RGDSS Memorandum
Phase 6 –Enhancement of Irrigated Parcel Datasets
Final

TO: File
FROM: Kelley Thompson, P.E.; Division of Water Resources Modeling and DSS Team
SUBJECT: RGDSS Groundwater Model – Phase 6: Enhancement of Irrigated Parcel Datasets
DATE: 12/16/2015

1. Introduction

The Irrigated Parcel Datasets for the Rio Grande Decision Support System (RGDSS) spatially represent parcels that were irrigated within the San Luis Valley during a particular year. In the Geographic Information System (GIS) based datasets, irrigated parcels are defined as contiguous areas of land cropped by a single crop type under a single irrigation system. A series of database attributes are associated with each irrigated parcel including parcel area, crop type, irrigation system type, surface water derived water sources, and groundwater derived water sources (wells). These attributes are used to define various structure acreages and spatial distributions within the RGDSS StateCU model and the RGDSS groundwater flow model.

In previous phases of the RGDSS, irrigated parcel datasets were developed and utilized for years 1936 and 1998. In Phase 6, the existing irrigated parcel datasets were enhanced and additional datasets were created such that irrigated areas are more completely and accurately represented through time. This memorandum describes enhancements to the irrigated parcel datasets and related datasets used for the RGDSS. These enhancements were completed as part of the Phase 6 efforts of the RGDSS Technical Advisory Committee (Peer Review Team (PRT)) to review and update the RGDSS groundwater model. The objectives of this task were to:

1. *Enhance the methodologies, data, and imagery for production of irrigated parcel datasets*
2. *Improve assignments of water sources to irrigated parcels*
3. *Refine the phase 5 irrigated parcel and related datasets utilizing a consistent application of enhanced methodology, data, and imagery*
4. *Produce new irrigated parcel datasets for years after 1998 to characterize irrigated areas in the contemporary time period*

2. Previous Efforts

Agro Engineering, Inc., developed the original irrigated parcel dataset representing year 1998 as part of the Consumptive Use and Water Budget component of the RGDSS (Agro Engineering, K.R. Thompson et. al. 2000). Satellite imagery with 5-meter resolution was used to delineate parcel boundaries and three Landsat satellite images were used for crop classification. The original land cover and ditch service area datasets were also developed. In RGDSS Phase 5, Leonard Rice Consulting Water Engineers slightly modified the original 1998 irrigated parcel dataset (as described in RGDSS, K. Thompson, 2015).

The Division of Water Resources produced the original irrigated parcel dataset for 1936. The Rio Grande Joint Investigation maps showing irrigated lands and crop types in 1936 were digitized and the ditch service area dataset was used to associate surface water sources.

3. Approach

The RGDSS Phase 6 was divided into two periods; the period contributing to the RGDSS groundwater model through version 6P35 and the following period contributing through model version 6P98.

3.1. Enhancements to Irrigated Parcel Datasets through Model Version 6P35

Almost all the Phase 6 enhancements to the irrigated parcel datasets were developed prior to model version 6P35. The process to produce the final irrigated parcel datasets in this period of the model involved development and subsequent enhancement of several intermediate datasets and was documented in the following reports and memorandums:

- *2002 Division 3 Irrigated Lands Assessment and Groundwater Use Evaluation* (Agro Engineering, K. Thompson 2005) – describes development of original 2002 irrigated parcel dataset and initial efforts to refine assignment of wells to parcels.
- *RGDSS Irrigated Land Coverage Enhancements and 2005 Irrigated Lands Assessment* (Agro Engineering, K. Thompson and K.R. Thompson 2010) – describes development of original 2005 irrigated parcel dataset and assignment of enhanced ditch service area and well assignments to the original 1936, 1998, and 2002 datasets.
- *Integration of Interview Data into RGDSS Ditch and Irrigated Parcel Datasets* (Agro Engineering, K. Thompson 2010) – describes process to ensure that data from Interview by Helton and Williamson P.C. were reflected in the enhanced 1998, 2002, and 2005 irrigated parcel datasets.
- *Interview with Monty Smith representing Trinchera Subdistrict Area* (Agro Engineering, K. Thompson (a) 2011) – describes information collected for Trinchera Subdistrict Area that was integrated into irrigated parcel datasets.
- *Revision of 1998, 2002, and 2005 RGDSS Irrigated Parcels – Project Task Summaries* (Agro Engineering, K. Thompson 2011) – describes refinement of 1998 irrigated parcel dataset utilizing enhanced methodology, data, and imagery that had been used in development of the 2002 and 2005 datasets as well as additional tasks to ensure consistency between the irrigated parcel datasets as well as the land cover datasets.
- *Summary of GIS data refinements by Agro Engineering between RGDSS Phase 5 and Phase 6 and Methodologies for Production of Irrigated Parcel Datasets* (Agro Engineering, K. Thompson (b) 2011) – summarizes enhancement of irrigated parcel datasets between RGDSS Phases 5 and 6.
- *Phase 6 DWR GIS Data Refinements* (RGDSS, C. Brown 2012) – describes development of 2009 and 2010 irrigated parcel datasets and additional refinements to ditch service area, well assignments, and land cover datasets. The 2009 irrigated parcel dataset was utilized in RGDSS model version 6P35 while the 2010 dataset was integrated into subsequent versions of the RGDSS model.

These reports and memorandums are attached at the end of this document in reverse chronological order.

Throughout RGDSS phase 6, the satellite imagery that was used to produce the final irrigated parcel datasets was processed and normalized to top-of-atmosphere planetary reflectance using methodologies and calibration coefficients described in Chander et. al. (2009). This document is also attached.

3.2. Enhancements to Irrigated Parcel Datasets through Model Version 6P98

A coverage percentage is used with the irrigated parcel datasets to avoid double counting within structure acreages when parcels can receive water from multiple ditches. In RGDSS phase 5 and the pre-2009 datasets utilized in model version 6P35, the coverage percentages were based on a fractional spatially based methodology (as described in Agro Engineering, K.R. Thompson et. al. 2000). In subsequent versions of the model, parcel centroids were used to spatially assign surface water sources to each parcel prior to calculation of coverage percentages and fractional (less than 100%) coverage of a parcel by a ditch service area was no longer considered. The new method is simpler as additional scripts are not required for processing; and the new method helps avoid potential inaccuracies in ditch service area boundaries.

The 2012 RGDSS memorandum (RGDSS, C. Brown 2012) listed previously was produced prior to model version 6P35, and the 2009 irrigated parcel dataset and many of the additional refinements described in the memorandum were integrated into model version 6P35. However, the 2010 irrigated parcel dataset and several refinements described in the memorandum, primarily for assignments of groundwater wells to parcels including several wells associated primarily with municipal and industrial uses, were integrated into subsequent versions of the model. For production of the 2009 and 2010 datasets, a master parcel database was developed and Crop Data Layer from National Agricultural Statistics Service was utilized for the crop typing process (i.e. image crop classification was not needed).

3.3. Summary of Phase 6 Enhancements to Irrigated Parcel Datasets

The following list summarizes specific enhancements that were incorporated into the irrigated parcel datasets with an indication if the enhancement was integrated into model version 6P35 or only 6P98.

- Methodologies, data, and imagery for production of irrigated parcel datasets were enhanced. This included use of high resolution aerial photography for parcel delineation, use of multiple (up to 20) Landsat images per season to evaluate irrigation and crop types throughout the growing season, improved normalization of satellite imagery to enable comparisons, use of the normalized difference vegetation index (NDVI) to define a quantitative threshold for irrigated status, improved crop classification techniques, and consistent water source assignments. (6P35)
- The 1998 irrigated parcel dataset was improved using a consistent application of enhanced methodology, data, and imagery. (6P35)
- New irrigated parcel datasets were produced for years 2002 and 2005 using a consistent application of enhanced methodology, data, and imagery. (6P35)
- New irrigated parcel datasets were produced for years 2009 and 2010. (6P35)
- The accuracy and extent of ditch service area mapping that is applied to irrigated parcels was improved. (6P35)
- The assignment of well water sources to irrigated parcels was improved. (6P35)
- The 1936 irrigated parcel dataset was revised with the improved ditch service area mapping. (6P35)
- The native lands classification theme was reprocessed considering revised 1998 irrigated parcels boundaries and extraction of urbanized and impervious areas. (6P35)
- New crop types of new alfalfa, cover crop, winter wheat, and bluegrass were added. (6P35)
- The new irrigated parcel dataset for year 2010 was integrated into the RGDSS model and additional refinements to water source information were added. (6P98)
- A simpler method was used to calculate parcel coverage percentages. (6P98)

4. Results

Total irrigated acreages from the original Phase 4 1998 irrigated parcel dataset and final Phase 6 datasets are compared in Table 1. Irrigated acreages are shown by crop type, water source, and irrigation type. The total irrigated acreage for the basin has been relatively consistent with a moderate reduction after 2002. The significant reduction in irrigated acreage in the very dry year of 2002 was primarily in parcels of grass pasture with surface water only and flood irrigation. Recent acreage reductions have been concentrated in row crops and flood irrigated crops while cover crop acreages have increased.

Table 1. Comparison of Irrigated Parcel Dataset Acreages by Attribute

Attribute	Phase 4*	RGDSS Phase 6 (acres)					
	1998	1936	1998	2002	2005	2009	2010
Crop Type							
Potatoes	80,064	46,045	77,524	73,005	64,366	59,840	63,732
Small Grains	114,214	117,554	108,432	82,821	78,326	113,550	99,416
Vegetables	7,583	11,509	8,282	5,701	5,509	1,768	1,367
Alfalfa	139,502	107,762	127,475	146,840	146,726	94,318	134,009
Grass Pasture	271,376	284,292	249,504	115,624	200,992	240,049	205,242
New Alfalfa	0	0	12,241	0	12,482	13,644	9,311
Cover Crop	0	0	1,605	0	6,077	8,509	2,411
Wheat Fall	0	0	394	0	2,670	247	62
Bluegrass	0	0	0	0	0	206	83
Water Source							
SW-only	225,424	462,178	262,174	113,610	218,618	224,531	213,275
GW-only	48,506	6,130	53,559	50,333	46,834	48,141	46,069
Conjunctive	335,747	28,129	268,975	259,684	251,253	258,871	255,666
GW Total	384,253	34,259	322,534	310,017	298,087	307,012	301,735
not listed	3,062	70,725	749	364	444	587	623
Irrigation Type							
Sprinkler	272,709	0	268,751	276,182	272,452	282,594	281,902
Flood	340,030	567,161	316,706	147,809	244,696	249,536	233,731
Total	612,739	567,161	585,457	423,991	517,148	532,130	515,633

*Note: * original "Phase 4" irrigated parcel dataset as provided by Agro Engineering*

5. Comments and Concerns

The following electronic files associated with irrigated parcel datasets were enhanced or produced in RGDSS Phase 6. Assemblies of GIS shapefiles are noted as .shp.

- *div3_irrig_1936_final.shp* – Irrigated parcel dataset representing year 1936
- *div3_irrig_1998_final.shp* – Irrigated parcel dataset representing year 1998
- *div3_irrig_2002_final.shp* – Irrigated parcel dataset representing year 2002
- *div3_irrig_2005_final.shp* – Irrigated parcel dataset representing year 2005
- *div3_irrig_2009_final.shp* – Irrigated parcel dataset representing year 2009
- *div3_irrig_2010_final.shp* – Irrigated parcel dataset representing year 2010
- *div3_ditchservice_pre_99.shp* – Ditch service area coverage for years prior to 1999
- *div3_ditchservice_post_99.shp* – Ditch service area coverage for years after 1998
- *div3_native_veg.shp* – Vegetation cover types for non-irrigated and non-impervious areas

References

Agro Engineering; Kirk R. Thompson, Kelley Thompson, and Maya ter Kuile. July 2000. *1998 Irrigated Lands Assessment using Satellite Imagery in the Rio Grande Basin of Colorado*. Agro Engineering, Inc. RGDSS Final Report attached to RGDSS Memorandum *Irrigated Lands Assessment, Task 1* from Kirk Thompson to Ray Bennett, Ray Alvarado, and Andy Moore, Colorado Division of Water Resources and Colorado Water Conservation Board, July 24 2000.

Agro Engineering; Kelley L Thompson. February 19, 2005. *2002 Division 3 Irrigated Lands Assessment and Groundwater Use Evaluation*. Report to Rio Grande Water Conservation District, Colorado Water Conservation Board, Conejos Water Conservancy District, Rio Grande Water Users Association, Alamosa La Jara Water Conservancy District, San Luis Valley Irrigation Well Owners Association, Rio Grande Canal Water Users Association, and Saguache Creek Water Users Association.

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Agro Engineering; Kelley Thompson. July 23, 2010. *Integration of Interview Data into RGDSS Ditch and Irrigated Parcel Datasets*. Memorandum to RGDSS Model Peer Review Team.

Agro Engineering; Kelley Thompson (a). March 22, 2011. *Interview with Monty Smith representing Trinchera Subdistrict Area*. Memorandum to James Heath and RGDSS File; Colorado Division of Water Resources.

Agro Engineering; Kelley Thompson and Kirk R. Thompson. March 2011. *Revision of 1998, 2002, and 2005 RGDSS Irrigated Parcels – Project Task Summaries*. Memorandum to James Heath, Mary Halstead, and Mike Sullivan; Colorado Division of Water Resources.

Agro Engineering; Kelley Thompson (b). November 7, 2011. *Summary of GIS data refinements by Agro Engineering between RGDSS Phase 5 and Phase 6 and Methodologies for Production of Irrigated Parcel Datasets.* Agro Engineering, Inc. Memorandum to James Heath, Mary Halstead, and Mike Sullivan; Colorado Division of Water Resources.

Chander, G., B.L. Markham, and D.L. Helder. 2009. *Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 ALIS Sensors.* Remote Sensing of the Environment 113 (2009) 893-903.

RGDSS; Chris Brown. July 17, 2012. *Phase 6 - DWR GIS Data Refinements*. Colorado Division of Water Resources. RGDSS Final Memorandum to File.

RGDSS; Kelley Thompson. December 4, 2015. *Phase 6 - Review and Enhancement of Sprinkler Acreage Timeline.* Colorado Division of Water Resources. RGDSS Final Memorandum to File.

Attachments

RGDSS; Chris Brown. July 17, 2012. *Phase 6 - DWR GIS Data Refinements*. Colorado Division of Water Resources. RGDSS Final Memorandum to File.

Agro Engineering; Kelley Thompson. November 7, 2011. *Summary of GIS data refinements by Agro Engineering between RGDSS Phase 5 and Phase 6 and Methodologies for Production of Irrigated Parcel Datasets.* Agro Engineering, Inc. Memorandum to James Heath, Mary Halstead, and Mike Sullivan; Colorado Division of Water Resources.

Agro Engineering; Kelley Thompson and Kirk R. Thompson. March 2011. *Revision of 1998, 2002, and 2005 RGDSS Irrigated Parcels – Project Task Summaries*. Memorandum to James Heath, Mary Halstead, and Mike Sullivan; Colorado Division of Water Resources.

Agro Engineering; Kelley Thompson. March 22, 2011. *Interview with Monty Smith representing Trinchera Subdistrict Area*. Memorandum to James Heath and RGDSS File; Colorado Division of Water Resources.

Agro Engineering; Kelley Thompson. July 23, 2010. *Integration of Interview Data into RGDSS Ditch and Irrigated Parcel Datasets*. Memorandum to RGDSS Model Peer Review Team.

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Agro Engineering; Kelley L Thompson. February 19, 2005. *2002 Division 3 Irrigated Lands Assessment and Groundwater Use Evaluation*. Report to Rio Grande Water Conservation District, Colorado Water Conservation Board, Conejos Water Conservancy District, Rio Grande Water Users Association, Alamosa La Jara Water Conservancy District, San Luis Valley Irrigation Well Owners Association, Rio Grande Canal Water Users Association, and Saguache Creek Water Users Association.

Chander, G., B.L. Markham, and D.L. Helder. 2009. *Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 ALIS Sensors.* Remote Sensing of the Environment 113 (2009) 893-903.

Attachment 1

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RGDSS Memorandum

Phase 6 – DWR GIS Data Refinements

Final

TO: File
FROM: Chris Brown, GIS Program Manager, Colorado Division of Water Resources
SUBJECT: RGDSS Groundwater Model – Phase 6: DWR GIS Data Refinements
DATE: 7/17/2012
CC: Mary Halstead

1. Introduction

This memorandum represents refinements to the GIS Data and the development of 2009 and 2010 irrigated lands assessments by the Colorado Division of Water Resources used in Phase 6 of the RGDSS ground water modeling. The RGDSS ground water flow model utilizes a number of GIS datasets for input to disseminate the spatial characteristics of the San Luis Valley for the ground water flow model. The summary of the scope of these enhancements is as follows:

1. *Irrigated Lands Development and Refinements.*
2. *Refinements to the Land Use Coverage.*
3. *Refinement of Ditch Delineations.*
4. *Refinement of Climate Station Regions of Influence.*
5. *Refinements to Ditch Service Areas.*
6. *Geometric Refinements to Stream Inflow, Rim Inflow, and Rim Recharge Areas.*
7. *Investigation of Wells.*

2. Previous Efforts

For RGDSS Phase 5, irrigated lands datasets for 1936 and 1998 were used. Previous efforts to refine and enhance the GIS data for Phase 6 of the RGDSS were performed by Agro Engineering and reported in the documents “2002 Division 3 Irrigated Lands Assessment and Groundwater Use Evaluation” (February 2005); “RGDSS Irrigated Land Coverage Enhancements and 2005 Irrigated Lands Assessment” (January 2010); “Integration of Interview Data into RGDSS ditch and irrigated parcel datasets” (July 2010); and “Revision of 1998, 2002, and 2005 RGDSS Irrigated Parcels” (March 2011). These refinements were summarized in the memo “Summary of GIS data refinements by Agro Engineering between RGDSS Phase 5 and Phase 6 and Methodologies for Production of Irrigated Parcel Datasets” (November 2011).

3. Approach

3.1. <u>**Irrigated Lands Development and Refinements**</u>

Irrigated lands were developed for the San Luis Valley for the 2009 and 2010 growing seasons. As part of this process, a number of refinements were applied to the development of the data: 1) Development of master parcels, 2) Refinement of ditch service area assignments, 3) Investigation and refinement of well to parcel assignments, 4) Utilization of the NASS Cropland Data Layer for crop types for 2009 and 2010.

Development of Master Parcels

To increase the efficiency of the development and the consistency of the relationship between irrigating structures and irrigated lands, a master parcel layer was created from the previously published data including 1998, 2002 and 2005. These datasets were overlaid with each other using the 2005 layer as the primary layer. Areas not covered in the 2005 layer but included in previous years were flagged to be included in the master layer. Once the extents of the data were set, the data was checked for overlapping topology and corrected. Structure assignments were maintained in the master dataset from the previous datasets.

Refinement of Ditch Service Area Assignments

Ditch service area assignments were also refined as part of this process. Previously, ditches were assigned using a fractional area method outlined in section 3.1.2 of the above referenced document produced by Agro Engineering (Thompson, January 2010). Currently, an irrigated parcel is assigned to a ditch service area based on the location of the parcel's centroid. If the centroid of a parcel is within a ditch service area, that parcel is assigned to that ditch. If multiple ditch service areas overlap a parcel's centroid, then service to that parcel is split between the ditch service areas equally.

There was also an investigation into parcels served by only ground water or only surface water. These parcels were flagged and maps were sent to Water Commissioners in Division 3 for review. Any corrections obtained as a result of this process were incorporated into the GIS files.

Investigation and Refinement of Well to Parcel Assignments

In 2009, pumping diversion records were available to analyze against parcels, crops and the irrigation water requirements for those crops. This analysis resulted in a list of parcels that were either water 'long' or water 'short', meaning that they either had too much or too little total water supply to meet the irrigation water requirement of the crops being grown. The well assignments to these parcels were reviewed and in many cases resulted in re-assignment of wells to parcels based on permit and water rights decree information from HydroBase. In addition to this analysis, there was an investigation into the extents of groundwater irrigation in the Saguache area. This analysis is detailed in Attachment B.

Utilization of NASS Cropland Data Layer for Crop Types in 2009 and 2010

Analyses of satellite imagery were used to identify crop types for the 1998, 2002, and 2005 irrigated lands datasets. In 2008, the National Agricultural Statistics Service (NASS) first published their Cropland Data Layer (CDL) for Colorado. This dataset is a statewide dataset that includes crop types in raster format that are easily extracted through GIS software to the irrigated parcel data Colorado currently uses. The CDL is produced by the Spatial Analysis Research Section of NASS from multiple satellite imagery sources with agricultural training and validation data from the Farm Service Agency using standard practices (see CDL metadata for methodologies and accuracy assessments). This data was used for the crop typing of the 2009 and 2010 irrigated parcels for the San Luis Valley. See Attachment A for a detailed description of the crop typing and irrigation extents analysis. Due to the additional crop typing available in the NASS CDL, a bluegrass crop type was added to 2009 and 2010 irrigated lands datasets while the more specific designations of barley, sunflower, wheat, and spring wheat were added to the 2010 dataset although they are summarized as small_grains in the Phase 6 model.

3.2. Refinements to the Land Use Coverage

The land use coverage is used in the RGDSS model to spatially distribute the calculation of native ET in the San Luis Valley. Previous versions of this dataset did not exclude urbanized or impervious areas like roads, parking lots and towns. Therefore, these areas were included in the native ET analysis. Using the latest version of the National Land Cover Dataset (NLCD), urbanized and impervious areas were extracted and unioned with the existing land use dataset. This procedure allowed for the subsequent reclassification of these areas from native vegetation to impervious area. The net result of this procedure yielded about 40,000 acres of native vegetation to be reclassified in the model.

3.3. Refinement of Ditch Delineations

There has been a continued effort to delineate ditches in the San Luis Valley. The latest effort resulted in the delineation of 134 additional ditches that previously did not have a ditch vector in the data but did have a ditch service area. These additional ditches were identified and delineated using ditch headgate information and recent aerial photography.

3.4. Refinement of Climate Station Regions of Influence

The regions delineating the influence of climate stations in the San Luis Valley were refined with polygons generated using the Thiessen polygon method. This method proportionally divides and distributes a point coverage (climate stations) into regions or polygons. Detailed information on this method and process can be found in the memorandum RGDSS Phase 6 – Review and Enhancement of Climate Station Weighting.

3.5. Refinements to Ditch Service Areas

There were inclusions and exclusions of irrigated parcels to the ditch service area coverage based on water user interviews and mapping. The ditch service area coverage was refined to reflect the changes in the service areas. In addition, due to the temporal nature of water rights, the ditch service area was split into two temporal coverages. There is now a pre-1999 and post-1999 ditch service area coverage to allow for the change in ditch service for certain irrigated parcels in 1999.

3.6. Geometric Refinements to Stream Inflow, Rim Inflow, and Rim Recharge Areas

The criteria for the delineation of the stream inflow, rim inflow, and rim recharge areas were refined in Phase 6. Stream inflow areas were refined to represent the drainage basins of the explicitly modeled streams that are outside of the active model grid of the RGDSS groundwater flow model.

The rim inflow areas were refined to represent the drainage areas outside of the active model grid of the groundwater model that were not included in the stream inflow areas. The rim inflow areas were delineated to represent areas of drainages that feed into and correspond one-to-one with the rim recharge areas.

The rim recharge areas were refined and are defined by a two mile buffer from the edge of the active model grid of the groundwater model. In areas of the San Luis Valley, the rim inflow boundaries were buffered at a distance of less than two miles due to geographic barriers. For example, on the west side of the valley, the Rio Grande Canal and Monte Vista Canal are considered to be geographic barriers. In these areas, the rim inflow boundary is set by these geographic barriers where they exist or by the standard two mile buffer. The rim recharge areas were further buffered a quarter mile away from the stream centerline of the explicitly modeled streams.

Additional information related to the stream inflow, rim inflow, and rim recharge areas and flow calculations can be found in the memorandum: RGDSS Groundwater Model – Phase 6: Stream Inflow, Rim Inflow and Rim Recharge Estimates.

3.7. <u>Investigation of Wells</u>

Once wells had been verified, tagged (assigned a WDID) and had flow meters installed, there were a number of wells permitted or decreed for irrigation that were not attributed to irrigated parcels. Each of these wells were researched and attached to the correct parcel(s) in the correct years for inclusion into the model. In some cases, newly identified wells were found to be M&I wells or were wells with permitted or decreed flow rates less than 50 gallons per minute. These wells were appropriately incorporated into the M&I or small flowing well lists, respectively.

4. References

USDA, National Agricultural Statistics Service, *2009 Colorado Cropland Data Layer Metadata*, USDA NASS Spatial Analysis Research Section. Available online at http://nassgeodata.gmu.edu/CropScape/ or at http://datagateway.nrcs.usda.gov/.

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5. Attachments

Attachment A – Process for Crop Typing and Defining Irrigation Extents

Attachment B – Memorandum: 1998 Irrigated Parcel Edits for Division 3

Attachment A

Process for Crop Typing and Defining Irrigation Extents

The process for crop typing and defining irrigation extents uses both ERDAS and ArcGIS software packages and a number of different data sources. The data used are shown below.

