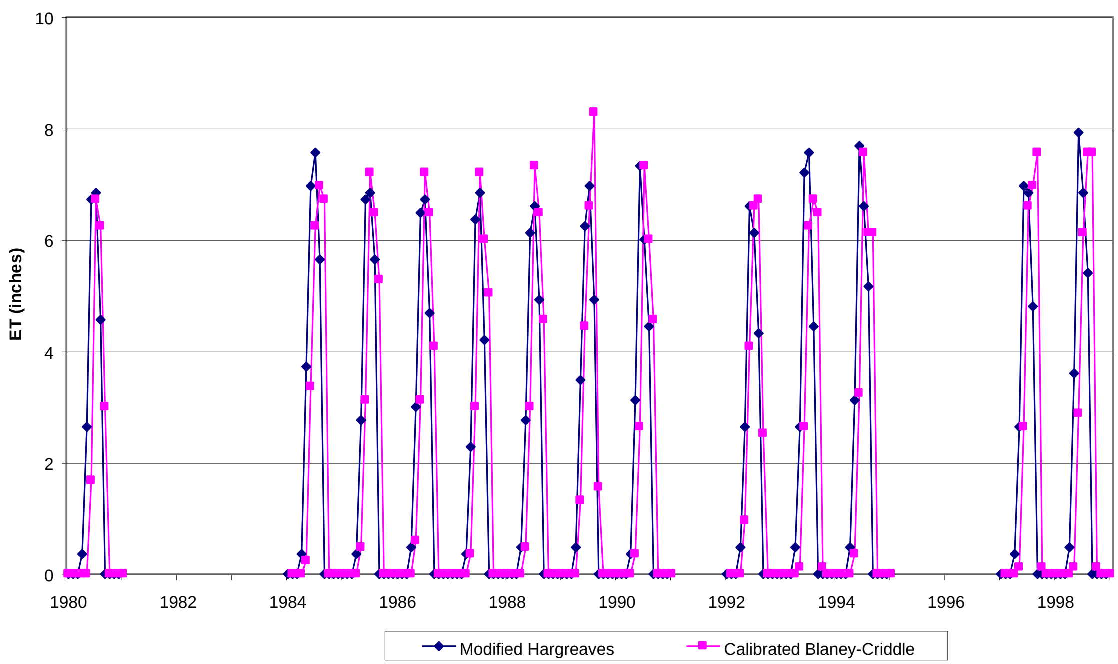


Figure 17
Monthly Pasture Grass ET - Modified Hargreaves and Calibrated Blaney-Criddle