Data Used:

Most recent aerial photography (NAIP)
1:24k Statewide DRG
NASS CDL for crop year
At least 3 NDVI scenes spread over growing season
Divisional Master Irrigated Parcel File (MIPF)
HBDMC for diversion records
Ditch Vectors and Headgates
Sections and Townships

Analysis Process:

The above data are loaded into ArcMap and organized in a way to allow for the examination of the NASS CDL beneath the MIPF. The MIPF should be copied to the project directory and renamed to create a new file (i.e. Div_'#'_Irrig_'year') for the snapshot year and water division.

The process begins with a section by section review of the snapshot MIPF, NASS CDL for the crop year and the most recent aerial photography. The goal is to identify multiple crops within a snapshot MIPF field boundary and split the field to according to the crop splits in the NASS CDL data. Only clear splits should be made. Speckled fields with multiple crop types should be left whole for later analysis. Once this process is finished, values from the NASS CDL and the NDVI scenes need to be extracted to the snapshot MIPF.

This process is done with EDRAS. ERDAS is used to pull over NASS CDL values, as well as, temporal NDVI values within field boundaries. NASS CDL values are used for assigning crop types to the master irrigated parcel file. For NASS CDL value extraction, under 'Image Interpreter>GIS Analysis>Zonal Attributes', load data as such:

Vector Layer = Snapshot MIPF
Raster Layer = NASS CD
Select Layer = 1
Check 'Ignore Zero in Zonal Calculations
Check 'Majority' with Attribute Name = Maj_Crp
Check 'Majority Fraction' with Attribute Name = Maj_Frac

This analysis attributes a parcel with the majority crop and the fraction of pixels that compose the majority within a field boundary. Currently, the crop values are a coded number. By joining the crop lookup table to the parcels, the actual crop values are brought over to the data. These crop values can be written to a new field, for example, 'NASS_Crp'. The various crop types now need to be examined. The NASS CDL data contains two types of data, index crop data and NLCD data. Index crop data are standard crop types like corn or alfalfa while NLCD data types are defined as shrubland or grassland herbaceous.

Next, the data from the NDVI scenes needs to be extracted to the parcels to identify fallow areas and irrigated areas. This process will need to be repeated for each NDVI scene used in the analysis. For NDVI value extraction, under 'Image Interpreter>GIS Analysis>Zonal Attributes', load data as such:

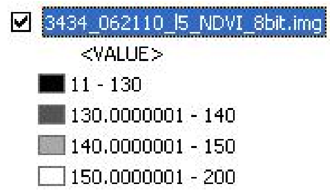
Vector Layer = Snapshot MIPF
Raster Layer = NDVI Scene
Select Layer = 1
Check 'Ignore Zero in Zonal Calculations'
Check 'Mean' with Attribute Name = NDVI_'Scene_Description'

This analysis needs to be run for each NDVI scene used for the project. Each analysis produces a mean NDVI value for a parcel. Once these processes are run, the resulting table should look something like this…

MASTER_ID	MAJ_CROP	MAJ_FRAC	NASS_CRP	MAY_3334_M	JUN_3334_M	JUL_3334_M	AUG_3334_M
100	152	0.848	Shrubland	115.328	116.664	117.198	127.879
101	171	0.56	Grassland Herbaceous	137.682	165.227	149.727	177.045
102	171	0.932	Grassland Herbaceous	139.946	140.838	136.718	148.804
103	171	0.509	Grassland Herbaceous	146.359	153.506	151.326	161.744
104	171	0.578	Grassland Herbaceous	128.559	122.162	121.11	127.199
108	36	0.435	Alfalfa	147.18	154.549	155.029	160.403
109	36	0.476	Alfalfa	145.222	146.444	149.444	161.556
110	152	0.524	Shrubland	133.744	141.267	142.267	149.744
1797	28	0.862	Oats	110.65	120.604	148.51	173.262
1798	21	0.878	Barley	125.858	175.781	175.143	133.225
1799	171	0.644	Grassland Herbaceous	119.534	166.783	166.624	138.414
1800	43	0.818	Potatoes	111.779	130.114	170.808	180.76

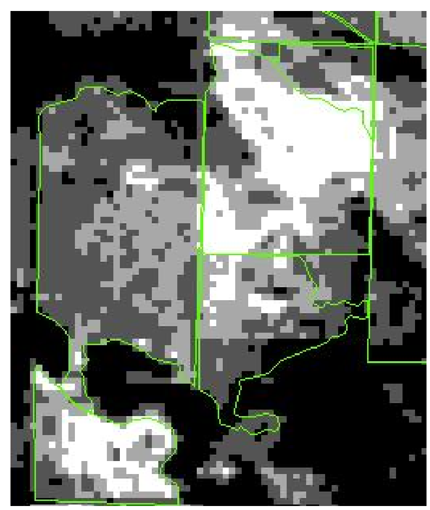
Once you have the table set, it's time to start analyzing and coding parcels. The first step in this process is to identify fallow parcels and code them as 'NO_CROP' in the 'CROP_TYPE' field. Any parcel with all NDVI scene values below 130 should be coded as 'NO_CROP'. For example, in the above table, the first record would fall into this category. Conversely, any parcel with a NDVI value above 150 for any month should be considered irrigated. In general, NDVI values fall into four categories for analysis:

NDVI <= 130 = Not Irrigated
NDVI > 130 & <= 140 = Possibly Irrigated
NDVI > 140 & <= 150 = Likely Irrigated
NDVI > 150 = Irrigated



The next step in the analysis process involves coding crops that are considered irrigated, have a ‘Maj_Frac’ value >= 70% and are an index crop. In the above table, master ids 1797, 1798 and 1800 would fall into this category. Oats, barley and potatoes are all considered index crops and all three have ‘Maj_Frac’ values above 70%. Also, each one has at least one month with an NDVI value above 150. These crops can be coded into the ‘CROP_TYPE’ field with barley and potatoes being directly attributed and oats being coded as ‘SMALL_GRAINS’. This process is repeated for all index crops with some crops being coded as CDSS values as opposed to their actual value. This mostly happens with small grains, such as, oats, millet, and rye.

Once this process is finished and the high probability index crops have been coded, each index crop needs to be examined and coded. Start with analyzing each individual index crop by adjusting the selection to include those crops with ‘Maj_Frac’ of 60-70% and reducing the ‘Maj_Frac’ value down by increments of 10% until reaching ‘Maj_Frac’ >= 50%. This process can be done by analyzing groups of parcels visually and making determinations on crop type. Parcels with a ‘Maj_Frac’ below 50% need to be examined individually, taking into account the NDVI values over the growing season and potential farming practices (i.e. Alfalfa cuttings).



After working through each index crop, the NLCD crop types need to be examined. Using the NDVI values as a guide to determine effective irrigation, examine each NLCD crop type. Most of these crops will be coded as ‘GRASS_PASTURE’, with extents of each field being analyzed based on the coded NDVI scenes. Analyzing each parcel using this graduated approach allows for the delineation of effective irrigation. Areas of white and light grey can be considered irrigated with dark grey being a potentially irrigated area and black being non-irrigated. Also, using topographic maps and recent aerial photography allows for the discovery of high spots and physical features that may limit effective irrigation and thus causing a low NDVI value. In addition, these areas tend to be flood irrigated and the delineation of effective irrigation will have to be analyzed year to year due to water availability.

Attachment B
MEMORANDUM

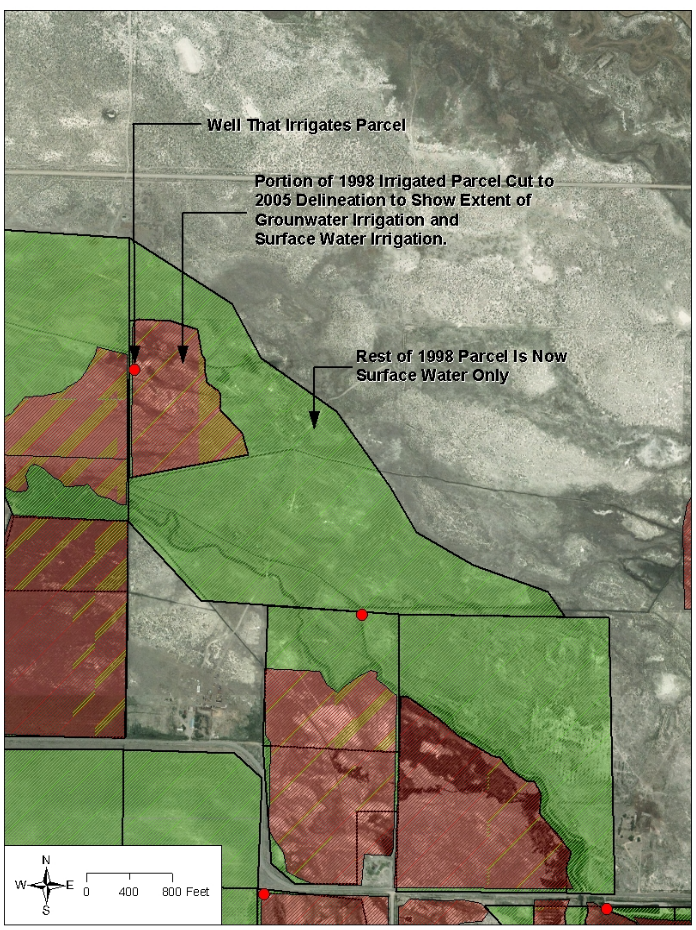
To: Mike Sullivan

From: Chris Brown, DWR GIS Program Manager

Date: October 13, 2010

Subject: 1998 Irrigated Parcel Edits for Division 3

In order to more accurately display the extent of groundwater irrigation in the Saguache area of Division 3, a number of irrigated parcels in the 1998 irrigated parcel file were cut to match the extent of groundwater irrigation in the 2005 irrigated parcel file. No acres were removed from irrigation but rather the extent of well supplied groundwater irrigation was trimmed. The figure below illustrates the type of edit that was performed.



The parcel shown was previously a combination of surface and groundwater irrigation. It was determined that the capacity of the well could not physically irrigate a parcel the size of the original 1998 parcels combined. To more accurately show the extent of groundwater assisted irrigation, the original parcel is now split into two parcels. The larger split is now surface water only irrigation and the smaller parcel is a combination of surface and groundwater irrigation. This type of edit was performed on 30 parcels in the Saguache area of Division 3.

Attachment 2

Agro Engineering; Kelley Thompson. November 7, 2011. *Summary of GIS data refinements by Agro Engineering between RGDSS Phase 5 and Phase 6 and Methodologies for Production of Irrigated Parcel Datasets.* Agro Engineering, Inc. Memorandum to James Heath, Mary Halstead, and Mike Sullivan; Colorado Division of Water Resources.

TO: James Heath, Mary Halstead, Mike Sullivan; Colorado DWR
FROM: Kelley Thompson; Agro Engineering Inc.
SUBJECT: Summary of GIS data refinements by Agro Engineering between RGDSS Phase 5 and Phase 6 and Methodologies for Production of Irrigated Parcel Datasets
DATE: November 7, 2011

This memo summarizes refinements and enhancements to GIS data that have been made by Agro Engineering between RGDSS Phase 5 and Phase 6. The methodologies that have been applied to the 1998, 2002, and 2005 irrigated parcel datasets are also described. For a more detailed description of data refinements and enhancements, please refer to the Agro Engineering reports and memos listed under "References". Some data methodologies, results, or details described in the original reports for the 2002 and 2005 datasets may have been subsequently refined or enhanced for finalized phase 6 datasets as described in subsequent reports or in this report.

Refinements between Phase 5 and Phase 6 Models – Agro Engineering, Inc.

Production of new irrigated parcel datasets for years 2002 and 2005, and revision of the 1998 dataset, using a consistent application of improved methodology, data, and imagery.
New datasets for year 2002 and 2005 were produced using improved methodologies and application of improved data and imagery sources. The 2002 dataset represents parcels irrigated in an extreme drought year while the 2005 dataset represents current parcels during a more average water year. Irrigated parcels for 1998 were revised using the improved methodologies and imagery sources used in the 2002 and 2005 datasets. The improved methodologies that have been applied to the current datasets are described in a following section.

Improvements to assignment of well water sources to irrigated parcels.
In the phase 5 model, wells were assigned to parcels using an automated spatial based process. The Division of Water Resources has made significant improvements to the well information in Hydrobase and most active wells have now been located with GPS coordinates. The spatial methodology was repeated using the improved well locations as a base, but then the automated assignments were improved significantly using: 1) evaluation of physical constraints and irrigation practices (i.e. wells do not typically cross highways or rivers or to up-gradient quarter sections), 2) comparison of well ownership within a parcel or to available parcel ownership, 3) comparison of 2009 meter pumping records with parcel size and water sources, 4) interpretation of physical infrastructure visible in aerial photography, and 5) evaluation of 2002 satellite imagery particularly in areas of flood irrigation that received little or no surface water in 2002. Well assignment changes that were made by Hendricks and Slattery in phase 5 were maintained where still appropriate, and additional assignments were changed through several meetings with water groups and with water commissioners. These improved well assignments were applied to the 1998, 2002, and 2005 irrigated parcel datasets.

Improvements to ditch service area mapping
A number of ditch service areas that were missing in the original phase 5 dataset were added, and limited improvements were made to existing ditch service area coverages. Most of new service areas were located outside of the groundwater model area on tributaries, and mapping of headgates, user reported acres, and canal lines and irrigated areas visible in aerial photography

could often be used to delineate these service areas. The original dataset was drawn somewhat roughly using USGS topo maps. Many service areas were improved on a small scale using roads, canal lines, parcel boundaries, user reported acreages, or actual irrigations visible in high resolution color aerial photography. Additional changes were facilitated through interviews and correspondence with ditch companies, water users, and water commissioners.

Reprocessing of native lands classification theme considering revised 1998 irrigated parcels
The native-lands classification theme describes land cover outside of irrigated parcel boundaries. As the 1998 irrigated parcels were revised and re-delineated, the new 1998 parcel boundaries were used to remove the irrigated area from original full native-lands classification theme. The original theme in UTM NAD27 projection was re-projected to UTM NAD83.

Improvement of fractioning methodology for assignment of multiple ditch sources
In some areas, multiple ditch service areas overlap individual irrigated parcels indicating that the parcel may have rights to multiple ditch sources. Therefore, coverage fractions are indicated in the irrigated parcel datasets for each surface water source so that area and consumptive use is not double counted. For the phase 5 dataset, this fraction was based purely on the spatial area of the parcel covered by each overlapping ditch. Small “slivers” of parcel areas covered or not covered by ditches are likely a result of mapping inaccuracies. Therefore, for the new 1998, 2002, and 2005 irrigated parcel datasets, ditch coverage areas of between 90% and 100% or less than 10% of the total parcel area were rounded to an area of 100% and 0% of the total parcel area, respectively, prior to calculation of fractional coverage.

Addition of cover crop, fall winter wheat, and new alfalfa crop types
The original datasets included crops of grain, potatoes, vegetables, alfalfa, and pasture grass. New crop types of cover crop, fall winter wheat, and new alfalfa were included in the new 1998, 2002, and 2005 irrigated parcel datasets along with appropriate crop coefficients in StateCU. The new crop types were included in the crop classifications and spectral analyses.

The spectral signature for cover crops reflected crops that were significantly water short under a center pivot sprinkler. Areas of “cover crops” were relatively small in 1998 and 2002. Since the 2002/2003 drought, more farms with reduced well water supplies having been using cover crops in rotation with potatoes and many cover crops can control nematodes and increase soil organics. In the 2005 dataset, the primary cover crop was sudan grass that was significantly shorted water but also included radishes, mustards, and other poorly irrigated grass-type covers. Estimates of crop evapo-transpiration from both actual recorded irrigations on fields of sudan grass and from the median satellite NDVI response from the cover crop parcels classified in 2005 were used to estimate average crop coefficients representing supply limitation for use in StateCU.

The spectral signature for fall winter wheat was a crop under center pivot irrigation where there was no NDVI greenness response throughout the summer months but became green in the fall. Only a few fields were identified as fall winter wheat but helped explain some fields that were previously defined as fallow. Standard fall winter wheat crop coefficients were used.

About every five years, alfalfa crops are often replaced for about one year then replanted. Methods and planting dates for new alfalfa crops can vary. However, the spectral signature for new alfalfa was a field that was fallow or with reduced water use through July or August but appeared similar to alfalfa after this time. For these later planted fields, there is less early season water use and this was reflected in the new alfalfa crop coefficients with a later start date.

Refinement of Sprinkler Acreage Timeline

For phase 5, mapping of sprinklers by the RGWCD was used to define the timeline of the sprinkler irrigation area from the 1970s until 1997 while the 1998 irrigated parcel mapping was used for 1998. Under many structures, there was a discontinuity between 1997 and 1998 areas primarily because a) fallow sprinklers or portions of sprinklers are not included in the GIS mapping of "irrigated" parcels while the RGWCD data shows all sprinklers regardless of cropping, and b) the GIS datasets were delineated using 1-meter aerial photography while the RGWCD data was represented with standard sized circles. For the phase 6 model, imagery and GIS was used to refine the timeline of areas irrigated with sprinklers through 2009.

A GIS database was constructed to associate the areas of sprinklers mapped in 1998, 2002, and 2005 at a particular location (i.e. quarter section) and the date of installation indicated in the RGWCD mapping. Several sprinkler parcels indicated in the RGWCD mapping that were no longer used by 1998 were also included. For all new sprinkler systems installed between 1998 and 2009, annual satellite and aerial imagery was used to define the precise years when these new sprinklers were installed. If the RGWCD mapping indicated that a sprinkler system was installed, dismantled, or changed in the 1984 to 1998 time period, all available Landsat "Quicklook" images (available at about 3 year intervals) were used to verify the actual year of change, and the area of some oddly (large) sized sprinklers was delineated. For sprinklers installed prior to 1984, the first year the sprinkler appeared in RGWCD maps was used.

The areas of many individual sprinkler systems have changed over time, and a certain portion of sprinkler systems are fallow every year. Mapping of full sprinkler areas including fallow or partially fallow areas was maintained for the 1998, 2002, and 2005 datasets and represented in the database. For partial or fully fallowed sprinkler system parcels, a "percent irrigated" value was calculated. It was considered that sprinkler systems would have been used fully in the year it was installed, so the percent irrigated value was interpolated from a value of one in the either the year the sprinkler was installed or 1975 to its percent irrigated in 1998. Annual sprinkler areas from its year of installation through 2001 were assumed to equal the sprinkler system areas mapped in 1998 multiplied by the annual "percent irrigated". The year 2002 mapping was used only for 2002. The sprinkler area from 2003 through 2009 was taken from the total sprinkler area in 2005. For sprinklers installed after 2005, the sprinkler was typically drawn from the new aerial photography available in 2009. As in phase 5, the areas of sprinkler systems present in 1975 was interpolated to zero in 1970.

New Methodologies for Production of Irrigated Parcel Datasets

Parcel Delineation

For the original 1998 dataset, parcels were delineated using IRS 5-meter satellite panchromatic imagery fused to 30-meter Landsat imagery as aerial photography was not available when the set was produced. Parcels for 1998 were re-delineated using black and white mosaiked digital ortho-photo quarter-quad (DOQQ) aerial photos with 1-meter resolution that were acquired by the United States Geological Survey (USGS) primarily in 1998 (with a limited number acquired in 1999). Parcels for 2002 were delineated using a combination of the same 1998/1999 DOQQs and 1-meter resolution color aerial section photos of the valley acquired in 2003. For the 2005 dataset, parcels were delineated using 1-meter resolution National Agricultural Imagery Program (NAIP) mosaics of color aerial quarter-quad photos acquired for the USDA-FSA-APFO.

Satellite Imagery

Use of multiple satellite images throughout the growing season is important in order to capture sporadic irrigation and seasonal crop growth patterns. Satellite imagery from the USGS Landsat-5 thematic-mapper (TM) and Landsat-7 enhanced-thematic-mapper (ETM) sensors were used for identification of irrigated parcels and crop classification. For the original 1998 dataset, only three Landsat-5 satellite images were used. For the 2002 dataset, eight satellite images were used (7 Landsat-7, 1 Landsat-5), while 13 Landsat-5 satellite images were used for development of the 2005 dataset. For reprocessing of the 1998 dataset, 20 Landsat-5 satellite images were used. For these three sets, nearly equal number of images covering the east and west flight paths over the San Luis Valley were used. Ortho-rectified Level 1 imagery using the USGS's most current geometric and radiometric standards was used. Changes in atmospheric and sensor properties cause significant inconsistencies between unprocessed satellite images. In order to allow combination and comparison of multiple satellite images, satellite TM data was standardized to a measure of planetary reflectance using the methodology presented in Chander et al. (2009).

Irrigated Threshhold Imagery

The irrigated parcel datasets are meant to represent only the parcels or portions of parcels that were irrigated in the given year. An irrigated threshold image was used during parcel delineation to evaluate if a parcel or a portion of parcel was potentially irrigated during the year. The normalized difference vegetation index (NDVI) ratio is used extensively to characterize the density of healthy vegetative biomass and is a partially normalized ratio scaled from minus one to positive one. The higher the NDVI value, the greener and more vigorous the vegetation is, and the NDVI of agricultural fields can directly reflect water supply and irrigation. NDVI images were produced for all of the processed Landsat satellite images for 1998, 2002, and 2005. A NDVI threshold image was developed by finding the maximum NDVI value from all images at each pixel and using representative colors. This image represented the "greenest" that an area became throughout the entire growing season so that the entire year could be considered at once to discriminate between irrigated and non-irrigated lands. Following assignment of well and surface water sources, green parcels that did not have an apparent surface or ground water source and may have been supplied only by sub-irrigation were removed.

Reference:

Chander, G., B.L. Markham, and D.L. Helder. 2009. Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 ALIS Sensors. Remote Sensing of the Environment 113 (2009) 893-903.

Crop Classification

The classification of irrigated lands consisted of three steps: (1) an initial determination of crop type based on multiple sources of available data, (2) a multi-spectral satellite classification and a subsequent multi-temporal probability analysis, and (3) classification refinements.

The initial crop type assignment was based upon a visual comparison of: 1) color aerial photography, 2) a colored composite of NDVI images from Landsat satellite imagery, 3) crop information from the Rio Grande Water Conservation District (RGWCD), and 4) knowledge of regional cropping practices and crop information from Agro Engineering data. For many areas, an initial distinction between alfalfa and grass hay was made using the aerial photography.

A supervised multi-spectral classification was then performed for each of the processed satellite images using a Bayesian classifier. Training sites included potatoes, grain, alfalfa, new alfalfa, pasture grass, canola, oat hay, sudan grass, winter wheat, other cover crops, and fallow; and multi-spectral signatures for Landsat bands one through five were used. For each satellite image, the probability that each pixel within the image was a particular crop type was estimated, and buffered parcel boundaries were used to find the mean parcel crop type probability for each date for each parcel. The probability that a parcel was a particular crop type was then summed across all images, and the crop type with the maximum overall seasonal probability was chosen as the most probable crop type for the parcel. Due to crop variability, vegetable fields were not classified using the satellite imagery but were maintained from the other data sources.

Classifications were refined, and parcels that were classified differently between the initial determination and the multi-spectral classification were re-evaluated. When available, RGWCD and Agro crop data was typically favored unless imagery crop patterns appeared definitive.

References

Thompson, Kelley L., February 19, 2005, report to Rio Grande Water Conservation District, Colorado Water Conservation Board, Conejos Water Conservancy District, Rio Grande Water Users Association, Alamosa La Jara Water Conservancy District, San Luis Valley Irrigation Well Owners Association, Rio Grande Canal Water Users Association, and Saguache Creek Water Users Association. *2002 Division 3 Irrigated Lands Assessment and Groundwater Use Evaluation.* Agro Engineering, Alamosa, Colorado.

Thompson, Kelley and Kirk Thompson, January 2010, report to Colorado Water Conservation Board and Colorado Division of Water Resources. *RGDSS Irrigated Land Coverage Enhancements and 2005 Irrigated Lands Assessment.* Agro Engineering, Alamosa, Colorado.

Thompson, Kelley, July 23, 2010, memo to RGDSS Model Peer Review Team. *Integration of Interview Data into RGDSS ditch and irrigated parcel datasets*. Agro Engineering, Alamosa, Colorado.

Thompson, Kelley, March 22, 2011, memo to James Heath. *Interview with Monty Smith representing Trinchera Subdistrict Area*. Agro Engineering, Alamosa, Colorado.

Thompson, Kelley and Kirk Thompson, March 2011, memo to James Heath, Mary Halstead, and Mike Sullivan; Colorado Division of Water Resources. *Revision of 1998, 2002, and 2005 RGDSS Irrigated Parcels*. Agro Engineering, Alamosa, Colorado.

Attachment 3

Agro Engineering; Kelley Thompson and Kirk R. Thompson. March 2011. *Revision of 1998, 2002, and 2005 RGDSS Irrigated Parcels – Project Task Summaries*. Memorandum to James Heath, Mary Halstead, and Mike Sullivan; Colorado Division of Water Resources.

TO: James Heath, Mary Halstead, Mike Sullivan; Colorado DWR
FROM: Kelley Thompson, Kirk Thompson; Agro Engineering Inc.
SUBJECT: Revision of 1998, 2002, and 2005 RGDSS Irrigated Parcels – Project Tasks
DATE: March 2011

Three GIS datasets characterizing irrigated parcels in the San Luis Valley (Division 3) for the years 1998, 2002, and 2005 have been produced by Agro Engineering for use in the Rio Grande Decision Support System (RGDSS) models. As part of phase 6 improvements to the RGDSS model and model data, Agro Engineering completed a number of tasks under two contracts. The first contract (A) was primarily focused on improving the 1998 irrigated land dataset using the improved methodologies used to develop the 2002 and 2005 datasets and applied several changes to all three datasets to improve consistency between the datasets. The second contract (B) focused on a number of smaller tasks to improve data in the irrigated datasets and evaluate modeling methodologies that were identified by the RGDSS groundwater model review group during a modeling workshop.

PROJECT "A"

For the first contract (A), the improved methodologies for processing of satellite imagery, delineation of irrigated parcels, assessing crop types, and evaluation of irrigated vs. non-irrigated parcels irrigated parcel dataset used to develop the 2002 and 2005 datasets were applied to the 1998 dataset to improve the consistency of data between these years. Several additional improvements were also applied to all three datasets.

TASK A1: Revision of 1998 Irrigated Parcels

Satellite Image Processing
It has been found that use of multiple satellite images throughout the growing season is important for both assessment of irrigated vs. non-irrigated parcels and accurate crop classification. For the original 1998 dataset, three satellite images were used for classification. For development of the 2002 dataset, eight satellite images were used, while 13 satellite images were used for development of the 2005 dataset. For reprocessing of the 1998 dataset, a total of 20 relatively cloud-free Landsat TM-5 satellite images from April through October were acquired as shown in Table 1.

Table 1. Landsat Imagery Acquired for 1998

West Images – path/row 34/34	East Images – path/row 33/34
4/1/98	4/10/98
5/3/98	5/12/98
6/4/98	5/28/98
6/20/98	6/13/98
7/22/98	6/29/98
8/7/98	7/15/98
8/23/98	8/16/98
9/8/98	9/17/98
9/24/98	10/3/98
10/10/98	10/19/98

Two Landsat TM-5 image "paths" are required to cover the San Luis Valley. The east and west images overlap over much of the central portion of the San Luis Valley, while Costilla County is covered only by the east images and portions of western Rio Grande County and northwestern Saguache County are only covered by the west images. An even number of west (10) and east (10) images were acquired.

The ortho-rectified Level 1 (L1) imagery obtained from the USGS was first converted to an at-sensor radiance (L in Watts / (square meter*sr*µm)) for each band (λ) using the gains and biases originally used in the L1 processing. Spectral radiance could then be converted to top-of-atmosphere planetary reflectance by normalizing for solar irradiances arising from spectral band differences. The following equation calculates planetary reflectance (P) using the earth-sun distance in astronomical units (d), mean solar exo-atmospheric irradiances (ESUN), and the solar zenith angle (θ) in degrees. Constants found in the image header files and in Chander et. al. (2009) were used.

$$L_\lambda = G_{rescale} \times Q_{cal} + B_{rescale} \qquad p_\lambda = \frac{\pi \; L_\lambda \; d^2}{ESUN_\lambda \; \cos(\theta)}$$

Cloud and cloud shadows in the imagery produce erroneous results if not masked. For each Landsat image set, band 1 (blue) and band 4 (near-infrared) were used to visually search for and delineate cloud and cloud shadows, and a mask of zero pixel value was placed in the processed imagery across all areas affected by clouds.

The normalized difference vegetation index (NDVI) is used extensively to characterize the density of vegetative biomass. NDVI can be calculated from Landsat TM data using the following formulas where TM 3 represents the Landsat TM red band and TM 4 represents the Landsat TM near-infrared band.

$$NDVI = \frac{TM\ 4 - TM\ 3}{TM\ 4 + TM\ 3}$$

NDVI images were produced for all 20 of the Landsat TM scenes. An Erdas Imagine (.img) multiband image was produced to "hold" all NDVI images. This image was often queried at a point to examine NDVI values across the entire year. A separate NDVI "three-color" image was produced by combining east and west image pairs for June, July, and August and using the monthly composites to represent the colors blue, green, and red, respectively. This image colored by "time period"of greenness was useful for noting crop differences for division of split-cropped fields and visually interpreting crop types.

A multi-temporal NDVI threshold image was developed by finding the maximum NDVI value from all twenty NDVI images at each pixel. This image represented the "greenest" that an area became throughout the entire growing season so that the entire year could be considered at once while discriminating between irrigated and non-irrigated lands. The image was scaled so that NDVI values above 0.5 were colored shades of green, colors for NDVI values between 0.3 and 0.5 varied from a light grey to bright white, and NDVI values below 0.3 were all colored as black.

Parcel Delineation

For the original 1998 dataset, parcels were delineated using IRS 5-meter satellite panchromatic imagery fused to 30-meter Landsat imagery as aerial photography was not available in 1999. After completion of the 1998 project, a complete set of black and white digital ortho-photo quarter-quad (DOQQ) aerial photos for the San Luis Valley was scanned by the USGS to 1-meter resolution, geo-referenced to UTM NAD83 (Zone13N), and mosaiked by county. The majority of the photos for these mosaics were acquired in 1998. However, it was found that the majority of the photos in Saguache County and Costilla County were actually acquired in 1999.

Most sprinklers did not change between 1998 and 2002. For the 2002 dataset, parcels were delineated using the 1998/1999 photography for the study of year 2002. As part of the 2005 project, sprinkler parcels in the 1998 set were replaced with the equivalent sprinkler boundaries drawn for the 2002 set. Changes between 1998 and 2002, primarily in the dividing of sprinkler parcels for split crops, where noted and parcels were adapted appropriately.

For the current studies, parcels irrigated by flood irrigation were re-delineated using the higher resolution aerial photography and the NDVI irrigated threshold imagery. Irrigated parcels were generally delineated when the aerial photography indicated an appropriate agricultural parcel, the NDVI image indicated that it was sufficiently green in 1998, and ditch and well mapping indicated there was a surface or ground water source for irrigation. Boundaries were often defined by noticeable boundaries such as fences, ditches, or roads; and by uniform areas of crops, cropping practices, irrigation systems, and water sources.

The same criteria used to distinguish between irrigated and non-irrigated parcels used for the 2002 and 2005 sets was used for the 1998 set. In areas with generally high groundwater tables, parcels were considered irrigated if maximum NDVI was consistently greater than 0.5, while in areas with lower ground water a consistent NDVI response of at least 0.4 was used to define irrigated. In areas with very little native vegetation and/or particularly bright soils (such as highly alkaline areas), a median NDVI threshold of 0.3 was sometimes used when aerial photos provided visual indications that suggested irrigation in 1998 (such as standing water).

In the majority of the valley area, parcel boundaries from 2005 were copied from the 2005 dataset to the 1998 dataset if parcel boundaries appeared relatively unchanged between the two years. In many cases, the copied parcel was adjusted to add to or remove irrigated portions when the NDVI imagery indicated additional or less irrigated area in 1998. In some cases, a 2002 parcel was more appropriate than a parcel from 2005, and parcels were copied from the 2002 dataset.

For 1998, over 10,800 flood-irrigated parcels covering over 315,600 acres were delineated. Along with sprinkler-irrigated parcels, over 13,400 parcels covering over 584,300 acres were delineated and defined as irrigated for 1998 in the San Luis Valley.

Crop Classification

Crop types were re-evaluated for 1998 using methodologies similar to the 2002 and 2005 studies.

The original 1998 crop classification relied heavily on parcel crop information collected by the Rio Grande Water Conservation District (RGWCD). The RGWCD conducts an annual field investigation to document crops in the central portion of Division 3. The 1998 RGWCD crop study did not extend west of Del Norte, north of road N in Saguache County, or into Conejos or Costilla Counties; and generally concentrated more on center pivot crop lands than river-land and flood irrigated areas. A supervised imagery crop classification was performed using the RGWCD for training sites.

Crops were re-classified for 1998 using a multi-spectral satellite classification and subsequent multi-temporal probability analysis with the twenty newly-processed satellite images and using the original 1998 crop classification as training sites. Fields of newly planted alfalfa that could identified in the imagery were added to the training sites, while known fields of vegetables (primarily carrots and lettuce) where not included in the classification. For each satellite image, files for each crop were created from the Bayesian classifier that estimated the probability that each pixel within the image belonged to a particular crop type given the similarity between the spectral characteristics of the pixel and the crop signature files that were developed for that image. The mean parcel crop type probability for each date was then calculated as the mean of each pixel within each buffered parcel area. The probability that a parcel was a particular crop type was then summed across the twenty images. The crop type with the maximum overall seasonal probability was chosen as the most probable crop type for the parcel.

Fields with new classifications that differed from original classifications were individually examined using visual examinations of aerial photography and the NDVI "three-color" image and a spot query of all seasonal NDVI values at a point. The seasonal variation of NDVI in a field often gave important indications of crop type for these fields. The spectral crop classification was used primarily for sprinkler-irrigated fields, while aerial photos were relied on more for flood-irrigated parcels. For flood-irrigated fields, alfalfa was often distinguished from grass pasture due to a darker coloration, visible linear dikes for flood or furrow irrigation, more regularly shaped boundaries, and more uniform coloration.

The crop for 92 sprinkler-irrigated fields totaling 7,187 acres was changed from the original 1998 classifications to the new classifications. For sprinklers and for the primary sprinkler crops of potatoes, small grains (including oat hay and canola), and alfalfa (including new alfalfa), the new multi-spectral classification agreed 97% with the final crop type chosen. This value of 97% can be considered a measure of the classification accuracy, although it is not a truly independent statistical measure. In addition to the sprinkler primary crops and the grass pasture crop type that is predominant in flood irrigated areas, the new 1998 crop classifications include new alfalfa, fall winter wheat, vegetables, and cover crops. Fall winter wheat describes winter wheat that was planted in a field that was fallow all summer.

TASK A2: Modification of Crop Types in 2002 and 2005 Irrigated Parcels

For the 2002 and 2005 irrigated parcel datasets, the crop types of oat hay and cover crops (2005) were classified independently. However, for the final datasets, these crops were added to the grass pasture classification. Therefore, the original classification results for the 2002 and 2005 studies were re-evaluated, and oat hay and cover crops (for 2005) were re-classified to small grains and cover crops, respectively. Therefore, these minor crops are now handled similarly in the 1998, 2002, and 2005 datasets.

In addition to crop types, the overall area of the 2002 and 2005 irrigated parcels changed somewhat due to additional evaluation of cover crop and winter wheat crops (several of these parcels had been considered fallow), addition of parcels that are temporarily but not permanently inundated with water (on the Alamosa Wildlife Refuge, Monte Vista Wildlife Refuge, and Russell Lake wildlife areas), addition of several small grass areas that are irrigated by dedicated irrigation/non-municipal wells (in Mosca, Hooper, Moffat, Ft Garland, Monte Vista, Alamosa, and Del Norte), and deletion of some marginal grass pasture parcels based on interviews with water users and managers that these parcels were supported by sub-irrigation rather than directly irrigated.

TASK A3: Preparation of Data and Deliverables

The 1998 GIS irrigated coverage were prepared for use in the RGDSS models. The well assignments that were developed previously for the 1998 set as part of the 2005 study were adapted to the revised 1998 set. Some refinements were made to the ditch service areas through the re-delineation of flood parcels primarily on upper stream tributaries outside the groundwater model area. Ditch surface areas were reassigned using the current fractional parcel methodology with fractional coverages smaller than 10% discarded and greater than 90% rounded up to 100%.

Table 2. TASK A RESULTS:

YEAR:	1998			2002			2005		
CROP	new		old	new		old	new		old
	(num)	(acres)	(acres	(num)	(acres)	(acres	(num)	(acres)	(acres
Potatoes	738	77524	77665	667	73005	73012	689	64366	63725
Small Grains	1426	108432	112727	938	82943	76673	1110	78326	64700
Alfalfa	3957	127442	137763	3078	146833	146926	3708	146689	168131
New Alfalfa	125	12241					167	12482	
Grass Pasture	7097	248199	271594	3669	114688	124906	5860	199631	212906
Vegetables	99	8282	7337	52	5701	5701	73	5509	5377
Cover Crop	22	1848					97	6077	
Wheat Fall	4	394					45	2670	
TOTAL	13468	584362	607086	8404	423170	427218	11749	515750	514838

PROJECT "B"

A number of tasks were identified by the RGDSS groundwater model peer review team that were completed by Agro Engineering to both evaluate and improve model methodologies and make continued improvements to the irrigated lands datasets.

TASK B1. Identify sprinklers under Rio Grande Canal where surface water is used for irrigation.

For several large ditches such as the Rio Grande Canal, the model assumes that sprinklers use only pumped well water. In order to evaluate the number of fields that violate this assumption, Agro Engineering client records and one day of field survey was used to identify sprinklers in the Rio Grande Canal service area that use surface water directly for irrigation. A separate memo was prepared for this task (attached).

TASK B2. Compare Agro Weather Station ET to StateCU ET estimates for 2009.

The ET estimates produced by StateCU using the Monte Vista and Del Norte weather stations indicate relatively low ET for 2009. Weather data from Agro Engineering's weather station network was used to compare ET using a modified Hargreaves approach to estimates produced by StateCU for 2009 in order to understand why the Monte Vista and Del Norte stations indicate lower ET. A separate memo was prepared for this task (attached).

TASK B3. Incorporate Orphan wells into irrigated lands sets and compare ground water parcel areas to 2009 flow meter data for reasonableness.

The state produced a list of "orphan wells" which were a list of wells that were deemed active, many (but not all) with meter data for 2009. Orphan wells with listed or suspected uses of irrigation were evaluated within GIS using aerial photos and satellite imagery.

A number of these wells were identified that likely irrigated existing parcels in the 1998, 2002, and/or 2005 datasets, and the well identifiers (WDIDs) were associated with the existing parcels. For most of these parcels, other wells had already been identified that served the parcel and then additional orphan wells provided additional supplemental supply. Wells were associated with several parcels that had previously only been associated with surface water supplies.

A number of the identified orphan wells were decreed or permitted as irrigation wells (not municipal), had decreed or permitted flow rates greater than 50 gpm, and irrigated primarily lawn grass areas in the study years. These parcels were mainly associated with schools in Sargent, Del Norte, Moffat, Hooper, Mosca, and Ft. Garland; Adams State College, and the Homelake Veterans Center, and small irrigated parcels were developed using aerial photography and added to the irrigated lands datasets.

A number of wells identified as orphan wells were not added to the irrigated lands sets as they were deemed to not being actively used for irrigation purposes or were not actively used in the years of 1998, 2002, or 2005. There were 2 wells that were used in new center pivots that were installed in 2008 and 2009, but did not appear to be in use in 1998, 2002, or 2005. These wells would be included if a newer irrigated lands dataset (such as for 2008 or 2009) was developed.

In total, about 130 identified orphan wells were added to the irrigated lands datasets while about 20 were not added to the irrigated lands sets.

In the irrigated lands datasets, single parcels are associated with multiple wells. A database was developed that aggregated parcel data so that the irrigated area associated with each well was calculated. A range of reasonable irrigation water requirements was used along with the 2009 meter data to flag wells that were potentially associated with an excessive or insufficient amount of irrigated acres. Where the total acres associated with a well did not appear reasonable, parcels were examined using aerial photos and satellite images to discern if visible infrastructure and irrigation practices suggested changes in well assignments.

A number of changes in well assignments were made. The comparison pointed out several situations where a well with limited use had been associated with a very large flood irrigated parcel, and in some cases efforts the large parcels where broken up to reduce the areas associated with groundwater supply to the area that looked to be irrigated in 2002 or to areas that looked to be directly irrigated with the well given ditches and flow paths visible in the aerial photography. For wells that were associated with a number of parcels but had low 2009 meter readings compared to their area, the greenness of the associated parcels in 2002 were re-evaluated. For these wells, the well service was removed from a parcel when the 2002 NDVI greenness was very near the "irrigated threshold greenness" and it was possible that the parcel was actually not irrigated in 2002.

However, less well assignments were changed with the evaluation that originally anticipated. In comparing associated well acreages to 2009 meter readings, the possibility that surface water supplies could supply most or all of a parcels supply had to be acknowledged. It was also acknowledged that sub-irrigation could be providing part of the parcels water supply, the parcel could be shorted from a full water supply, or the parcel may have been fallow in 2009 but was not fallow in 2005 or other years. The general prospective of the GIS data was maintained that well assignments represented where a well could reasonably be used in a single year.

TASK B4. Refine Timeline of Sprinkler Acreages.

For previous model efforts, mapping of sprinklers by the RGWCD was used to define the timeline of the area of sprinkler systems from the 1970s until 1997 and the 1998, 2002, and 2005 irrigated datasets were used to define sprinkler areas for those years while interpolation was used to estimate areas of sprinkler systems for intermediate years.

A common mapping database was constructed to associate a sprinkler system location to both the areas of the same sprinkler systems mapped in 1998, 2002, and 2005 as well as the sprinkler shapes mapped by the RGWCD prior to 1998. The common shape represented the full system area including any portions of the sprinkler area that had been fallow in individual years. For several sprinkler systems mapped by the RGWCD, it was deduced that the mapping location was somewhat off the annual series represented by the RGWCD was associated with a system in a slightly different location.

For all new sprinkler systems installed between 1998 and 2009, annual satellite and aerial imagery was used to define the precise years when these sprinklers were installed. For each of these years, the Landsat satellite near-infrared band for an east and west image was processed and displayed. For these new sprinkler systems, response to greenness in the the near-infrared often indicated the first year the system was used. Agro Engineering collected color aerial section photos of nearly the entire valley in 2003, 2008, and 2010; and these photos along with the high-resolution DOQQ and NAIP aerial imagery available for 1998, 2005, 2006 (at a lower 2m resolution), and 2009 was often used to verify interpretations of the satellite imagery.

If the RGWCD mapping indicated that a sprinkler system was installed or dismantled/changed in the 1984 to 1998 time period, easily available Landsat satellite imagery was also used to verify the year of these changes. All available Landsat satellite "Quicklook" images (natural color rather than near-infrared) were downloaded for years between the deployment of the satellite in 1984 and 1998 (available at about 3 year intervals). In many cases, the imagery indicated that the sprinkler system changes actually occurred several years before they were mapped by the RGWCD.

The areas of many individual sprinkler systems have changed over time. In particular, endguns and corner systems were removed from many systems in 2003. The areas of the sprinkler parcel boundaries, drawn using 1-m aerial photography, were noted explicitly for 1998, 2002, and 2005 in the common sprinkler "database". Areas for sprinklers for years prior to 1998 through 2001 were assumed to equal the sprinkler system areas mapped in 1998. The year 2002 mapping was used only for year 2002; although it should be noted that the new boundaries for 1998 were taken directly from the newer 2002 work if the boundary did not change. The sprinkler area from 2003 through 2009 was typically taken from the total sprinkler area in 2005. For sprinklers installed after 2005, the sprinkler was typically drawn from the new aerial photography available in 2009.

In past modeling efforts, the area of sprinkler systems present in 1975 was interpolated to an area of zero in 1970. A number of sprinkler systems did have partial or full fallow areas in 1998, 2002, or 2005, and a "percent irrigated" value was calculated for each of these years. The "percent irrigated" value for sprinklers partially or fully fallow in 1998 was interpolated to a value of one in the either the year the sprinkler was installed or 1975. Although the irrigated area of an individual sprinkler would not respond in this way, this should help maintain a representation of typical annual "fallowness" quantified in 1998 to the years nearest to 1998 when aggregated across an entire ditch system.

The database for individual sprinkler systems was assigned to the system mapping from 2005 (or 2009 if installed after 2005). These areas were intersected with the ditch service area mapping, and the identical fractional methodology used to assign percent coverage by ditch to irrigated parcels was used to assign ditch coverage to each sprinkler. The program script was then used to aggregate sprinkler areas by ditch for every year between 1970 and 2009 and generate an appropriate sprinkler area text file for use in StateCU.

TASK B5. Develop Crop Curves for "Cover Crops"

Areas of "cover crops" were relatively insignificant in 1998 and 2002. However, since the 2002 drought, use of cover crops in the San Luis Valley has increased. With diminished well water supplies particularly in the eastern portion of the cropped closed basin area, more farms are splitting center pivot fields with half potatoes and the other half a cover crop. Lower returns for grain crops and recent findings that plowing under a cover crop as a “green manure” can control soil pests such as nematodes and amend soil organics has also increased cover crop use.

The designation of a “cover crop” in the irrigated lands datasets included a wide range of actual crop types. The spectral signature used to classify cover crops generally identified crops that were provided significantly less than a full water supply. In the 2005 dataset, the primary crop was sudan grass that was significantly shorted water but also included radishes, mustards, and other poorly irrigated grass-type covers.

Cover crops had been identified as a spectral class in the original 2005 study, but these crops were identified as “grass_pasture” for the dataset originally entered into the RGDSS. These identified crops were re-designated as “cover_crop” for the new dataset. About 6000 acres of cover crops were identified in the 2005 irrigated lands dataset. The spectral class was also included in the new spectral evaluation of the 1998 irrigated lands dataset, about 1800 acres were identified in the 1998 set.

In order to assist in the evaluation crop coefficients for these cover crops, Agro re-examined irrigation schedules and estimated evapotranspiration for several fields of sudan grass for which it provided irrigation water management services in 2007. Water use statistics are shown for these fields in the following table. Rainfall amounts measured near the fields and irrigation from a center pivot sprinkler totaled between 7.6 inches and 10.4 inches. Modeled evapotranspiration (ET) rates ranged from about 7.9 to 9.5 inches with an average of 8.6 inches. For these particular fields, the irrigation and subsequent water use was generally highest early and late season. The irrigation was based on available water supply and the crop was significantly shorted water for extended periods.

Table 3. Irrigation and Modeled Evapotranspirations for Sudan Grass Fields (inches)

	Irrigation	Rain	Total App.	Modeled ET
MIN	4.40	3.20	7.60	7.92
AVG	5.20	3.63	8.83	8.57
MAX	5.75	4.70	10.40	9.53

Agro Engineering also evaluated the NDVI spectral signature curves that represent the “median” seasonal pattern of fields classified as “cover_crops” in the 2005 irrigated lands dataset. The “median” seasonal pattern of water use of cover crop fields across Division 3 as indicated by NDVI was more generally centered at the center of the growing season. For the “median” field, greenness increased beginning in early July, peaked near the first of August, but was dry by the end of August. ET estimation methods using satellite NDVI indicated a water use for this “median” field between 7 and 9 inches of water.

This information was provided to Leonard Rice who developed the actual “cover_crop” crop coefficients for use in StateCU. Reportedly, the new “cover_crop” coefficients generally yield an annual consumptive use rate of between about 8 and 10 inches given annual variations in weather. It is important to note that the cover crops, and particularly sudan grass, have a much higher potential consumptive use if given a full water supply. In contrast to the other crops in the RGDSS for which StateCU estimates a full potential consumptive use, the estimates of consumptive use for “cover_crop” produced by StateCU will be supply limited.

TASK B6. Evaluate sub-irrigated ET Curves for irrigated lands and native lands.

Agro reviewed literature and evaluated if the irrigated crop ground water ET curves could be refined. A separate memo was prepared for this task (attached).

TASK B7. Recut Native Lands Classification from 1998 irrigated parcels.

The original native lands classification image was re-vectorized. As the original image was prepared in the UTM NAD27 projection, vectors were re-projected to UTM NAD83. The native lands vectors were then unioned with the new 1998 irrigated lands dataset and the 1998 parcel boundaries were effectively "cut" from the native lands vectors so that the theme represented the classification of areas outside of irrigated parcels.

TASK B8. Evaluate mapping of well assignments and incorporate changes

Mapping of well assignments to irrigated parcels was evaluated with several groups of water users and water managers, and their comments and changes were incorporated in the GIS.

AMEC evaluated well assignment mapping with water users of the Conejos (and San Antonio) River. Modifications and changes were drawn on several maps organized by ditch system. Agro Engineering attended a meeting with primarily water commissioners that serve areas throughout Division 3 organized by the state. Agro Engineering prepared maps for the Saguache Creek and San Luis Creek areas that were used by others to collect user information. Although beyond the current scope, Agro Engineering also prepared several large maps and at three meetings interviewed water users from the proposed Trinchera Subdistrict, Subdistrict 2, and Subdistrict 4 groups. Appropriate changes that were indicated with well assignments, ditch service area boundaries, and irrigated parcels were incorporated into the GIS sets.

Evaluation of well assignments in both TASK B3 and B8 reduced areas with wells assigned as a water source from 299,600 acres to 296,298 acres in the 2005 irrigated lands dataset; and areas in the 1998 and 2002 were reduced similarity.

Attachment 4

Agro Engineering; Kelley Thompson. March 22, 2011. *Interview with Monty Smith representing Trinchera Subdistrict Area*. Memorandum to James Heath and RGDSS File; Colorado Division of Water Resources.

TO: James Heath, RGDSS – File
FROM: Kelley Thompson, Agro Engineering Inc.
RE: Interview with Monty Smith representing Trinchera Subdistrict Area
DATE: 3/22/2011

The following paragraphs are summaries of an interview with Monty Smith representing the Trinchera Subdistrict area regarding irrigation practices.

RE: Groundwater assignment

In areas of ditch service, irrigators use surface water when it is available and only pump wells when the surface water is no longer available. Many wells in the central portion of the Trinchera District flow into a ditch, supplement surface water, and therefore can supplement irrigation over fairly large areas. The well assignments do represent this ability to use these wells over fairly wide areas in drier years or when surface water is no longer available. In 2009, there was a fair amount of surface water, so many of these wells were not used much and in some cases not even turned on. There were also some fallow fields in 2009 due to ownership and other issues.

RE: Sub-irrigation

The area around Smith reservoir and to the north and east of Smith Reservoir is supplemented by sub-irrigation. The area nearest to the reservoir can receive a significant portion from sub-irrigation and the areas further out a partial supply from sub-irrigation. It is difficult to quantify exactly the portion provided by sub-irrigation. Timing is probably fairly constant somewhat based on annual surface water amounts and reservoir levels. Areas supplied by the New North Ditch system and the Fred Etter Ditch system may also be supplemented by sub-irrigation.

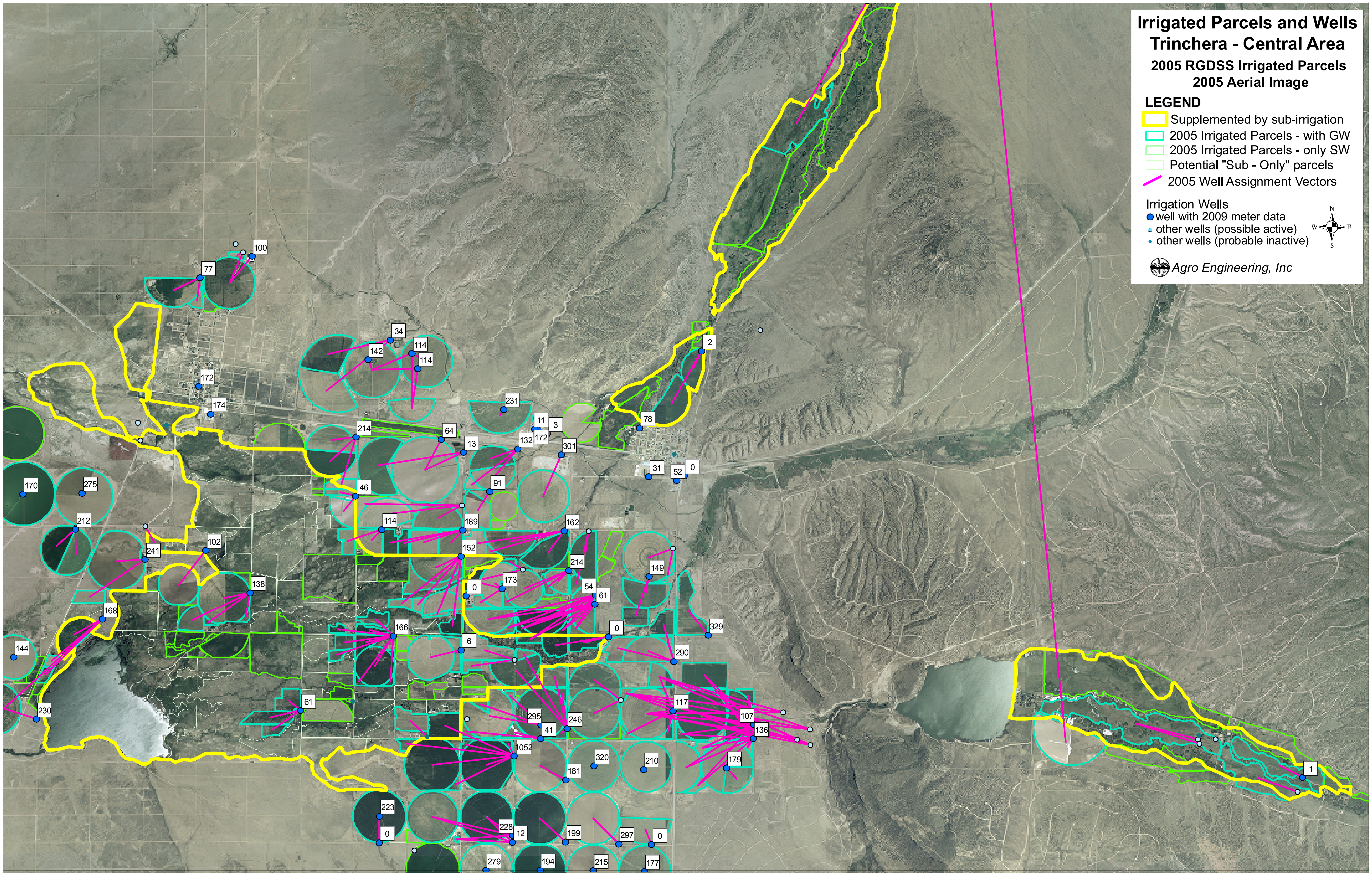
The potential areas supplemented by sub-irrigation as well as parcels that are likely supplied primarily by sub-irrigation and not actively irrigated are noted in the following figure.

RE: Efficiencies of Ditch System

The group didn't have any exact numbers on ditch conveyance efficiency. However, there is a lot of flexibility in the system through the use of numerous water sources and the ability to exchange water from Smith Reservoir so that the system itself may operate more efficiently than other ditch systems.

RE: Water Supplies

Something similar to deficit irrigation has been used on the grain and alfalfa on the San Luis Hills Farm area (~35 pivots in GW only area) for some time due to well production and management issues. Grain and potatoes under most of the other center pivots are not typically shorted significantly. Some alfalfa may be shorted somewhat due to economic and management issues. On some of the alfalfa and other hay fields, some farmers could choose to get only 2 cuttings rather than turn the pumps on due to electric cost and demand billing issues.



Irrigated Parcels and Wells
Trinchera - Central Area
2005 RGDSS Irrigated Parcels
2005 Aerial Image
LEGEND
Supplemented by sub-irrigation
2005 Irrigated Parcels - with GW
2005 Irrigated Parcels - only SW
Potential "Sub - Only" parcels
2005 Well Assignment Vectors
Irrigation Wells
well with 2009 meter data
other wells (possible active)
other wells (probable inactive)
Agro Engineering, Inc

Attachment 5

Agro Engineering; Kelley Thompson. July 23, 2010. *Integration of Interview Data into RGDSS Ditch and Irrigated Parcel Datasets*. Memorandum to RGDSS Model Peer Review Team.

MEMORANDUM

To: RGDSS Model Team, file
From: Agro Engineering Inc.; Kelley Thompson PE
RE: Integration of Interview Data into RGDSS ditch and irrigated parcel datasets
Date: July 23, 2010

INTRODUCTION

Agro Engineering recently completed a state funded project primarily to a) develop a new 2005 irrigated parcel dataset for division 3 and b) reproduce new datasets for 1998 and 2002 using the new data and improved methodologies. For the 1998 and 2002 datasets; limited spatial modifications to parcels, improved well data developed in-part by the state's meter certification process, improvements to ditch service areas made through development of the 2002 and 2005 sets, and improved methodologies for fractional ditch coverage calculations were applied.

In late 2003 and early 2004, Slattery and Hendrix (then with Helton and Williamson P.C.) conducted a number of interviews with water users in division 3 relative to the original 1998 irrigated parcel dataset. Changes to parcel shape, well assignment, and/or ditch assignment were made directly to the irrigated parcel sets, and these changes were applied to the parcel set that was posted on the CDSS website and integrated in the RGDSS models. Changes to ditch service areas were not integrated into the ditch service area coverage so they could be maintained spatially for future application.

For the most recent Agro Engineering work, an attempt was made to maintain well assignment changes from Slattery and Hendrix that could be inferred from the 1998 CDSS irrigated parcel set and evaluate changes to parcel shapes. However, without additional documentation, it was difficult to evaluate all changes and changes to ditch service areas in particular. In June 2010 (after Agro's work was complete) the original GIS data set modified by Slattery and Hendrix was produced that included comments on changes made to 1341 parcels. This prompted a more in-depth examination of the Slattery/Hendrix changes to ensure that changes that were still relevant were carried forward in the 1998, 2002, and 2005 datasets.

RESULTS

To retain information from the Slattery/Hendrix interviews, each of the 1341 comments were evaluated, an additional comment was made in the GIS file describing how the change was dealt with in the new sets. The way the change was dealt with was also tracked in five general categories. The following table sums the total number of each of these five categories.

Number	General Method of Addressing Change in New Data Sets
776	change was considered no longer relevant to new sets due to new processing
268	change appeared relevant and new sets were modified to retain change
145	change was not considered to be appropriate to 1998 set and change not retained
134	change was to note drain source and drain source comment was added to parcel
18	change was to hardwire a fractional coverage which was not maintained
1341	total parcel changes noted by Slattery/Hendrix

The majority (776) of the noted changes were related to issues that had already been addressed in the new datasets; primarily well assignments and ditch overlap issues. In the original set that Slattery/Hendrix was referencing, wells had been assigned using a purely spatial methodology as directed by the state at that time, and a well set including unused wells and wells without accurate locations. An improved set of wells with accurate locations was used for the new sets, and an extensive effort went into manually adjusting well assignments for the new datasets; as described in the project report. These improvements solved many of the well assignment issues noted by Slattery/Hendrix in the new datasets. Many ditch service areas boundaries were both improved using aerial photography prior to unioning with the new irrigated parcel sets, and a new methodology was used for the new sets that threw out overlap “slivers”.

About 265 changes or errors that were identified by Slattery/Hendrix appeared to still be relevant to the newer datasets. Changes were made changes were made to 1998, 2002, and 2005 irrigated parcel datasets including changes to the parcel shapefiles through adjustment of polygons, parcel splitting, adding parcels, and deleting parcels. Well and ditch assignment data associated with the parcels were adjusted manually. A number of additional adjustments were also made to the ditch service area coverage so that a spatial merging of current or future irrigated parcel datasets with the ditch service area coverage would maintain parcel data changes.

About 145 changes noted by Slattery/Hendrix were not considered to be appropriate for the 1998 irrigated parcel dataset. Many of these changes may have been appropriate for later time periods and were often included in the 2002 or 2005 sets, but the 1998 dataset is meant to represent conditions in the 1998 growing season. The majority of these changes were a deletion of flood irrigated parcels and a replacement with a center pivot irrigated parcel. In each case, the 1998 aerial imagery was examined and a determination was made the center pivot was not installed in 1998. As mentioned, in almost all cases these parcels had changed to center pivots either in the 2002 or 2005 datasets. An additional common change was addition of a new irrigated parcel. Although a large progression of satellite imagery had not been collected for the 1998 study, NDVI images were produced from mid-June, mid-July, and late-August satellite images and examined, and if a green response was not recorded in any of these three images than it was deemed that this parcel was not irrigated in 1998 and the new parcel was not added. In a very few cases, changes to well assignments or ditch service areas were deemed not valid due to a close evaluation of 2002 imagery, ditch diversions, or field examination.

Slattery/Hendrix noted a number of parcels that receive water from drains as a source. Drain sources information has not been maintained at the parcel scale, but these parcels could potentially be dealt with more specifically in the future. In the new irrigated parcel datasets, these were noted in the irrigated parcel comment field as “from slattery/hendrix drain source”.

Slattery/Hendrix also hardwired a number of parcels with overlapping ditches with ditch fractions that were not based on spatial area but may have been based on a general comment from the water user. These hardwired percentages were not maintained as the coverage fractions are meant to be calculated based on spatial areas and the ditch water supply analysis should address annual amounts available from overlapping ditch systems.

When changes were made to parcels or parcel water sources as a result of the evaluation of the Slattery/Hendrix interview data, a comment was added in the irrigated parcel dataset comment field beginning with "from slattery/hendrix" and a brief description of the change that was made. Some additional changes were made to the datasets as a result of the Slattery/Hendrix evaluation process, although not indicated directly by the Slattery/Hendrix data. Comments for these changes do not include the "from slattery/hendrix" phase.

As a result of the evaluation of the Slattery/Hendrix interview data, a new ditch service area was produced as well as new irrigated parcel datasets for 1998, 2002, and 2005. The ending of each dataset was changed from "20101" to "20102" to indicate the second edition of the 2010 datasets. A brief description of the Slattery/Hendrix evaluation was added to metadata. The metadata process comment added to the 1998 irrigated parcel dataset was:

> "In June 2010, an additional refinement was made to the second generation set. A number of additional adjustments were made to the irrigated parcel datasets through an examination of changes to a 1998 irrigated parcel set made by Slattery and Hendrix (with Helton and Williamson P.C.) through interviews with water users. Changes made to irrigated parcels through the evaluation of the Slattery and Hendrix data are indicated with a comment beginning "from slattery/hendrix". Changes were also made to the ditch service area coverage so that many of these changes could be maintained spatially for future efforts."

ADDITIONAL DISCUSSION

For many Slattery/Hendrix well assignments, a comment of GW well service was noted but an actual well was not assigned. It was noted that in this case, a well assignment was not made in the CDSS maintained set and therefore was not being considered in the RGDSS models.

One issue that had a moderately significant effect is the state's rule for hydrobase that surface water coverage (if greater than zero) for all parcels must be rounded up to 100 percent total coverage. In some cases, slight boundary inaccuracies caused a slight ditch overlap of a "groundwater only" parcel that was rounded up to define a 100% ditch coverage of the parcel; some of these errors were identified by Slattery/Hendrix. For the new datasets, ditch service was removed from all parcels that were almost entirely in a "groundwater only" area and had ditch service listed due to a slight service area overlap. Several center pivots were identified by Slattery/Hendrix where, apparently, about half of the pivot is within a legal ditch service area and half not. This would probably be best represented by a 50% fraction in the data table. However, these pivots maintained a rounded up 100% area coverage by the ditch as a requirement for hydrobase entry.

In the previous new sets, Slattery/Hendrix well assignments that could be gleaned from older CDSS sets were designated a well "class" of 6 through 10 using the same spatial related class system of well classes 1 through 5 (adding 5 to these classes). However, the state indicated that some higher well class numbers may not be retained in processing steps to integrated the data into the model systems. Therefore, all classes that had been previously designated classes 7 through 10 were all renumbered to a well class of 6.

Attachment 6

Agro Engineering; Kelley Thompson and Kirk Thompson. January 2010. *RGDSS Irrigated Land Coverage Enhancements and 2005 Irrigated Lands Assessment*. Report to Colorado Water Conservation Board and Colorado Division of Water Resources.

RGDSS IRRIGATED LAND COVERAGE ENHANCEMENTS AND 2005 IRRIGATED LANDS ASSESSMENT

RIO GRANDE DECISION SUPPORT SYSTEM

FINAL REPORT

January 2010

Agro Engineering, Inc.

Kelley Thompson, P.E.
Kirk Thompson, P.E.

ACKNOWLEDGMENTS

The work described in this report was funded by the State of Colorado, Colorado Water Conservation Board for the Rio Grande Decision Support System. The program is directed by Ray Alvarado of the Colorado Water Conservation Board and Ray Bennett of the Colorado Division of Water Resources. Jennifer Gimble is the director for the Colorado Water Conservation Board. Carolyn Fritz, the GIS Coordinator for the Colorado Water Conservation Board, coordinated our efforts and interfaced with other individuals and organizations to obtain data necessary for the study. In addition, Doug Stenzel with the Colorado Division of Water Resources queried well data for the study, the Rio Grande Water Conservation District provided cropping data, and Davis Engineering provided sprinkler maps.

TABLE OF CONTENTS

TABLES

FIGURES

1. EXECUTIVE SUMMARY

The purpose of this project was to perform a 2005 Irrigated Lands Assessment and to enhance previous Irrigated Land Assessments. The purpose of the Irrigated Lands Assessment was to determine the extent (i.e. acreage) and character (i.e. crop type, irrigation system type, and irrigation source) of irrigated parcels within the Rio Grande Basin during the 2005 irrigation season. The CWCB purchased a set of satellite imagery for Colorado from year 2005 with the intent to refresh the irrigated lands assessment for DSS projects around the state.

The development of the 2005 Irrigated Lands Assessment required the following procedures:

1. Delineating parcel boundaries.
2. Assessing which parcels were irrigated versus non-irrigated during 2005.
3. A crop classification to determine what crop type was grown on each parcel during 2005.
4. An assignment of the wells that could be used on each parcel.
5. An assignment of the surface water supplies that could be used on each parcel.

The second objective of the proposed work was to enhance the existing 1936, 1998, and 2002 irrigated land coverages so that they provided information consistent between the different time periods.

This objective required:

1. Applying a common ditch service area coverage to all datasets that includes enhancements made in the 2002 and 2005 studies.
2. Re-evaluating the time at which center pivot sprinkler irrigation systems were installed.
3. Applying common well assignments to all datasets that include both improved well data and enhancements made to well assignment methodology.
4. Reconsidering the thresholds used in the 2002 coverage to determine if parcels were irrigated.

The following GIS themes were developed as products of this project:

1. Enhanced Ditch Service Area Coverage.
2. New Irrigated Parcel Coverage for Year 2005.
3. Enhanced Irrigated Parcel Coverages for years 1936, 2002, and 1998.

Enhanced Ditch Service Area Coverage. A ditch service area coverage was developed in GIS to indicate service area boundaries for surface water ditch systems. The original ditch service area theme was developed as part of the 1998 Irrigated Lands Assessment based upon ditch system maps and water user interviews. This effort did not concentrate on ditches in upper reaches of the Rio Grande or on tributaries which were not within the ground water model domain. Consequently, 122 ditches in Division 3 defined as currently active did not have ditch service areas defined in the GIS coverage. Enhancements to the ditch service area coverage concentrated on delineating service areas for as many of these ditches as possible. Sixty new ditch service areas were delineated along with corresponding irrigated parcels. Thirty-three ditch service areas that had been previously delineated, but without irrigated parcels, were adjusted or irrigated parcels reconsidered so that irrigation is now shown. Eight additional service areas had previously been delineated but are so junior that they are reported not to be in use and do not have irrigated parcels during the years of the irrigated land assessments. Ten ditch service areas were found that should most appropriately be combined into existing or new ditch area aggregates. Four ditches were found to no longer have a decreed right and/or did not have diversions after 1997. Additionally, the spatial mapping of service area boundaries was improved for many ditches. Many boundaries that were relatively rough and drawn without actual aerial photography were improved using the higher resolution aerial photography that is now available.

2005 Irrigated Parcel Theme. A new irrigated parcel theme was developed describing parcels where crops were irrigated during the 2005 growing season. New parcel boundaries were drawn using high-resolution color aerial photography from 2005. An assessment of whether the parcel was irrigated or not during 2005 was made by comparing to an irrigation threshold developed from 13 satellite images taken throughout the growing season and by ensuring that a well or ditch irrigation source was available. The crop that was grown on the parcel during 2005 was determined using a multi-spectral classification of the 13 Landsat satellite images along with an evaluation of several other data sources. Sprinkler or flood irrigation type was assigned using visual evaluation of aerial photography as well as mapping from previous years. The Enhanced Ditch Service Area Coverage was spatially applied to irrigated parcels to assign ditches to parcels within its service area. Groundwater wells that could have irrigated the parcels were assigned using an evaluation of new well data, aerial photography, ownership, and irrigation in the extremely dry year of 2002.

Enhancements to the Previous Irrigated Parcel Themes. Enhancements were also applied to prior irrigated parcel themes that had been developed for years 2002, 1998, and 1936 to improve consistency between different time periods. Parcel irrigation for year 2002 was re-evaluated using the methodology developed for year 2005. The thresholds developed for 2005 to evaluate if a parcel was irrigated was applied to 2002 satellite imagery, and parcels were both added and deleted from the original set. The assignment of well service was improved for both the 1998 and 2002 datasets by applying, with limited modification, the well assignments developed for year 2005. The enhanced ditch service area coverage was also applied spatially to the 1936, 1998, and 2002 irrigated parcel datasets.

2. INTRODUCTION

The Rio Grande Decision Support System (RGDSS) is a collection of models developed by the state of Colorado as a tool to better understand and examine water use and groundwater movement within the upper Rio Grande Basin, Colorado Division of Water Resources Division 3. The Irrigated Lands Assessment was performed for the State of Colorado as part of the Rio Grande Decision Support System. The goal of the Irrigated Lands Assessment is to determine the extent (i.e. acreage) and character (i.e. crop type, irrigation system type, and irrigation water source) of irrigated parcels within the Rio Grande Basin at a particular snap-shot in time. Basin wide assessments of irrigated lands in Division 3 have provided the base data to estimate agricultural water use and ground water consumption. The Irrigated Lands Assessment has provided input data to support water use modeling and ground water modeling for the RGDSS. Previously, Irrigated Lands Assessments have been produced by Agro Engineering for years 1998 and 2002. Maps of irrigated lands in 1936 were drawn as part of the Rio Grande Joint Investigation. The Division of Water Resources has subsequently digitized the 1936 maps to serve as another Irrigated Lands Assessment from that time period.

The RGDSS Irrigated Land Coverage Enhancement and 2005 Irrigated Lands Assessment was proposed to fulfill two overall goals: a) characterize irrigated crops in Division 3 for year 2005 by developing a new GIS data set with irrigated parcels, crop classification, and evaluations of water sources for use in the RGDSS, and b) to apply improvements in data and methodology made through the 2005 set to the existing 1936, 1998 and 2002 irrigated land coverages so that they provide more consistent information.

The following GIS themes were developed as products of this project:

1. Enhanced Ditch Service Area Coverage.
2. New Irrigated Parcel Coverage for Year 2005.
3. Enhanced Irrigated Parcel Coverages for years 1936, 2002, and 1998.
4. Sprinkler System Coverage

This report summarizes the project, and is generally organized by project scoped tasks. The following section provides descriptions of the approach taken, including data acquisition, data processing and results. The results sections present statistical summaries of the final products.

3. METHODOLOGY

3.1 Ditch Service Area Coverage Enhancements

The original ditch service area theme, developed as part of the 1998 Irrigated Lands Assessment, did not delineate many ditches in upper reaches of the Rio Grande or on tributaries which were not within the ground water model domain. Minor improvements were made to the ditch service area boundaries as part of the 2002 irrigated lands assessments, but these improvements were not applied to the earlier irrigated land coverages. The high-resolution color aerial imagery available for 2005 enables both identification and continued improvement to ditch service areas. Therefore, this task involved two sub-tasks to: 1) further enhance the current ditch service area coverage to include as many additional ditches as possible, and 2) apply the enhanced coverage to all of the irrigated land coverages to create more consistent sets.

3.1.1 Additional Delineations for Ditches without GIS Coverage

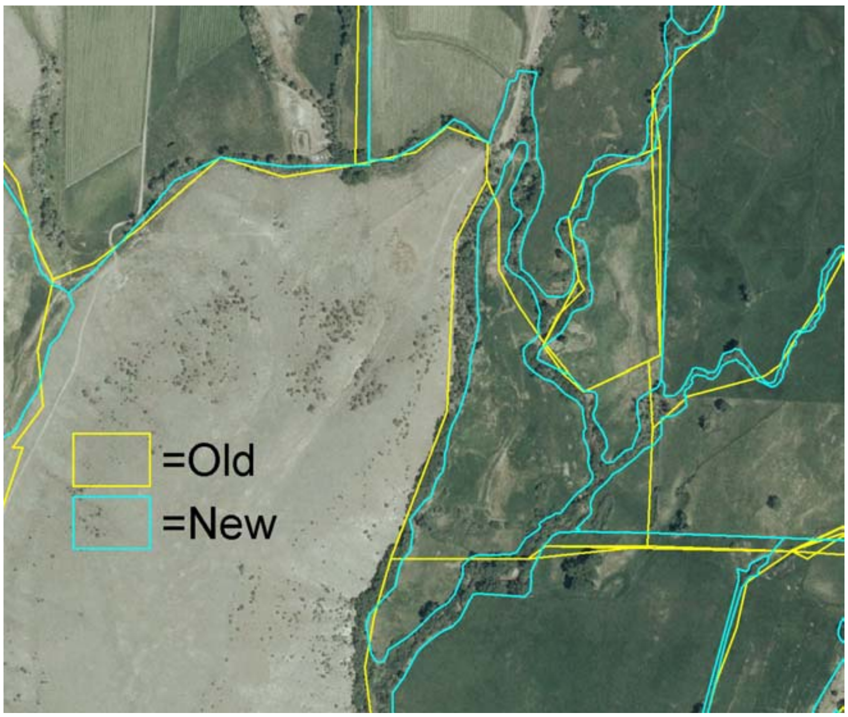
The RGDSS consumptive use processing has been using three files called NoGIS_1998, NoGIS_1936 and NoGIS_2002. These files attempt to identify lands that have current diversion records and irrigated acreage reported by water commissioners but do not show up in the irrigated acreage coverage. The acreage identified on these lists is approximately 4,000 acres. Nearly all these lands are estimated to be outside the ground water model area. However two of the ditches are in the ground water model area.

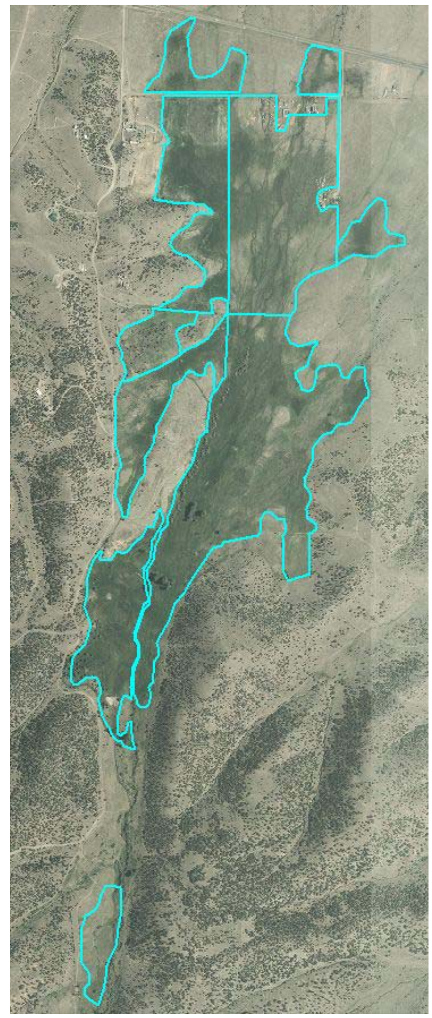
The majority of "NoGIS" ditches were located up small streams well away from the groundwater model. From the head gate location, ditches and their corresponding service areas could be observed relatively easily in the new aerial photography and delineated in many cases. Areas served by single ditches could be delineated with relative certainty, but the certainty of the delineation was less when multiple ditches appear to serve the same area.

Several ditch service areas had been previously delineated, but did not have irrigated area delineated in 1998 or 2002. This prompted some reconsideration of irrigated parcels in 1998 and 2002, and some additional irrigated parcels were delineated to be added to the 1998 and 2002 sets. However, when there was no evidence of irrigation for a particular year or diversions were not indicated for that year, new parcels were not delineated.

In the larger agricultural area, refinement typically meant adjustment of boundaries to include areas already delineated as irrigated but previously included within other ditch service areas. Therefore, the methodology within the model to hardwire ditches with no previously mapped irrigated areas to user reported acreage generally overestimates overall irrigated acreage, and the adjustment of ditch service areas should result in less overall acreage considered by the model within the larger irrigated area. As a result, there should also be less modeled "return flows" from percolation of flood irrigation contributing to the ground water system.

Significant improvements were also made to a large number of ditch service areas in GIS to clean up roughly drawn boundaries using the 2005 aerial photography and mapping of head gate and canal lines. In some cases, user listed irrigated acres and data from water rights studies were also integrated to alter service areas where these changes could be clearly justified. An example of improvements made to the ditch service area mapping, as well a location where missing ditch service areas could be located and delineated with aerial photography is shown in Figure 1.





Left: example of improvements to ditch service area boundaries
Right: example of new ditch service area mapping

Figure 1. Examples of Enhancements to Ditch Service Area Theme

The scope for Task 1 called for delineation of at least a majority of ditches listed in the "NoGIS" files using, at a minimum, ditch head gate locations and aerial photography. Ditch service areas or irrigated parcels for nearly all of the "NoGIS" ditches were delineated. Of the 122 ditches identified in the 1998 and 2002 "NoGIS" files, only eight were not found that should apparently remain in a "NoGIS" list for the model. The ditch service area for six of these eight ditches could not be differentiated because of overlap with other ditches such that its location of use could not be discriminated with aerial photography. Sixty new service areas were delineated along with the corresponding irrigated parcels. Thirty-three service areas had been delineated previously, but without irrigated parcels, whose areas were adjusted or irrigated parcels reconsidered so that irrigation is now shown. Eight additional service areas had been delineated previously but these ditches are so junior that they did not have any user reported acreage and did not have any diversions or irrigated parcels in the time frames of the irrigated land assessments. Consequently, the "NoGIS" file should report 0 acres for these eight ditches. Thirteen ditch service areas were found that should most appropriately be combined into existing or new ditch area aggregates. There is one ditch which has irrigated parcels and user reported irrigated acreage, but the "NoGIS" listing is apparently forcing zero acreage in the model, presumably because this ditch is a drain ditch. The "NoGIS" ditches are listed in the Table 1 with a description of how the service area was dealt with.

Suggested changes and additions to ditch aggregate structures are listed in Table 2. A description of "existing" indicates that the listed ditches should be added to an existing structure already included as an aggregated structure while a description of "new" indicates all listed ditches should be included in a new aggregate structure.

3.1.2 Applying Ditch Service Area Enhancements to Irrigated Parcels

The enhanced ditch service area coverage, including the minor improvements made in 2002 and the additions from the current study were applied to the 2005 irrigated parcel coverage and also applied to the 2002, 1998 and 1936 data sets. New surface water supply WDIDs and fractional coverage percentages were calculated and applied to each data set. The fractional methodology to apply ditch service area coverage to the irrigated parcel datasets in the original 1998 study was used along with improvements as applied in the original 2002 study. Improvements include throwing out small coverage "slivers" and rounding up of all coverage to 100% as now required for Hydrobase.

To apply ditch service area coverage to the irrigated parcel datasets, irrigated parcels are first spatially intersected with ditch service areas. Many ditch service areas overlap and create multiple coverages of all or portions of an irrigated parcel. To avoid double-counting acreage, the fractional coverage by each ditch is calculated for each parcel. For each parcel, the amount of acres covered by each ditch is summed and the area covered by each ditch is individually divided by this sum to calculate the fractional coverage for each ditch. For example, if two ditches cover a parcel, than each ditch has a 50% fractional coverage. This represents the fraction of the parcels water requirements supplied by each ditch. The fractioning is based purely on spatial coverage rather than any sort of primary versus supplemental source information on a particular parcel. This fractional methodology is described in more depth in the 1998 and 2002 study reports.

As the ditch coverage theme contains slight boundary deviations, the boundaries of the ditch areas often slightly overlap small portions of parcels that are probably not in the service area or may not completely cover a parcel that is in the service area. Therefore, for the 1998, 2002, and 2005 datasets, ditch coverage area of between 90% and 100% or less than 10% of the total parcel area were rounded to an area of 100% and 0% of the total parcel area, respectively, prior to calculation of fractional coverage. Due to large parcel size within areas with many small ditches, parcel coverage or coverage gaps of less than 1%, rather than 10%, were thrown out for the 1936 dataset.

The current error checking "rules" for integration of GIS irrigated parcel data into the Hydrobase system requires that the sum of the fractional coverages for a parcel must equal 100. This was not originally required of the original 1998 RGDSS irrigated lands assessment. In the original 1998 set, less than 100 percent coverage of parcels appeared appropriate when larger parcels were only partially covered by ditch service areas while the uncovered portion may have been served by a well. In the current methodology, parcel portions outside of mapped ditch service areas are disregarded so that the sum of the fractional coverages for a parcel generally equal 100. A correction factor was added when necessary to correct any slight deviations from 100 percent due to rounding.

Although ensuring that fractional ditch coverages sum to 100 is appropriate for many parcels and is much less of an issue in the newer irrigated lands datasets, the rule could create some erroneous characterizations in earlier datasets and in the 1936 dataset in particular. In some areas of the 1936 set, very large parcels may include areas served by ditches but extend well beyond areas that could physically be served by any ditch. When ditch coverage is forced to 100 percent, acres served by individual ditches could be inflated well beyond the area that could ever be served by the ditch. Upon examination of the 1936 set, examples of this situation were noted particularly in northern portions of Saguache County.

Within the ditch service area coverage, close to 50 areas were defined as aggregates of multiple ditches. In these areas, water from more than one surface are either truly commingled, separate service areas could not be distinguished, diversion numbers for at least one right are (at least at some times) accounted for within a different right, or rights have recently been transferred to a different headgate for use on the same area. For the original 1998 and 2002 datasets, ditch aggregate codes (not WDIDs) were placed in the SWID columns for aggregate areas; although these codes were replaced by the WDID for the first ditch listed with the aggregate in the ditch service area coverage. For the new 1998, 2002, and 2005 datasets, the WDID for other ditches within the aggregate where also assigned to the parcel using the fractional methodology if diversions were listed for the ditches between April and October of the year described by the dataset. For the 1936 dataset, all aggregated ditches were applied to each parcel. A complete listing of ditch aggregates and annual diversion amounts is included in the Appendix.

Table 1. Evaluation of Ditch Service Areas on the “NoGIS” List

Ditch ID	Name	Source	“NoGIS” Reported Acres
New Ditch Service Area Delineated and New Irrigated Parcels were also Delineated.			
200506	ALDER CR D 1	ALDER CREEK	100
200507	ALDER CR D 2	ALDER CREEK	50
200508	ALDER CR D 3	ALDER CREEK	40
200526	BELLOWS CR D 4	BELLOWS CREEK	40
200529	BAUER D 1	SCHRADER CREEK	5
200530	BEIGER-LADD D	EMBARGO CREEK	42
200532	BELLOWS CR D 2	BELLOWS CREEK	25
200533	BELLOWS CR D 3	BELLOWS CREEK	40
200551	BREENE MYERS D	EMBARGO CREEK	88
200559	CADLE D 3	ROCK CREEK	70
200561	CAMPBELL BAUER D	MINERS CREEK	40
200568	CHADWICK D 1	WILLOW CR AT S FK	60
200570	CHADWICK D 3	WILLOW CR AT S FK	10
200616	ELLIOTT D	ELLIOTT CREEK	30
200626	EWING D 1	EMBARGO CREEK	75
200649	GRUBB D 3	BEAR CR AT S FK	75
200650	GRUBB D 2	BEAR CR AT S FK	40
200651	GWINN CR D	GWINN CREEK	30
200669	HILTON CR RIVER D	WOODFERN CREEK	20
200692	JESSUP D 1	RIO GRANDE	20
200695	JOHN R GRANT D	SHALLOW CREEK	30
200721	MACKENZIE D 1	MINERS CREEK	30
200748	MILL D	ROCK CREEK	10
200751	MINERS CR D	MINERS CREEK	100
200788	PHILLIPS D 1	ELK CREEK	58
200789	PHILLIPS D 2	ELK CREEK	34
200830	VALDEZ D 2	WOLF CREEK	10
200831	SCHRADER D 1	SCHRADER CREEK	80
200832	SCHRADER D 2	SCHRADER CREEK	60
200867	VALDEZ D 1	WOLF CREEK	25
200878	TROUT DALE D	CLEAR CREEK	60
200894	WASSEN D	WILLOW CR AT CREEDE	100
200895	WASON DEEP CR D	DEEP CREEK	50
200896	WASON D	RIO GRANDE	60
200909	WOLF CR D 1	WOLF CREEK	60
200910	WOLF CR D 2	WOLF CREEK	60
201000	VOSS SEEPAGE D	SEEPS	20
201026	DEER CREEK D	DEER CREEK	20
201692	4 U R DITCH	GOOSE CREEK	100
210543	JOSE E ATENCIO D	HOT CREEK	85
210712	LOUISE SHAWCROFT D	MORTENSON PETERSON DRAIN	120
240510	ALFONSO DITCH	ALBAN	60

250624	NEELAND D	NEELAND CREEK	80
250636	ROBINSON D	SPRING CREEK-MOORE	180
250664	STUMP D 2	CLOVER CREEK	4
250665	STUMP D 3	CLOVER CREEK	5
260568	HOUGLAND D	SAGUACHE CREEK	100
260670	SHEEP CREEK NO 775 D	SHEEP CREEK	45
260672	SHEEP CREEK NO 777 D	SHEEP CREEK	40
260673	SHEEP CREEK NO 778 D	SHEEP CREEK	80
270528	LA MAGOTES D	CARNERO CREEK	5
350507	CALDWELL D 1	MIDDLE CREEK	5
350508	CALDWELL D 2	MIDDLE CREEK	5
350514	DENTON D 1	MIDDLE URRACCA CREEK	5
350515	DENTON D 2	MIDDLE URRACCA CREEK	3
350520	GALLOWAY D	MIDDLE URRACCA CREEK	100
350535	LEGGITT D	MIDDLE URRACCA CREEK	1
350538	LOS OJOS D	BIG SPRING CREEK	360
350577	SOUTH URRACA D	SOUTH URRACA CREEK	100
350585	URRACA D	MIDDLE URRACCA CREEK	100
Ditch Service Area was Previously Delineated without Irrigated Area. Ditch Service Area Boundary was Adjusted or Irrigated Parcels Delineated.			
200522	BACHMAN D 2	EMBARGO CREEK	40
200523	BACHMAN SEITZ D	EMBARGO CREEK	50
200588	DAVIES BROS D	EMBARGO CREEK	400
200590	DAVIES D 2	EMBARGO CREEK	150
200622	EMBARGO D	EMBARGO CREEK	400
200835	SEITZ D	EMBARGO CREEK	20
200836	SHAW D 1	SPRING CR - SHAW CR	10
200837	SHAW D 2	SPRING CR - SHAW CR	50
200986	CHARLESWORTH D 1R	EMBARGO CREEK	75
210717	J H VALDEZ D	ALAMOSA RIVER	1
220516	BRAIDEN OVERFLOW D NO 2	SAN ANTONIO RIVER	80
220517	BRAIDEN OVERFLOW D NO 3	SAN ANTONIO RIVER	70
220544	FOX CREEK D	FOX CREEK	60
220545	FOX CREEK D NO 1	FOX CREEK	40
220546	FOX CREEK D NO 2	FOX CREEK	40
220556	HUGHES OVERFLOW NO 1	SAN ANTONIO RIVER	320
220607	MOUNTAIN D	TRAIL CREEK	120
240506	ACEQUIA MADRE D	COSTILLA	100
240507	ACEQUIACITA D	COSTILLA	30
240508	ALAMO D	SAN FRANCISCO	200
240572	MONTEZ D	RITO SECO	2
240593	TRUJILLO D	COSTILLA	10
250620	MCNULTY D	MILLER CREEK	60
250633	RIDENOUR D	GARNER SPRINGS	30
250669	TOBLER ROMINGER D	SAN LUIS CREEK	40
250747	1920 D	KERBER CREEK	10
260694	WERNER B D	WERNER ARROYO	20
260695	WERNER CLARK D	WERNER ARROYO	30
270503	BIEDELL D NO 2	LA GARITA CREEK	200

270530	MANUEL D 1	LA GARITA CREEK	5
270551	WHITE D	CARNERO CREEK	10
270632	C DITCH	CARNERO CREEK	60
350513	DENTON D	SOUTH URRACA CREEK	10
Ditch Service Area was Previously Delineated without Irrigated Area. User Reported Acres are also zero. No Irrigated Parcels Delineated. "NoGIS" file should report 0 acres irrigated.			
250565	DRISCOLL D	SAN LUIS CREEK	0
250588	HENRY WHITE D	KERBER CREEK	0
250657	SQUIRES D 1	SAN LUIS CREEK	0
250667	SWIDENSKY D	GOOSEBERRY CREEK	0
260572	JAYS D	WERNER ARROYO	0
260602	MIELY D	WERNER ARROYO	0
260829	ALEXANDER OVERFLOW D	RIO GRANDE CANAL OVFL	0
270527	LA LOMA D	CARNERO CREEK	0
Ditch Should be Included in an Existing or New Aggregate Structure			
200785	PEACHY D 2	ROCK CREEK	40
200849	SMITH D 1	ROCK CREEK	200
200569	CHADWICK D 2	WILLOW CR AT S FK	60
200571	CHADWICK D 4	WILLOW CR AT S FK	100
220552	GARCIA D	CONEJOS RIVER	320
220556	HUGHES OVERFLOW NO 1	SAN ANTONIO RIVER	320
220557	HUGHES OVERFLOW NO 2	SAN ANTONIO RIVER	0
220588	LOVATO D	ESPINOSA, LOVATO SPR	40
220650	VEGA GRANDE AND SABINE D	CONEJOS RIVER	0
250512	BACA GRANT 4 IRR D 8	SOUTH CRESTONE CR	30
260809	VIRDEN ARROYO D	SEEPS	80
350561	NORTH SWAMP D	NORTH SWAMP	595
350576	SOUTH SWAMP D	SOUTH SWAMP	80
Model List Forcing Zero Acreage for the Delineated Irrigated Area. No Additional Action Required.			
200500	ADAMS D 1	CHENOWETH SEEPAGE	0
Ditch Service Area Still not Located. Water Commissioner Needs to Research.			
200739	MCNEIL D 1	LOWER ROCK CREEK	160
200935	HAY PRESS RES SUP 6 INCH	ROARING FORK CREEK	10
201130	KNOBLAUCH D 1	RIO GRANDE	40
201690	KNOBLAUCH D NO 2	RIO GRANDE	40
250704	TOBLER AND KENNEDY D 3	SPRING CR-SAN LUIS	0
260702	TARBELL TM D	TRANSBASIN WATER	350
350533	KING D 2	MIDDLE CREEK	5
350638	SQUAW LATERAL	BARBARA CREEK	1

Table 2. Changes to Ditch Aggregates

Ditch ID	Desc.	Ditches to Be Included
20_MS_3	Existing	200706 (Larrick 2), 200784 (Peachy 1), **200849 (Smith 1) and 200785 (Peachy 2)**
20_MS_7	New	200568 (Chadwick D1), 200569 (Chadwick D2), and 200571 (Chadwick D4)
21_MS_2	InDMI/New	210539 (Head Overflow D5), 210716 (Seaman Flume)
21_MS_3	New	210521 (Empire Canal-La Jara), 210522 (Empire Canal-Alamosa)
21_MS_4	New	210560 (Miller D-La Jara), 210561 (Miller D-Alamosa)
22_MS_9	Existing	220630 (Seledonio Valdez), 220623 (San Jose D), **220647 (Vega Grande), and 220648 (William Sabine D1)**
22_MS_12	InDMI/New	220611 (Overflow, Vega Grande, Sabine), 220650 (Vega Grande and Sabine)
22_MS_13	New	220692 (Garcia Ditch-R), 220552 (Garcia)
22_MS_14	New	220506 (Arch-Trogillo No 2 (Springs)), 220588 (Lovato), 220708 (Arch-Trogillio Lwr Div 1), and 220844 (Arch-Trogillio Lwr Div 2)
22_MS_15	New	220619 (Romero Ditch), 220575 (Jose Bonifacio Romero Ditch)
25_MS_9	D.Deleted	250698 (Hoffman Neidhardt D), 250548 (Cotton Cr Airline D) *deleted 250619 (Mcfarland D A B)*
25_MS_13	New	250508 (Baca Grant 4 Irr. Ditch 4), 250512 (Baca Grant 4 D 8)
26_MS_2	D.Changed	Primary changed from *260658 (Russell Ditch 4)* to 260655 (Russell Company D), 260656 (Russell Ditch 1), 260657 (Russell Ditch 2)
26_MS_6	New	260501 (Ashley Proffitt Ditch), 260809 (Virden Arroyo D)
35_MS_3	Existing	Trinchera District Aggregations 350571 (Sangre de Cristo), 350521(Garland D, HDGT 1), 350523 (Garland D, HDGT 2), 350529 (Indian Creek D), 350546 (Mill D), 350560 (Newton D2), 350563 (Ojito Creek D), 350564 (Ojito Creek D 1), 350570 (Sangre de Cristo Tinchera), 350579 (Trinchera Canal), 350581 (Trinchera Garland Canal), 350582 (Trinchera Highline Canal), 350588 (Walsen D 1), **350531 (Juel D), 350561 (North Swamp D), and 350576 (South Swamp D)**

Note: additions to existing aggregates shown in bold

3.2 Remote Sensing Data Used for the 2005 Irrigated Lands Assessment

The irrigated parcel delineation and crop classification relied upon remote sensed data. Two different sources of data were used. Imagery from the thematic-mapper (TM) sensor on the United States Geological Survey's (USGS) Landsat 5 satellite was used to differentiate irrigated parcels from non-irrigated lands and to perform the multi-spectral crop classification. Color aerial photo mosaics taken by the USDA Farm Service Agency (FSA) as part of the National Agriculture Imagery Program (NAIP) was used to delineate irrigated parcel boundaries.

3.2.1 Landsat 5 TM Imagery

Landsat TM images were acquired to provide multi-spectral data of the San Luis Valley. The Landsat 5 satellite is in a sun-synchronous orbit at an altitude of 705 kilometers above the earth. The satellite orbits the earth every 98.9 minutes, making fourteen revolutions around the earth each day. This orbit gives the satellite worldwide coverage, as it passes over a given location once every 16 days. Data availability tends to be an issue, as some scenes are unusable due to cloud cover and sensor malfunction. The sensor records a 185-kilometer swath on the ground. The overlap of these image swaths lay within the central portion the San Luis Valley, so that the entire Rio Grande River Basin is not covered in a single scene. Ground resolution is 30 meters.

The Landsat TM sensor provides data from seven different radiation wavelength ranges including three visual bands (Blue, Green, and Red), one near infrared band, two mid infrared bands, and one thermal band. Table 3 describes the characteristics of these band ranges.

The human eye can detect wavelengths from 400 to 700 nm, corresponding to the blue, green and red bands of TM data. Consequently, this range of bandwidth is called the visible spectra.

Table 3. Landsat Thematic Mapper Sensor Characteristics

Band	Spectral Range (nanometers)	Description	Resolution (meters)	Principal Application
1	450-520	Blue	30	Useful for Soil/Vegetation Differentiation.
2	520-600	Green	30	Measures Green Reflectance from Vegetation.
3	630-690	Red	30	Aids in Plant Species Identification as well as Soil Differences.
4	760-900	Near Infrared	30	Useful for Determining Vegetation Types and Biomass Content.
5	1550-1750	Middle Infrared	30	Indicative of Vegetation Moisture Content and Soil Water Content.
6	10400-12500	Thermal Infrared	120	Used in Vegetation Stress Analysis and Temperature Sensing.
7	2080-2350	Middle Infrared	30	Similar to Band 5 in Measuring Vegetation Water Content. Low Reflectance in Water Bodies. Also Used for Discriminating Mineral and Rock Types.

Vegetation has specific spectral characteristics that help in plant identification from satellite data. The cells in plant leaves effectively scatter light because of the high contrast in refraction between the water rich leaf cells and the intercellular air spaces. Vegetation is dark in the visible spectra because of the high absorption of pigments such as chlorophyll in the plant leaves. There is a slight peak in reflectivity around 550 nm (visible green and hence its visible color) because pigments are least absorptive at that bandwidth. In the spectral range of 700 to 1300 nm (near infrared), vegetation is very bright. This fact makes the TM Band 4 very good at measuring vegetation. From 1300 nm to about 2500 nm (the mid infrared bands), vegetation is relatively dark because of the adsorption of these wavelengths by leaf water. Cellulose, lignin and other plant materials also absorb in this spectral range.

Satellite information is expressed in raster data. With raster systems, the image is subdivided into a fine mesh of grid cells. Each cell, or pixel, contains a numeric value which represents the condition of the earth's surface at that point. Each measured picture element (or pixel) that makes up a TM satellite image covers an area of 30 meters by 30 meters.

Although Landsat TM5 imagery has a relatively coarse resolution, the data from the seven different radiation wavelengths or "bands" are quite suitable for crop classification. Two Landsat images (east and west) are required to cover the irrigated portions of Division 3. It has been found that multiple satellite images are important in order to exploit seasonal crop patterns for crop classification.

3.2.1.1 Data Preprocessing

The contract scope detailed that the CWCB would provide 2005 satellite imagery. A set of raw imagery was geo-referenced and processed by Riverside Technology, Inc (RTi). RTi was tasked with geo-referencing the entire area of these large scale images without geo-rectification. Possibly due to topographic effects across the large images, the geo-referencing of the imagery in portions of Division 3 was not precise, and, in several images, clouds were not adequately masked (particularly large areas of thin clouds). Therefore, Agro Engineering re-processed all of the available satellite imagery using a new ortho-rectified Level 1 processed imagery product available from the USGS.

RTi had processed twelve Landsat images covering Division 3. One of the east images (5/15) processed by RTi was not available from the USGS, as clouds had blocked ortho-rectification control points. However, two additional images were available (6/7 and 7/18). Consequently, Agro Engineering processed thirteen relatively cloud-free images with dates shown in the following table.

Table 4. Landsat Imagery Acquired for 2005

West Images – path/row 34/34	East Images – path/row 33/34
4/20/2005	4/13/2005
5/22/2005	6/16/2005
6/07/2005	7/02/2005
7/09/2005*	7/18/2005
8/26/2005	8/3/2005
9/11/2005	10/22/2005
10/13/2005	

*Note: *contains a high proportion of thin clouds*

The east and west images overlap over much of the central portion of the San Luis Valley, while Costilla County is covered only by the east images and portions of western Rio Grande County and northwestern Saguache County are only covered by the west images. The temporal distribution of available images was good in the overlapping area, but was limited in the non-overlapping areas. The available west images were primarily taken early and late in the growing season while the east images were primarily mid-season.

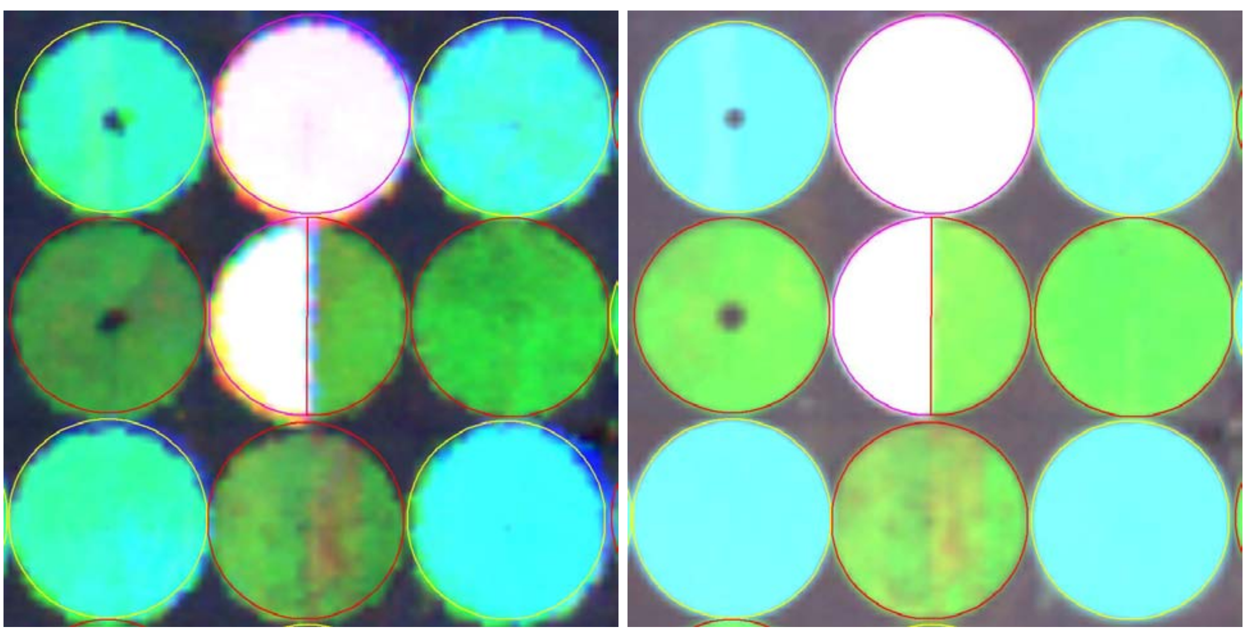
Landsat TM data as measured at the satellite is effected by a number of factors. In order to allow comparison of multiple satellite images, satellite TM data should be standardized to a measure of planetary reflectance. Chander et al. (2009) provides the most current methodology and calibration coefficients to convert Landsat data to top-of-atmosphere planetary reflectance.

The ortho-rectified Level 1 (L1) imagery obtained from the USGS was first converted to an at-sensor radiance (L in Watts / (square meter*sr*µm)) for each band (λ) using the gains and biases originally used in the L1 processing. Spectral radiance could then be converted to top-of-atmosphere planetary reflectance by normalizing for solar irradiances arising from spectral band differences. The following equation calculates planetary reflectance (P) using the earth-sun distance in astronomical units (d), mean solar exo-atmospheric irradiances (ESUN), and the solar zenith angle (θ) in degrees. Constants can be found in the image header files and in Chander et. al. (2009).

$$L_\lambda = G_{rescale} \times Q_{cal} + B_{rescale} \qquad p_\lambda = \frac{\pi\ L_\lambda\ d^2}{ESUN_\lambda\ \cos(\theta)}$$

Cloud and cloud shadows on the processed reflectance bands were removed. For each image date, a natural color composite of visible bands was created to visually search for cloud and cloud shadows, and a mask of zero pixel value was placed across all areas affected by clouds.

The following figure shows a comparison of three-date NDVI composite images from the data preprocessed by RTi in comparison to the data preprocessed by Agro with subsequently delineated parcels. NDVI imagery will be explained in the following section. As the NDVI composite consists of a June, July, and September image, blue fields are typical of grain, green fields typical of potatoes, and white fields typical of alfalfa. Georeferencing inaccuracies between the images from different time frames will result in fuzzy edges. The figure shows the increased parcel edge resolution that was obtained by reprocessing the imagery. Slight coloration differences in the example are due, in part, to the color display "stretching".



Left – RTi processed imagery Right – Agro Engineering processed imagery

Figure 2. Comparison of Preprocessed Satellite Imagery NDVI Composites

Reference:

Chander, G., B.L. Markham, and D.L. Helder. 2009. Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 ALIS Sensors. Remote Sensing of the Environment 113 (2009) 893-903.

3.2.1.2 NDVI Threshhold Image

The normalized difference vegetation index (NDVI) is a very common vegetation index ascribed to Rouse et al. (1973) and Kriegler et al. (1969). NDVI is used extensively to characterize the density of vegetative biomass. To calculate NDVI, first the simple ratio is computed. The simple ratio (SR) divides the near infrared band to the red band to help eliminate various albedo effects. The simple ratio (SR) and normalized difference vegetation index (NDVI) can be developed from LANDSAT data using the following formulas where TM 3 represents the Landsat TM red band and TM 4 represents the Landsat TM near infrared band.

$$SR = \frac{TM\ 4}{TM\ 3} \qquad NDVI = \frac{SR - 1}{SR + 1} \qquad NDVI = \frac{TM\ 4 - TM\ 3}{TM\ 4 + TM\ 3}$$

Use of the vegetation index requires a few assumptions. First, all bare soil in an image will form a line in spectral space. The red-near-infrared line for bare soil is considered to be the line of zero vegetation. Secondly, all ratio-based indices such as NDVI assume that all iso-vegetation lines converge at a single point. The results of the NDVI calculation are floating point images scaled from minus one to positive one. NDVI values below zero tend to indicate areas without vegetation cover, while NDVI values above zero tend to indicate the presence of vegetation. The higher the NDVI value, the greener and more vigorous the vegetation is. Floating point images were rescaled to 8-bit numbers (0-255) to reduce computer memory requirements.

NDVI images were produced for all thirteen of the Landsat TM scenes. A multi-temporal NDVI threshold image was developed by finding the maximum NDVI value from all thirteen NDVI images at each pixel. This image represented the “greenest” that an area became throughout the entire growing season so that the entire year could be considered at once while discriminating between irrigated and non-irrigated lands. The image was scaled so that NDVI values above 0.5 were colored shades of green, colors for NDVI values between 0.3 and 0.5 varied from a light grey to bright white, and NDVI values below 0.3 were all colored as black.

An Erdas Imagine (.img) thirteen band image file was also created such that the NDVI for any three image dates could be viewed at one time as a color composite. Viewing combinations of three NDVI images from critical time periods at once provided coloration useful for visually interpreting crop types and noting crop differences for division of split-cropped fields and also provided an added to for subsequent processing for the crop classification.

References:
Rouse, J.W., Haas, R.H., Schell, J.A. and Deering, D.W. (1973) Monitoring Vegetation Systems in the Great Plains with ERTS, “3rd ERTS Symp, NASA SP-351, Vol. 1, pp. 309-317.

Kriegler, F.J., Malila, W.A., Nalepka, R.F. and Richardson, W. 1969. Preprocessing Transformations and their Effects on Multi spectral Recognition, Proceedings of 6th International Symposium on Remote Sensing of Environment, University of Michigan, Ann Arbor, MI., pp. 97-131.

3.2.1.3 Tasseled Cap Transformation Threshold Image

A tasseled cap transformation image is calculated by multiplying the tasseled cap coefficient by the reflectance of each band and adding up these products for all bands. A tasseled cap greenness image was created for each of the thirteen Landsat images. Table 5 lists the tasseled cap coefficients for the TM bands.

Table 5. Tasseled cap coefficients for at-satellite reflectance

Index	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Greenness	-0.3344	-0.3544	-0.4556	0.6966	-0.0242	-0.2630
Brightness	0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
Moistness	0.2626	0.2141	0.0926	0.0656	-0.7629	-0.5388

A tasseled cap threshold image was also created from the maximum tasseled cap greenness value at each pixel from the thirteen separate tasseled cap greenness images. This threshold image was used as an additional source of information for discriminating irrigated vs. non-irrigated cover types. However, the tasseled cap threshold was not developed extensively as results were similar in most respects to the results obtained with NDVI which has been used more in other studies.

3.2.1.4 Image Classification

Image enhancement is the process of modification of the image values to highlight desired information within the image. Image classification is one technique used for image enhancement to identify crop types. Image classification refers to the computer-assisted interpretation of remotely sensed images. Image classification can be either supervised or unsupervised.

Unsupervised classifications use cluster analysis to distinguish differences in reflectance values across a set of three bands and creates a classification from typical reflectance patterns. This is equivalent to searching for the peaks in a one-dimensional histogram, where a peak is defined as a value with a greater frequency than its neighbors on either side. Once the peaks have been identified, all possible values are assigned to the nearest peak. A three-dimensional histogram is used because the composite is derived from three bands. A peak is defined as a three dimensional area where the frequency is higher than that of all of its neighbors.

Supervised classification procedures work from known "training sites", in this case areas of known crop type whose location is designated. The spectral signature of each training site is statistically characterized for all of the bands of spectral data used in the analysis. Once a statistical characterization has been achieved for each information class, the image is then classified by examining the reflectance for each pixel and making a decision about which of the signatures it most likely resembles. There are several techniques for making these decisions, and these operating logic procedures are often termed hard classifiers. Several different hard classifiers exist including: parallelepiped, minimum distance to means, and the maximum likelihood classifier.

A maximum likelihood classifier is one of the most popular methods of classification in remote sensing, in which a pixel with the maximum likelihood is classified into the corresponding class. The maximum likelihood procedure consists of a multi-dimensional probability function where each pixel is analyzed and assigned to the class that it has the highest probability of belonging to, based upon its band signatures.

The Bayesian classifier is one of a group of soft classifiers. Unlike hard classifiers, soft classifiers defer making a definitive judgment about the class membership of any pixel in favor of producing a group of probability statements about the degree of membership of that pixel in each of the possible classes. Like traditional supervised classification procedures, the Bayesian classifier uses training site information to define signature files for the purpose of classifying each image pixel. However, unlike traditional hard classifiers, the output is not a single classified land cover image, but rather, a set of images (one per class) that expresses for each pixel the probability that it belongs to each class.

Bayesian probability theory is an extension of classical probability theory. Bayesian probability theory allows one to combine new evidence about a hypothesis along with prior knowledge, or assumptions, to arrive at an estimate of the likelihood that a hypothesis is true. The Bayesian classifier is closely related to the maximum likelihood classifier, in that it computes the posterior probability of belonging to each considered class according to Bayes' Theorem:

$$p(h/e) = \frac{p(e/h) * p(h)}{\sum p(e/h_i) * p(hi)}$$

where:
p(h/e) = the probability of the hypothesis being true given the evidence
(the posterior probability of a pixel belonging to a crop type)
p(e/h) = the probability of finding that evidence given the hypothesis being true
(derived from the signature file data based on training sites)
p(h) = the probability of the hypothesis being true regardless of the evidence
(prior probability).

The posterior probability is the same quantity that the maximum likelihood classifier evaluates to determine the most likely class. In this context, the variance/covariance matrix derived from the training site data is that which allows one to assess the multivariate conditional probability. This quantity is then modified by the prior probability of the hypothesis being true and then normalized by the sum of such considerations over all classes. This latter step is important in that it makes the assumption that the classes considered are the only classes that are possible as interpretations for the pixel under consideration. Thus even weak support for a specific interpretation may appear to be strong if it is the strongest of the possible choices given.

The prime motivation for the use of the Bayesian classifier is that, rather than assigning a hard crop type to each pixel, a percent probability that a pixel belongs to each crop type is assigned. Different crop types have different spectral responses over the growing season and are easier or more difficult to classify depending on timing. In combination with multi-temporal analysis, this approach allows one to examine pixels from multiple time frames across the season and determine the crop type that a pixel has the greatest probability of belonging to.

3.2.2 NAIP Imagery

In 2005, a complete set of color aerial photograph mosaics with 1-meter resolution was available for all of the San Luis Valley. These photo mosaics were taken by the USDA Farm Service Agency (FSA) as part of the National Agriculture Imagery Program (NAIP) and are geo-referenced to UTM NAD83 (Zone13N). The 2005 NAIP imagery was used to manually delineate the irrigated parcel boundaries. A NAIP photo mosaic with 2-meter resolution was also available for 2006 and provided as a check for fine-tuning parcel boundaries.

3.3 2005 Irrigated Parcel Delineation

3.3.1 Boundary Delineation

Irrigated parcels throughout Division 3 had previously been delineated for the 1998 irrigated lands assessment and the 2002 irrigated lands assessment. Between 2002 and 2005, the boundaries of the majority of center pivot irrigated parcels were reduced, as end-guns and corner systems were removed, as a result of a multi-year drought and a strong community effort for voluntary acreage reductions. Higher resolution imagery was available in 2005 then was available in 1998. The 1998 irrigated parcel boundaries were delineated using 5 meter resolution IRS satellite imagery. The 2002 irrigated parcel boundaries were delineated using 1-meter resolution, black-and-white, USGS digital ortho-photo quarter-quad (DOQQ) aerial imagery. Since little surface water was available for diversion during 2002, many parcels irrigated solely by surface water were not irrigated that year and were not delineated with the higher accuracy imagery. Consequently, significant work was needed to delineate new 2005 irrigated parcel boundaries. In 2005, a complete set of NAIP color aerial photograph mosaics with 1-meter resolution was available for all of the San Luis Valley. The high-resolution color photography provides more information relative to irrigation and crops than the prior black-and-white photos or coarser resolution satellite imagery. The 2005 NAIP photography was used to delineate parcels that were irrigated in 2005. Although most parcels were redrawn, some parcel boundaries that did not change significantly between 2002 and 2005 were not redrawn.

The 2005 NAIP image was developed by combining a series of individual scenes. The collection date for the individual scenes included in the image varied across the 2005 growing season depending on county. The majority of the 2005 imagery was collected early in the growing season, while a portion of the imagery was collected late in the growing season. The early image date was not optimum for an accurate delineation of some parcel boundaries. NAIP photography with a 2-meter resolution was also available for 2006. The 2006 imagery was often collected at a time that was more useful for parcel boundary delineation. While the crop grown in 2006 on individual parcels was not representative of the crop grown in 2005, a majority of the parcel boundaries did not change from one year to the next. Consequently, the 2006 imagery was available as a check to fine-tune the boundary delineation, and was relied on when the 2005 image was difficult to use. The 2006 imagery could also sometimes be used to evaluate the full extent of the irrigation that occurred in 2005 for some flood irrigated parcels.

The irrigated parcel boundaries were manually delineated using the 2005 NAIP imagery. The multi-temporal NDVI threshold image was available to help in discriminating between irrigated and non-irrigated lands. The multi-temporal NDVI image produced by the composition of the thirteen individual dates was also available for review. The 2006 NAIP imagery was available when boundaries were difficult to differentiate from the 2005 aerial photography. The irrigated parcels that had previously been drawn in 1998 and 2002 were also available for comparison. The irrigated parcel was defined as a uniformly irrigated area, with a similar crop type, a single irrigation system, uniform cropping practices and a defined water source. The boundaries between parcels were divided by changes in water source (i.e. noticeable boundaries in ditch service area), ownership, use, or other noticeable boundaries (i.e. a fence, ditch, or road) that were apparent in the imagery.

The irrigated parcel boundary set was meant to represent areas actually irrigated in 2005, and parcels that may have been irrigated in other years, but were fallow in 2005, were not delineated. Center pivot irrigated parcels which were fallow in 2005 were maintained in a separate theme so that statistics on the total number of center pivots could be calculated.

If portions of a parcel were irrigated while other portions of the parcel were clearly not irrigated, an attempt was made to delineate the irrigated portion of the parcel and not the entire larger area. Although this practice was also used in the 1998 and 2002 delineations, it was even more prominent in the 2005 delineation. The high-resolution color aerial photography and multi-temporal NDVI threshold imagery allowed tighter delineation of irrigated and non-irrigated areas within a larger parcel.

In many cases, the boundary between irrigated parcels and natural "un-irrigated" features was difficult, but important, to define. Large areas of trees were not included within irrigated parcels, although some individual trees were included in some meadow parcels. Sloughs near or within parcels were examined using the available imagery to determine if they dried up and supported vegetation, or if were typically covered in open water. Large sloughs with an open water surface for the majority of the year were not included in irrigated parcels; as the water surface was probably supported by ground water levels and the area is better represented as native lands. More ephemeral sloughs that dried up, showed vegetation growth later in the season, and appeared to potentially be supported by ditch water were often included within larger irrigated meadow parcels.

Close to 12,000 parcels were delineated for the 2005 set. A number of these parcels were removed from the final parcel set after further discrimination of whether the parcel was irrigated or non-irrigated. More parcels were delineated in 2005 than in 1998 and 2002. In comparison to the 1998 set, an increase in the number of parcels reflects a finer discrimination of parcel boundaries, although a lower total acreage was delineated. The coarser resolution of the 1998 satellite imagery may have resulted in more area being delineated as irrigated than was actually irrigated, often between or around areas defined as irrigated in 2005. As very little surface water was available in 2002, the overall area and number of parcels was lower in 2002 than in 2005. The division of parcels into small areas was actually finer in 2002 than in 2005. Some attention was made in 2005 not to “over-divide” parcels, in order to better represent farm unit parcels that may be tracked in the future.

3.3.2 Discrimination between Irrigated and Non-Irrigated

Perhaps the most important part of the parcel delineation is the discrimination of irrigated versus non-irrigated parcels. The irrigated parcel boundary set was meant to represent areas actually irrigated in 2005. Initially, the NDVI threshold image was used along with the aerial photography to delineate irrigated parcels. As described earlier, the threshold image characterized the maximum NDVI for thirteen satellite images taken throughout the growing season. In the image, black areas (NDVI < 0.3) were clearly not irrigated, widespread green areas (NDVI > 0.5) cleared received water from irrigation or groundwater tables, and parcels w with a predominance of white and some green and water supplies were probably irrigated. The threshold between irrigated and non-irrigated did vary by region. The color green was generally used to define irrigation in areas with generally high groundwater tables (i.e. Conejos County and near rivers), while whiter colors generally indicated irrigated parcels in areas of lower groundwater that supported little native vegetation.

Once the parcels had been initially delineated as irrigated, they were reconsidered using both an automated comparison of parcel NDVI with NDVI thresholds and an evaluation of water sources. The median NDVI value from all pixels of the NDVI threshold within parcel boundaries was calculated, and parcels with median NDVI values below 0.30 were removed from the set or altered to remove un-irrigated areas. Use of a median for the entire parcel reduced edge or outlier effects. Following assignment of well and ditch water sources (as described later), parcels that may have appeared green in the aerial photography or satellite imagery, but did not have an reasonably apparent surface or ground water source were removed from the coverage.

Some times, lands that appear as pasture/meadow may have vegetative growth that is supported by high groundwater tables, but without intentional irrigation. These lands are best defined as native vegetation. Ideally, the use of the RGDSS models to assign consumptive use to native lands, based on groundwater levels, should depend on an accurate merging of irrigated parcels and a native lands classification for each modeled year. Beneficial use also provided some measure for inclusion as an irrigated parcel. If areas clearly appeared to be a weedy, unused, or not pastured or hayed, they were not included. However, the discrimination between intentional irrigation and native sub-irrigation is difficult in some areas and it is expected that some areas that are not intentionally irrigated may still be included within some larger parcels.

As examples of parcel delineation and discrimination of irrigated and non-irrigated areas, the following figures highlight an area within the Centennial Ditch service area. Parcel boundaries are shown on top of both the 2005 NAIP aerial photo and the NDVI threshold image. It can be noted that some large meadow areas and pasture parcels were reduced to irrigated areas using the NDVI threshold imagery and by noting areas of reasonable ditch service and open water.

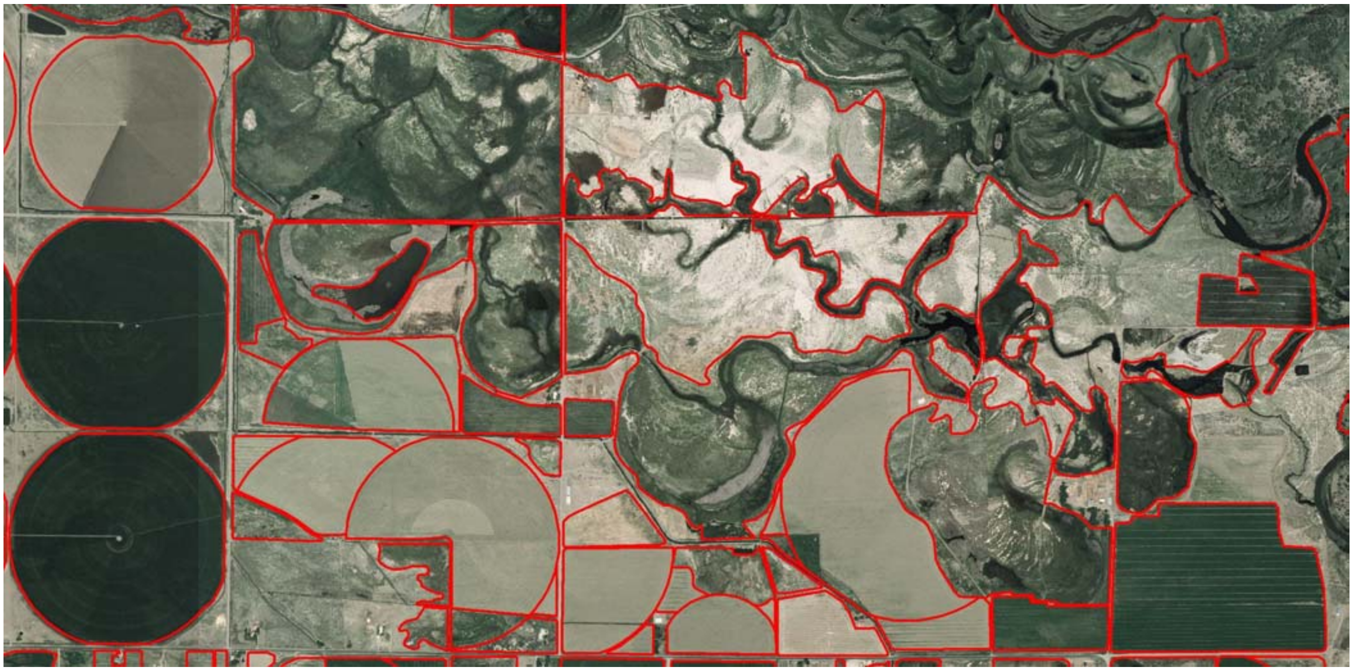


Figure 3. Irrigated Parcels on 2005 NAIP Aerial Photography

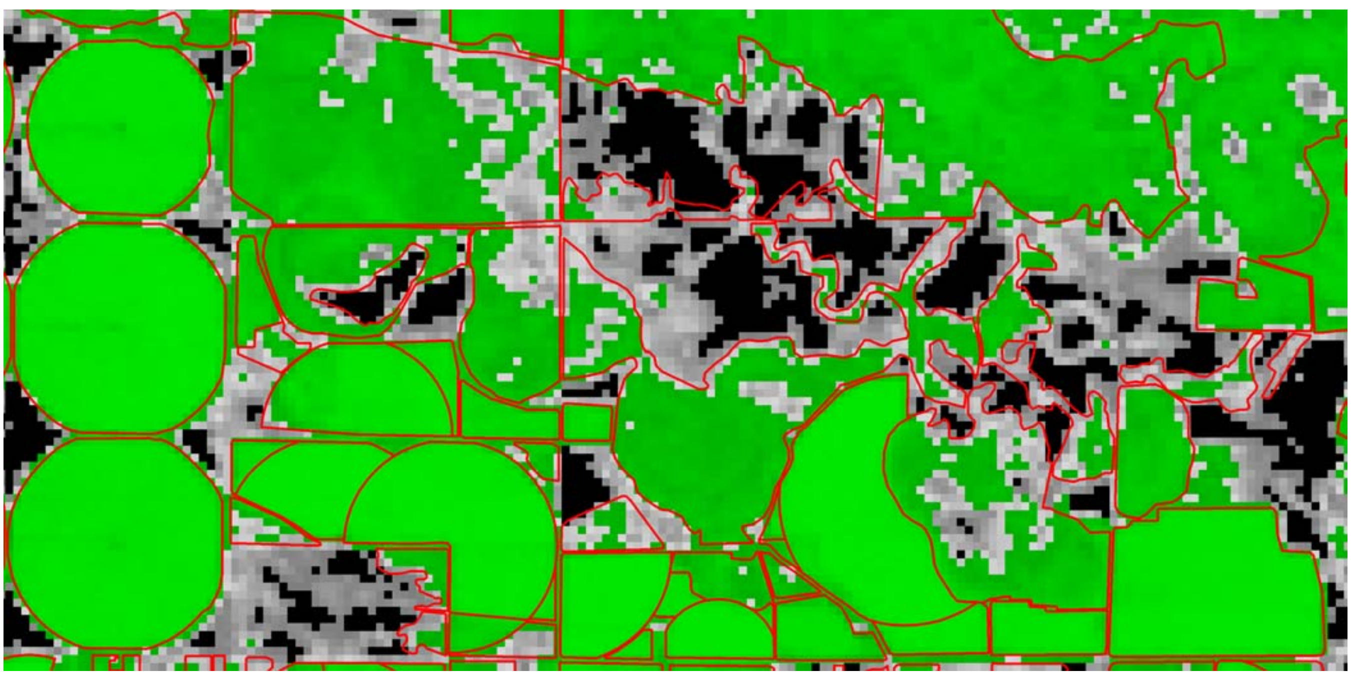


Figure 4. Irrigated Parcels on NDVI Threshold Image

3.4 2005 Crop Classification

The classification of irrigated lands consisted of three main processes including, (1) a manual visual determination of crop type based on multiple sources of available data, (2) a multi-spectral satellite classification and a subsequent multi-temporal probability analysis, and (3) classification refinements.

3.4.1 Manual Visual Determination

A manual assignment of a crop type was given to each parcel based upon a visual comparison of available data sources. Crops types were determined for 2005 parcels using an evaluation of the following sources: 1) color aerial photography, 2) a composite of NDVI images from Landsat satellite imagery, 3) crop information from the Rio Grande Water Conservation District, and 4) knowledge of regional cropping practices and crop information from Agro Engineering data. While engineering judgment was required to make a decision about the crop type for every single parcel from these multiple sources of information, this approach was preferable as no single sources of information described crop type in a completely accurate manner and was comprehensive over all of Division 3.

3.4.1.1 Aerial Photography

The color NAIP aerial photography available for both 2005 and 2006 was discussed previously for parcel delineation. The high-resolution 2005 photography was of significant value for crop classification. Although the photography only provided one snapshot in time, reliable interpretations of crop type could often be made when combined with knowledge of regional cropping practices and interpretations of the satellite imagery composite. Details such as coloration, rows, dikes, jagged edges (characteristic of early season potatoes), cut hay, and irregular irrigation could be noted in the aerial photography. The 2005 color aerial composites were primarily taken either early or late season. This time-frame accentuated differences between fields of potatoes and grain. However, care had to be taken as the image mosaic changed from an early season, to a late season, and back to an early season photo across the valley from west to east.

Interpretation of the aerial photos was relied on particularly for flood irrigated parcels. Alfalfa parcels were deemed to generally be a darker green, more typically had linear dikes for flood or furrow irrigation, tended to be more regularly shaped, and tended to have a more uniform coloration than nearby pasture-native grass parcels

3.4.1.2 NDVI Satellite Imagery

NDVI images were produced for all thirteen of the Landsat TM scenes. A multi-temporal NDVI image was created from the thirteen individual NDVI images such that any three image dates could be viewed as a color composite. Viewing combinations of three NDVI images from different time periods at once provided coloration useful for visually interpreting crop types and differences such as split-cropped fields. The multi-temporal NDVI image produced by the composition of the thirteen individual dates was useful for manual interpretation of the crop classification.

A multi-temporal NDVI threshold image was also created by taking the maximum NDVI value from all thirteen NDVI images at each pixel. This NDVI threshold image was useful in discriminating between irrigated and non-irrigated lands.

3.4.1.3 Rio Grande Water Conservation District Data

The classification process for the 1998 and 2002 RGDSS irrigated lands studies relied heavily on parcel crop information collected by the Rio Grande Water Conservation District (RGWCD). The RGWCD conducts an annual field investigation to document crops in the central portion of Division 3. The RGWCD crop study does not extend west of Del Norte, north of road N in Saguache County, or into Costilla County, and generally concentrates more on center pivot crop lands than river-land and flood irrigated areas. The 1998 and 2002 RGDSS irrigated lands studies relied on the set as a field verified data source with very high reliability. Definitive differences with the satellite image classification indicated that the 2002 RGWCD classifications were approximately 98.6% accurate on sprinkler irrigated parcels. However, 2005 was a transition year for the RGWCD for both how crop information was collected and recorded and was the first year that the RGWCD began to implement GIS. Comparisons with aerial photography and the satellite imagery indicated that the RGWCD crop classifications were less reliable for 2005 and could not be relied on as a near perfect field verified data source.

The following table compares the final crop classification to parcels for which RGWCD crop data was available and could be easily matched to 2005 parcels. Matching for accuracy assessment was more difficult with flood irrigated parcels due to more significant differences in parcel boundaries. Accuracies ranged from below 80% on a parcel basis to above 80% if considered on an area basis. This accuracy range was not considered sufficient to rely on this data as a near-perfect field verification source. Therefore, the RGWCD data was evaluated along with the other data sources, but was not relied upon as the sole source of data as it was in past studies.

Table 6. Comparison of Crop Classification with RGWCD Crop Data

	All Crops		Grain = Oat Hay	
	Parcels	Area	Parcels	Area
Sprinkler Irrigation	78.6%	83.6%	79.5%	84.3%
Flood Irrigation	81.9%	87.0%	83.8%	88.6%

Note: Parcels: calculated by number of parcels, Area: calculated by parcel areas
Grain=Oat Hay: calculated as RGWCD grain classification includes oat hay

The change in the aerial image mosaic from an early season to a late season across the valley may have caused some of the inaccuracies in the RGWCD set, as it appears that the RGWCD data may have reflected some of the timing differences seen in the aerial photography. Another inaccuracy in the RGWCD data was related to split fields. In some cases, a split crop may not been observed on the ground, and in many more cases split crop pairs were assigned to the wrong sides in the GIS, potentially due to changes in the early and late season imagery or data entry issues.

Some differences between the RGWCD classifications could also be explained by differences in how the same crop in the field is interpreted. For instance, a common practice is to plant new alfalfa with a nurse crop of oats. It appears that many of these parcels were often interpreted in the field by the RGWCD as grain, but due to the continued dominance of the alfalfa into September and October, were classified as new alfalfa by the satellite methodology. There was a lot of new alfalfa replanted in 2005. More oat hay was classified than would be expected. Generally, a mixture of alfalfa and oats was classified as oat hay if the greenness pattern followed the typical oat pattern and had little response in September and October, but would be classified as alfalfa if the crop remained somewhat green into September and October

3.4.1.4 Agro Engineering Information

An additional source of data evaluated during the manual classification included client fields on which Agro Engineering worked in 2005 and a field classification of the parcels between South Fork and Del Norte, performed by Agro Engineering in 2004, which were involved in a transfer of trans-mountain water with the Division of Wildlife. Although this study was not conducted in 2005, fields of alfalfa in 2004 generally remained in alfalfa in 2005. For client fields, Agro collected between one and five infrared aerial photos of each field throughout the 2005 growing season that could be re-examined for crop details such as crop splits. Knowledge of farm ownership and cropping practices throughout regions of the San Luis Valley added to crop classification evaluations.

3.4.2 Multi-Spectral Satellite Classification

A supervised classification was then performed to use the multi-spectral responses from the thirteen Landsat images to estimate crop type for each parcel. A Bayesian classifier was used. This technique determines the percent probability that each pixel in an image belongs to a particular crop type. Different crop types have different spectral responses over the growing season and are easier or more difficult to classify depending on timing. In combination with multi-temporal analysis, this Bayesian classification technique allows one to examine multiple time frames across the season to determine the crop type that a parcel has the greatest probability of being.

As recommended by previous studies, each parcel was buffered by reducing the boundary by 30 meters prior to training site generation and classification processing in order to remove potential edge effects.

Training sites were developed using parcels that had a high confidence in actual crop type based upon the manual classification. Training sites were developed for a larger set of crops than are currently used by RGDSS including: potatoes, grain, alfalfa, new alfalfa, pasture and native grass, canola, oat hay, sudan grass, winter wheat, other cover crops, and fallow. The training sites were used to create multi-spectral signature files for TM bands one through five of each of the satellite image. A signature for vegetables was not developed as the variability in timing of this short season crop complicated classification. Rather, classifications for vegetable fields were noted in the RGWCD crop data, satellite imagery, and aerial photography, and classification results for vegetable fields were disregarded.

A Bayesian probability classifier was used to create probability images for each crop on each satellite image. For each satellite image, files for each crop were created from the Bayesian classifier that estimated the probability that each pixel within the image belonged to a particular crop type given the similarity between the spectral characteristics of the pixel and the crop signature files that were developed for that image. The mean parcel crop type probability for each date was then calculated as the mean of each pixel within each buffered parcel area. The probability that a parcel was a particular crop type was then summed across the thirteen images. The crop type with the maximum overall seasonal probability was chosen as the most probable crop type for the parcel. A probability preference was given to the primary crops of potatoes, grain, and alfalfa over the less widespread minor crops that were classified.

3.4.3 Classification Refinements

Following the first classification iteration, parcels that were classified differently between the manual evaluation and the multi-spectral classification were re-evaluated. Additional crop splits were added, the visual interpretations were re-evaluated, and new training sites were defined. The multi-spectral crop classification process was then run a second time and differences between the manual evaluation and the multi-spectral classifications were again re-evaluated.

For parcels where definitive indications of the crop type were evident from the aerial photography, NDVI satellite imagery, RGWCD data, or Agro Engineering data; the manual determination was maintained. Where available evidence supported the multi-spectral classification, it was relied on.

3.4.4 Multi-Temporal Analysis

Classification using NDVI values rather than a full multi-spectral classification was also evaluated, but classification accuracy was reduced. However, seasonal patterns of NDVI values across each image date provide useful information on how the spectral signatures differ between crop types. The median NDVI value for all crop parcels for each image date are provided in the following two figures for sprinkler and flood irrigated parcels.

For sprinkler irrigated parcels, alfalfa fields became green the soonest and were generally green through September. However, in the figure, definite drops in NDVI were predominant in the 7/2 and 8/3 images which indicates relatively common hay cutting periods. Grain fields became green (had a high NDVI) in late May and June but were dead by late August. Both spring-wheat and barley fields were included in this classification, and wheat fields were noted to remain greener into August. Potato fields began greening up in July with a maximum NDVI in late July and early August. Most potato fields remained somewhat green in late August, although potato seed fields that were dead by late August were a source of some classification error.

Of the minor crops, canola fields were generally noted in the RGWCD data or Agro Engineering data and could be recognized in the aerial photography. On the other hand, oat hay classifications were called grain in the RGWCD data, but had a distinct coloration in the NDVI composite image that was not typical of barley or wheat. The mean NDVI for the oat hay class often indicated greenness in July and August but fell off in September and October. Therefore, this could have included some late-planted crops or potentially some hay crops with limited irrigation. The classification of oat hay, although of less acreage than suggested by the large grain classification of the RGWCD, may be on the high side. A classification of sudan was often used to represent a cover crop with less green biomass than other crops. It typically had the highest mean NDVI in late July to early August, and may include other types of cover crops. Fields classified as winter wheat did not have a crop during the growing season but became green in October.

Flood irrigated parcels generally had a lower overall peak NDVI than similar sprinkler irrigated crops. However, flood irrigated parcels had a higher minimum NDVI, indicative of a response from fields that may be in areas with higher groundwater tables. Although several fields of flood irrigated potatoes and winter wheat were classified, these crops are not indicated in the figure due to the low number of classified parcels. The classification of pasture grass includes a wide range of crops from poorly irrigated pasture to very well irrigated wet meadow or native grass hay. The classifications of oat hay and sudan were included with pasture grass, canola and winter wheat was included with small grains, and new alfalfa was included with alfalfa for the final RGDSS irrigated lands set.

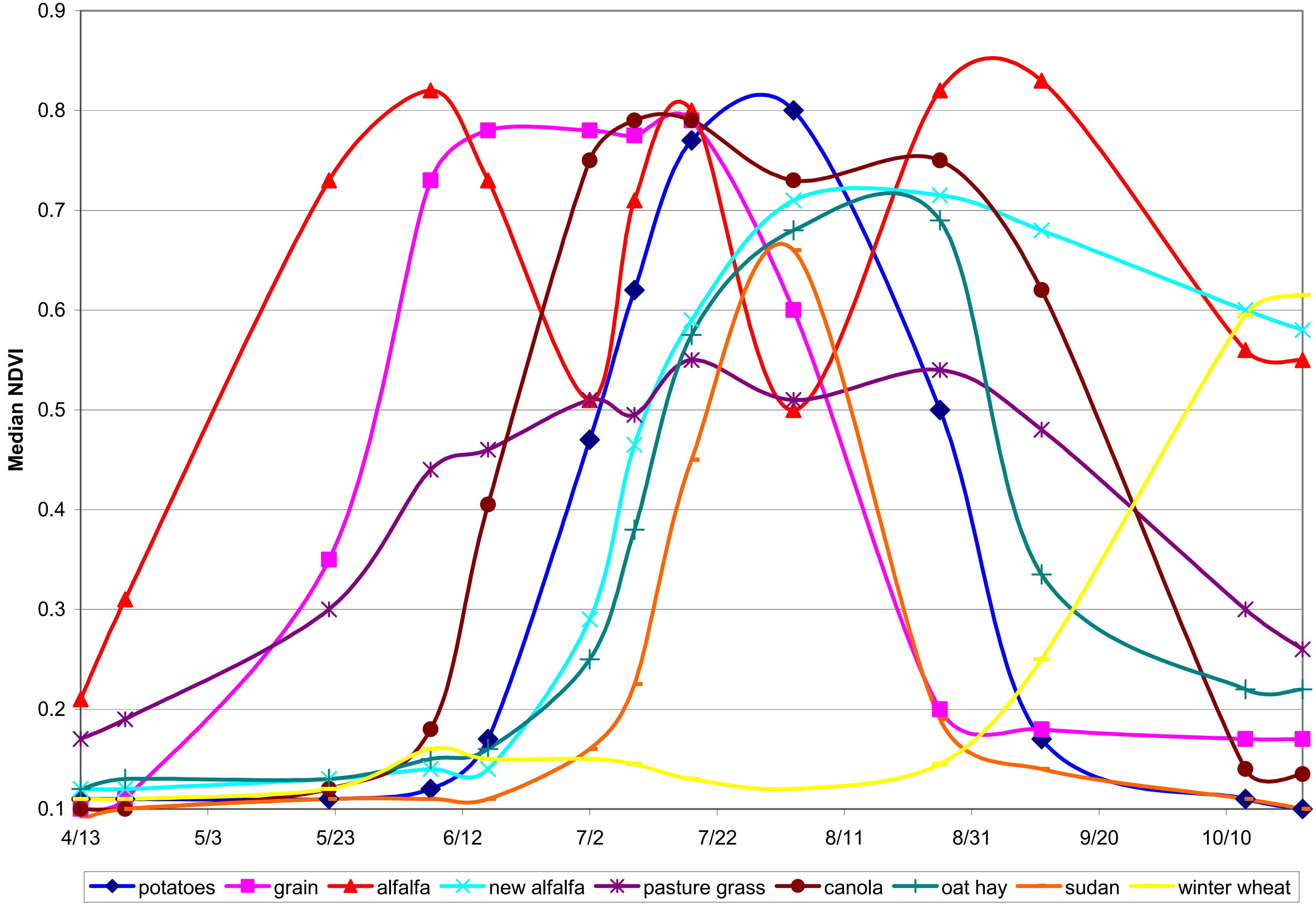


Figure 5. Median NDVI Distribution for Sprinkler Irrigated Parcels

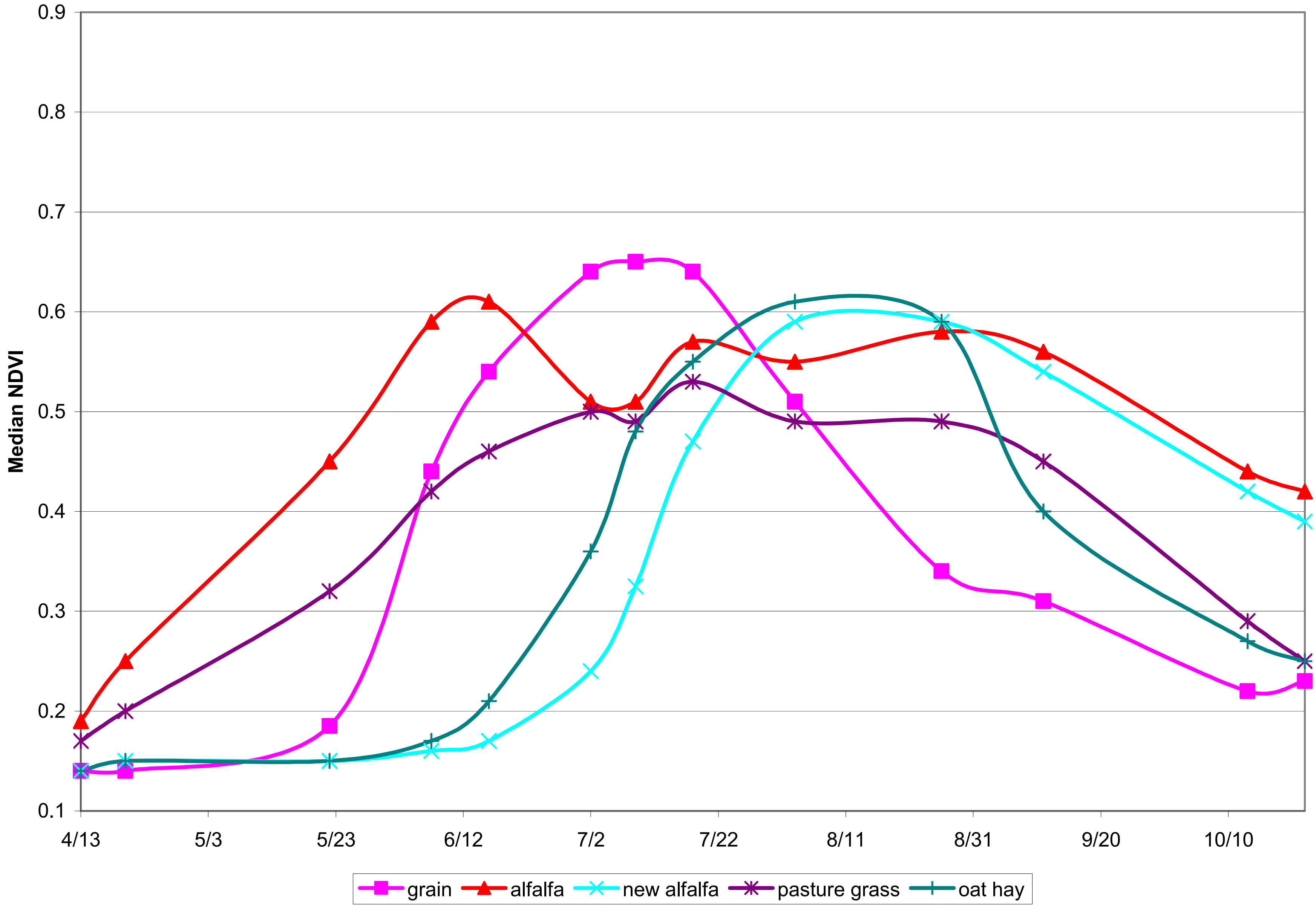


Figure 6. Median NDVI Distribution for Primary Crops for Flood Irrigated Parcels

3.4.5 Accuracy Assessment

The accuracy of the computer classification technique was estimated by comparing the multi-spectral classification results to the final classification that was made. The following table shows the accuracy of the computerized classification for the sprinkler irrigated parcels. Across all sprinkler irrigated parcels in Division 3, the classification accuracy was 97.5% for the primary crops of potatoes, grain, and alfalfa and 95.3% for all crops including minor crops on an area basis.

The distribution of satellite image dates was relatively uniform in the central portion of the San Luis Valley where there was satellite path overlap, but was relatively poor in the non-overlap areas in the north and west of the valley and in Costilla County. As such, the classification accuracy was higher in the overlap area than the non-overlap area. A classification of 96.3% for all classified sprinkler crops and 98.8% for the primary crops of potatoes, grain, and alfalfa was achieved in the overlap area which includes about 69% of the total area of sprinkler irrigated parcels.

Table 7. Estimated Accuracy for Multi-spectral Classification

	Total Sprinkler Area		Image Overlap Area	
	Parcels	Area	Parcels	Area
Potatoes, grain, and alfalfa[1]	97.3%	97.5%	98.6%	98.8%
All crops including minor crops[2]	94.0%	95.3%	95.1%	96.3%

Note: [1] With new alfalfa considered together with alfalfa
[2] Potatoes, grain, alfalfa, new alfalfa, pasture-grass, canola, oat hay, sudan grass, and winter wheat

Classification for flood irrigated parcels was conducted separately from the sprinkler irrigated parcels. For flood parcels, more reliance was placed on the visual assessment using the aerial photography, satellite imagery composites, and the RGWCD classifications than the computer classification. The classification accuracy for flood irrigated parcels was more difficult to access and was not calculated explicitly but is expected to be somewhat less than for sprinkler irrigated parcels due to the difficulty of discrimination between alfalfa and pasture grass.

An accuracy assessment was also performed to evaluate the accuracy of the final irrigated crop type classification. Quantitative classification accuracy assessment involves the comparison of a parcel within the classification against reference information for the same site. The accuracy assessment of irrigated crop types used reference data from Agro Engineering's records of clients worked with during 2005. To obtain this reference data, end-of-season client reports were reviewed that contained information on irrigation scheduling and crop water use, crop fertilizer recommendations, and crop pest scouting reports. This reference data had not been relied on for the manual classification of crop type or used in the development of the training sites for the computerized multi-spectral classification. While this reference data was a small set of the total irrigated parcels from 2005, it was a set that could be relied on for accuracy.

The reference set contained representative parcels from throughout Division 3. However, this reference set is skewed in proportion toward potatoes, grain and vegetable crops; since these tend to be the crops that Agro Engineering is hired to consult on. The reference set is under-representative of alfalfa and meadow/pasture grass in comparison to the proportion of acreage of crops grown in Division 3. In comparison to the reference set, 98.97% of the parcels were assigned the correct crop type.

Table 8. Irrigated Crop Type Accuracy Assessment

CROP	Parcels (#)	Proportion of Crops in Reference Set (%)	Proportion of Crops in Division 3 (%)	Crop Area in Reference Set (acres)	Classified Crop Area (acres)	Area Classified Wrong (acres)	Accuracy (%)
Alfalfa	15	11.0%	28.5%	1545.4	1545.4	0.0	100.00%
New Alfalfa	3	2.6%	3.2%	367.4	399.1	31.7	91.38%
Grain	42	26.8%	11.6%	3774.6	3713.9	60.7	98.39%
Potatoes	62	40.6%	12.0%	5723.8	5764.5	40.8	99.29%
Meadow/Grass Pasture	1	0.0%	37.4%	4.3	4.3	0.0	100.00%
Canola	2	1.7%	0.3%	242.9	242.9	0.0	100.00%
Lettuce & Carrots	14	11.9%	1.0%	1684.8	1684.8	0.0	100.00%
Oat hay	1	0.9%	1.6%	122.3	122.3	0.0	100.00%
Sudan & Cover Crops	9	3.1%	1.2%	432.9	421.1	11.7	97.29%
Winter Wheat	4	1.5%	0.4%	209.3	209.3	0.0	100.00%
Fallow	7	1.1%	2.8%	158.7	158.7	0.0	100.00%
TOTAL	153	100.0%	100.0%	14107.8	14107.8	144.9	98.97%

3.5 Well Assignments

A primary justification for the 2002 study was that, because of the extreme drought so little surface water was available that it was easier to discriminate which parcels could be irrigated with ground water. This allowed well assignment improvements to the 2002 set of parcels, but these well assignment improvements were not transferred to the 1998 set. Recent well metering rules have resulted in a better discernment of the actively used wells and most active wells have been located with GPS coordinates by Division 3 staff, well owners, and well meter certifiers. All active wells in Division 3 have now been assigned a WDID code maintained within Hydrobase (the 1998 and 2002 sets contained a mix of receipt, permit, and WDID numbers).

The overall purpose of the well assignment work was to utilize the new well location mapping, the 2002 satellite imagery, and other data available to make the best possible assignment of individual wells to parcels irrigated in 2005 and also transfer these new well assignments to the 1998 and 2002 data sets (with modifications where necessary) to improve the quality and consistency of all of the data sets.

The most current well location data was queried from Hydrobase by the Colorado Division of Water Resources in mid-December 2009. In addition to GPS coordinates, the data set also included the most current ownership information which proved to be quite useful. Although the well set included commercial and municipal use wells, a use designation was attached if irrigation was included in the well permit and well decree. Only wells with a designated irrigation use were considered for assignment to irrigated parcels. In some cases, the designation of irrigation use did not agree between the well permit and decree, but in these cases the decreed use was considered over the permitted use. The 2009 well data indicated a number of wells as inactive or with an inactivation variance filed during the meter certification process. Some of these currently inactive wells could have been in use during 2005 or earlier, therefore the location data for these inactive wells was maintained for the matching process. A total of 3,704 irrigation wells from the state's current well set were considered for assignment to irrigated parcels.

The assignments of wells listed as inactive in 2009 were specially noted in the 2005 evaluation. Inactive wells were not assigned to parcels if an additional active well also served the same parcel, or if the parcel served by the inactive well was fallow and considered non-irrigated during the time period of the irrigated acreage coverage. However, an inactive well was assigned to a parcel if it was the only well in a quarter section serving a sprinkler system or was the only well serving a set of flood irrigated parcels that were irrigated in 2002, and physical indications were not apparent in the aerial photography where water from a more distant active well could have been conveyed to the parcel. Of the 3,722 irrigation wells considered in the initial well list, 158 were listed as inactive and 77 were maintained in the parcel data with the expectation that they may have produced water in 2005.

Wells were initially assigned to irrigated parcels using the state's spatial methodology for well assignment that had been used in prior evaluations (steps 1-5 below). The assignment "class" used is noted in a field in the irrigated parcel database. Again, this matching process is only considered between irrigation wells and parcels deemed to be irrigated during the coverage year. This methodology for assigning wells to parcels progressed sequentially as outlined below:

1. If an irrigation well is located within a sprinkler irrigated parcel or within a flood irrigated parcel, assign the well to that parcel. (Class 1).

2. If an irrigation well is not assigned in Step 1 above, but is located within 0.25 mile of a parcel served by a center-pivot sprinkler, assign the well to that parcel. (Class 2).
3. If an irrigation well is not assigned in Steps 1 or 2 above, but is located within 0.25 mile specified distance of a flood irrigated parcel assign the well to that parcel. (Class 2).

4. If a field irrigated by a center-pivot sprinkler is planted with two or more crops, resulting in a separate parcel for each crop, assign all wells associated with adjacent portions so that all portions of a complete pivot circle are each served by the same well or wells. (Class 5).

5. For lands irrigated by a center pivot sprinkler but not assigned a well in steps 1 through 4 above, assign the closest nearby well with 5 miles. (Class 4).

6. Wells that were manually assigned to parcels from interviews with water users as part of the original RGDSS process were re-assigned to those same parcels where still appropriate. (Class 7-10).

7. All previous well assignments were manually evaluated using an extensive examination of aerial photography, 2002 and 2005 satellite imagery, well ownership data, assessor data, and use of field knowledge of actual well locations from selected clients of Agro Engineering. (Class 6).

Step 7 is indicative of the tasking of Agro Engineering to make engineering judgments to improve the data set to represent real physical conditions using knowledge of regional irrigation practices and available data, rather than propagating obvious errors resulting from the spatial rules. Examination of well assignments made purely with the spatial methodology (steps 1-5) showed numerous errors in the well assignment. For 2005, every sprinkler except one was located within five miles of a well, so this methodology would suggest that every sprinkler in the valley (except one) is irrigated by ground water, while wells are assigned to very few flood irrigated parcels. This assumption is clearly not true. Spatial well assignments can be noted crossing rivers, large ditches, roads, and highways; all erroneous. However, the numerous data sources available in 2005 allowed for vast improvements in these assignments and relative certainty in numerous well assignment changes. The spatial methodology was applied without modification to the 1998 irrigated parcel coverage in the previous irrigated lands assessment. Well assignment was evaluated much more extensively in 2002, but without accurate well locations and without all data sources available in 2005. Therefore, the new well assignments are considered greatly improved from assignments in the original 1998 and 2002 data sets.

The following paragraphs discuss the methodology used to modify the well assignments (step 7) from those produced by the spatial methodology (steps 1-5). Typically (but not always) wells within a parcel irrigated by a center pivot sprinkler serve the parcels within the same quarter section. A coverage of quarter-sections was created, and all well assignments that crossed quarter section lines were highlighted, prompting additional scrutiny, especially of those assignments that crossed full section lines, major roads, and water courses. Wells generally serve down-gradient areas. For example, in the central valley area, well pipelines typically flow from west to east as a remnant of earlier flood irrigation. This is not an absolute rule, but also suggested changes to well assignments where the spatial assignment indicated well water was being pumped up-gradient a long distance. These assignments were scrutinized and could often be verified with other data. Well assignments were examined on a parcel basis over the 2005 high-resolution aerial photography. Physical infrastructure was sometimes visible in the aerial photography including pipelines, ditches, reservoirs, and gated pipe; indicating which parcel was being served.

The current well ownership information was a data source that was checked for almost all well changes and matching well ownership with parcel ownership justified the correctness of changes for a majority of wells. Multiple wells serving a sprinkler system or within a common quarter section generally had the same listed owners (or at least probable family members), and a "methodology based" well service vector that crossed out of a quarter section to supply a sprinkler with other wells with a different listed owner often warranted a change of well service back to the quarter section with the same owner listed on other wells. For multiple wells, a change was only made if a well had the same ownership as an additional well serving the same parcel. Ownership data justified well assignment changes in a surprisingly high number of cases in the central portion of the valley, and following visual work, a textual data check was also performed to compare well ownership for parcels with multiple wells. In Rio Grande County, online assessor data was used to verify parcel ownership. Agro Engineering's client/parcel database also indicated ownership for many parcels outside of Rio Grande County. When in question or when a single well was present, wells were checked to ensure that wells owned by one owner and located on one owners land did not serve parcels on an unrelated owners land.

The comments attached to wells in Hydrobase also provided some additional information for well assignment, such as notes of alternate point of diversions and limitation of irrigation to certain quarter sections.

Following the initial well assignment, satellite imagery from the 2002 study was carefully examined in the areas that rely more heavily on flood irrigation. The 2002 satellite imagery was utilized to justify changes in well assignments from the spatial methodology. As the well mapping changed so drastically, an attempt was not made to maintain irrigation by the particular well that was noted in the original 2002 data. Rather, the most likely well (i.e. closest well or best well following physical indications) was assigned if groundwater supply still appeared likely. Strong NDVI responses in the 2002 satellite imagery were indications that well water was available, while very weak NDVI responses may indicate that a ground water supply was not available. Therefore, some weak associations that were indicated in the original 2002 set as ground water irrigation were not maintained in the 2005 set and the re-assessment of the 1998 and 2002 sets. Figure 7 shows an example area where 2002 satellite imagery was relied upon for 2005 as surface water was not available in 2002.

Generally, the 2002 NDVI threshold by which ground water associations were applied was less in areas without surface water in 2002 than in areas that had some surface water supply in 2002. As 2002 was an extremely dry year, it is expected that ground water usage was higher and more widespread in that year than in normal years such as 1998 and 2005; particularly in areas that commingle surface and ground water supplies. Therefore, the number of parcels with ground water service may be overstated for 1998 and 2005, particularly in areas of commingled supply. However, as the RGDSS models distribute surface water supplies first in these areas, there should not be excessive error.

A number of well assignments were maintained from user interviews conducted by Hydrosphere. The majority of these were made from several large wells that discharge into the Sanford and Ephraim ditches and therefore can serve any parcel within the ditch service areas. For the new assignments, wells 2205933, 2205984, and 2205985 were assigned to most parcels served by the Sanford Ditch and wells 2205128 and 2205129 were assigned to most parcels served by the Ephraim Ditch. For the 2005 data set, 619 assignments were made under the Sanford and Ephraim ditches. 33 other Hydrosphere assignments were maintained. These assignments were noted as well classes 6 through 10 depending on well to parcel edge distance.

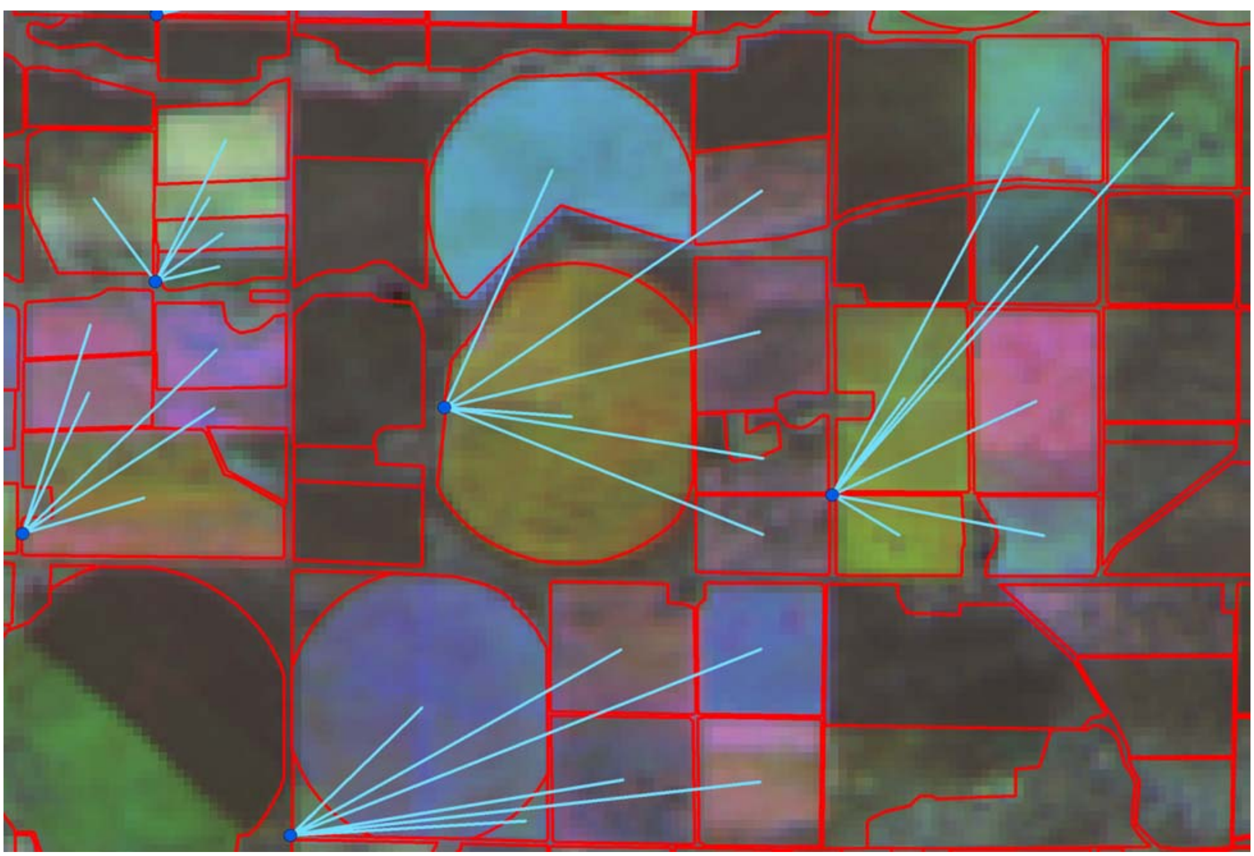
A number of parcels were outside of ditch service areas and could not reasonably be served by an irrigation well. The majority of these parcels was in Saguache County and appeared to be served by free-flowing, confined aquifer, stock wells. If a stock well with an apparently valid decree and/or permit was located near an irrigated parcel not served by a ditch or an irrigation well, than this well was assigned to the parcel. It is expected that many of these wells do exist and are being used for irrigation. Some of these wells may have been used in 2005 or earlier, but are no longer active in 2009. However, some of these wells may be erroneous. Well WDIDs, that were not included in the State's current well set, but were assigned to parcels as an irrigation source are shown in the following table. Additional wells not in the state well set and not applied in the 2005 set, but applied in the 1998 and 2002 sets are also shown. Several wells were also noted as suspicious due to location or ownership and could be checked by the DWR.

Table 9. WDID's for Wells Assigned to Parcels but Not in the Active Well Set

2005470	2005471	2005517	2005518	2008702	2009011	2009578	2009669	2009727	2010235
2010696	2012032	2012038	2012309	2012310	2013920	2505093	2505110	2505111	2505183
2505184	2505305	2505360	2505376	2505454	2505491	2505494	2605277	2605387	2605388
2605531	2605532	2605534	2605535	2605536	2605537	2605538	2605540	2605541	2605542
2605543	2605544	2605545	2605560	2605561	2605565	2605566	2605716	2605724	2605727
2605731	2605732	2605733	2605798	2605800	2605801	2605802	2605862	2605869	2705244
2705655	2705656	2705851	2705852	2706104	2706215	2013777	2605626		
2002:	2010201	2505167	2705236	2005733	2005732	2005734	2005737	2005735	2005736
	2008226	2008227	2008228	2013918	2006484	2010904			
1998:	2505168	2005641	2005491	2005492	2005473	3505380	2405008	2005201	

Table 10. WDID's for Additional Wells to be Checked

2008693	GPS location somewhat in error	2013955	Ownership data/location suspicious
2605557	GPS location somewhat in error	2013644	Ownership data/location suspicious
		2014348	Ownership data/location suspicious



Note:2005 parcels(red) and well assignments(light blue) shown on 2002 NDVI satellite imagery composite
Area shown did not have surface water diversions in 2002

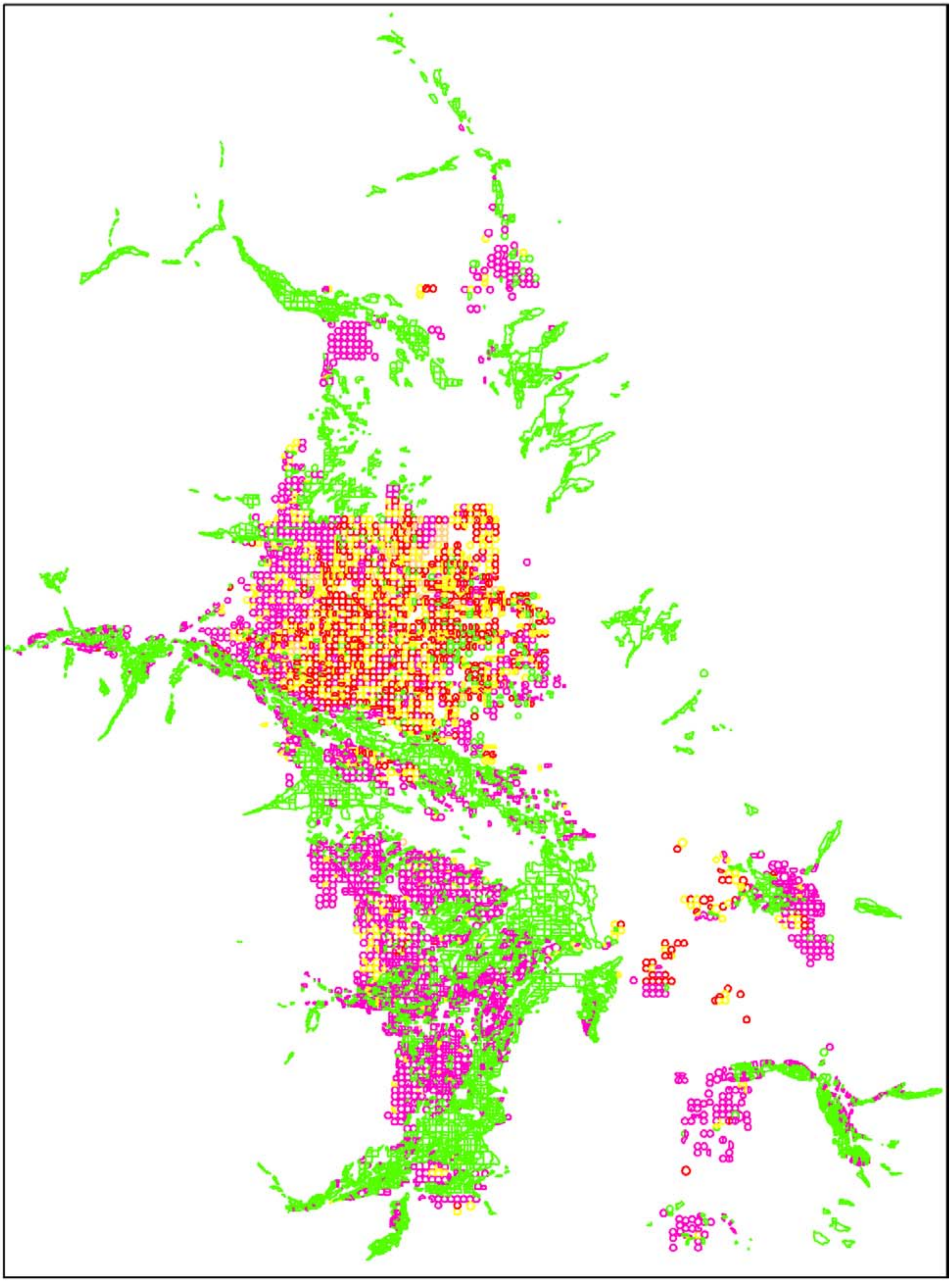
Figure 7. Example of Well Assignments using 2002 Satellite Imagery

3.6 2005 Irrigated Parcel Theme

The 2005 irrigated parcel theme contains the vector boundaries for the irrigated parcels that were delineated for 2005 and has a database of attributes associated with each parcel. Associated with each parcel is:

- area,
- crop type,
- irrigation system type,
- a list of all surface water sources that the parcel falls within the ditch service area boundary of,
- The fractional coverage of each surface water source,
- The WDID for each well that serves the parcel,
- The well assignment class code.

This theme is intended to represents the total amount of acreage that was actually irrigated during the 2005 growing season. As such, it serves only as a reference or a snapshot in time of the amount of irrigation in the basin. It is not intended to indicate the total amount of acreage that has been irrigated at any other point of time in the past or indicate the total amount of acreage that can legally be irrigated in the future. Irrigated land included all parcels that clearly had a water supply and were actively growing a crop. Irrigation has been defined as the purposeful act by man to divert water and place it to a beneficial use for the growing of crops. The following figure shows the 2005 irrigated parcel theme with nearly 12,000 parcels colored by crop type. Some parcels to the west of the figure window located along the upper reaches of the Rio Grande are not shown.



Crop Types: red=potatoes, yellow=small grains, orange=vegetables, purple=alfalfa, green=grass/pasture

Figure 8. Irrigated Parcel Theme

3.7 Enhancements to Previous Year Data Sets

3.7.1 Enhancements to the 2002 Data Set

Commentary received by Agro Engineering regarding the 2002 irrigated lands data set included statements that the coverage did not include enough irrigated acres while others that the coverage included too much acreage. Differences in acreages under ditch services areas between the 1998 and 2002 studies that were pointed out were primarily the result of improvements in both the ditch service area coverages and ground water assignment that were used for the 2002 study, but had not been applied back to the 1998 coverage. The methodology used to define an irrigated parcel did change between the 1998, 2002, and 2005 studies; although it can safely be said that the methodologies improved considerably for each new study. However, increasing consistency between data sets is important, and Agro Engineering was tasked to re-evaluate the discrimination of irrigated parcels in the 2002 study.

For the 1998 study, one IRS satellite image, shaded by the infrared band of a Landsat satellite image, was visually inspected to define an irrigated parcel. For the 2002 study, a composite of tasseled cap greenness images from multiple Landsat images was used to discriminate between irrigated versus non-irrigated parcels. In particular, eight Landsat images were combined into four "monthly" image pairs and combined into both an early weighted and a late weighted three-band composite. As 2002 was so dry, a slight greenness response above background often triggered delineation of an irrigated parcel, rather than the use of a greenness threshold value. However, a small greenness response in relatively deep-rooted perennial hay crops could be due to use of residual soil moisture or relatively high groundwater levels rather than intentional irrigation. For the 2005 study, the maximum NDVI value from thirteen Landsat satellite images was selected as the greenness threshold, and this image was used to discriminate between irrigated and non-irrigated parcels. Although a crop classification of "fallow" was included in all of the studies in the classification phase, this was a spectral based classification rather than a classification based on greenness or NDVI.

For reconsideration of the 2002 irrigated parcel data set, the maximum NDVI value was selected from the four "monthly" satellite image pairs to create a maximum-NDVI image similar to the 2005 image. Although the common opinion was that insufficient irrigated acres were delineated for 2002, it was found that many parcels delineated as irrigated in 2002 would not have been delineated using the 2005 NDVI threshold. An initial evaluation was performed using the maximum-NDVI image and 2005 NDVI thresholds to identify any parcels that may have been irrigated but were not delineated in the 2005 set. Generally, parcels were considered irrigated and included if mean NDVI values for the parcel exceeded 0.45 to 0.5. Parcels totaling about 3,000 acres were delineated and added to the 2002 coverage; although some of these parcels were later re-removed following further evaluation of water source. About 200 acres was also added for 2002 under new ditch service areas that were defined primarily on upstream tributaries as part of the ditch service area enhancement. Parcels in the original 2002 set that had been delineated as irrigated but fell far below the 2005 NDVI threshold were also re-evaluated for "deletion". Generally, parcels were removed from the irrigated set if the average NDVI fell below a threshold of 0.3 to 0.35, with a somewhat higher threshold for areas where surface water diversions were reported in 2002. Many "full size" parcels were also reduced in size to generally include only the area of the parcel with an NDVI above threshold values. Given all types of changes, the 2002 irrigated parcel set was reduced in size by close to 50,000 acres, over 10% of the total area delineated as irrigated in 2002.

Commentary on the under-delineation of 2002 irrigated acreage was focused on the Centennial Ditch. The Centennial Ditch is one of the most senior ditches on the Rio Grande, and is special because ditch diversion was not particularly impacted in 2002. The ditch reported to Division 3 that it irrigated 8,700 acres every year from 1991 through 2004. A close look at acreage in the ditch service area indicates that for this number to be correct the acreage has to include waste areas between parcels, trees, wetlands, and sloughs; much of which can not be physically irrigated using ditch water and is not being beneficial used for agricultural purposes. Admittedly, the rougher 1998 irrigated lands coverage drawn using only satellite imagery did include some of this waste area (over 7,000 acres were delineated in 1998), but this waste area was generally not included in the 2002 and 2005 delineations. About 1,000 irrigated acres were added to the Centennial Ditch area in this re-evaluation to increase 2002 irrigated area to more than 5,700 acres (including some parcels also served by other ditches in addition to the Centennial). For 2002, the Centennial diverted a total of 20,519 acre-feet. Assuming a 60% conveyance efficiency and 60% application efficiency, this would indicate an average consumptive use of about 1.3 acre-feet/acre (15.5 inches) for 2002 within the Centennial Ditch. This rate seems quite reasonable for the dry year 2002. For 2005, irrigated parcels within the Centennial Ditch summed to over 6,400 acres. The RGDSS model is reported to have a "hard-wired" (*.cds and *.ipy files) irrigated acreage of 7,166. Given the re-evaluation of irrigated area within the Centennial for 2002, this "hard-wire" no longer seems appropriate.

The well assignments for the 2002 GIS coverage were also re-evaluated. Initially, well assignments made for the 2005 set were applied spatially to the 2002 parcels. As mentioned, the 2005 study used the 2002 satellite imagery extensively to evaluate groundwater use. The 2005 well assignments had to be adjusted somewhat for 2002, especially where parcels varied somewhat between the two years. Irrigated parcels were compared to ditch service areas and 2002 diversions, and in areas where no (or very little) surface water was available in 2002, the satellite imagery was examined carefully with regard to well locations and potential service. As mentioned earlier, the NDVI threshold to extend groundwater use was generally higher in this study than in the original 2002 study, so acreage indicated as potentially irrigated by groundwater was reduced between the previous and current studies of 2002.

3.7.2 Enhancements to the 1998 Data Set

Agro Engineering was not scoped to re-evaluate irrigated areas from the 1998 study. However, some improvements were made to the GIS data set. The current 1998 data set that can be downloaded from the CDSS site and is apparently used in the RGDSS models was modified from the original set supplied by Agro Engineering. The new set contains thirteen sprinklers and several large flood parcels (ie 40002, 40004, 40006, and 40007) that did not show signs of irrigation in the satellite imagery used in the study, as well as seventeen new sprinklers that were not installed in 1998 (as evidenced in aerial photography) but that instead overlay land that was flood irrigated in 1998. Therefore, the original set provided by Agro Engineering was used as a base set without these subsequent new parcels. Some modifications to parcels from the CDSS set that appeared appropriate were added to the base set, and 32 parcels were deleted from the base set that were deleted from the CDSS set because they potentially were fallow. Changes or modifications to the original 1998 parcels were noted in the parcel data "comment" field.

The 1998 parcel boundaries were originally delineated using 5-meter resolution satellite imagery, while one-meter resolution aerial photography was used to delineate the 2002 and 2005 sets. To improve the accuracy of the 1998 base set, sprinkler boundaries made in 1998 were replaced with the equivalent sprinkler boundaries drawn for the 2002 set. Most sprinklers did not change between 1998 and 2002. After 2002 but prior to 2005, many end guns and corner systems were removed from sprinkler systems, so it was not appropriate to use the parcel boundaries drawn for 2005. Several systems that changed significantly from 1998 to 2002 were modified from the 2002 boundary using the 1998 aerial photography. A number of parcels were added to the 1998 set as a result of the additional parcels drawn during the ditch service area enhancement. A few modifications were made to parcels as part of other improvements to ditch service areas. A total of 43 parcels were deleted and a number of parcel boundaries were modified to ensure that every parcel had an assigned water source as part of the improvements to ditch and well service areas.

The 1998 data set could potentially be improved using the newer methodologies of the 2002 and 2005 studies. The boundaries of almost all flood irrigated parcels are still "rough" as drawn from the coarser satellite imagery, and could be improved significantly using the high resolution aerial photography that is now available, or replaced with parcel boundaries drawn for years 2002 or 2005. The threshold of what defines an irrigated or not-irrigated parcel could also be improved using the newer NDVI methodology using multiple satellite images.

3.7.3 Enhancements to the 1936 Data Set

The Rio Grande Joint Investigation Committee had prepared paper maps of the irrigated lands that existed during 1936 for purposes of the Rio Grande Compact negotiations. These irrigated land maps from 1936 were digitized by DWR personnel (see Memo from Chris Brown, DWR). Wells appropriated by 1936 were assigned to parcels using the spatial methodology, and ditch service areas were assigned. A number of ditches not included in the current service area mapping were included, apparently based on head gate location. Agro Engineering was scoped to apply the newest ditch service area to the 1936 set using the fractional methodology, although they were not scoped to re-evaluate irrigated areas or well assignments. In some areas, the mapping has some spatial deviation from current coordinate system areas so that some irrigated parcels do not lie accurately under ditch service area boundaries. Where obvious, some parcels were moved spatially to align with ditch service areas prior to intersection with the current ditch service area coverage. Fractional coverages were calculated, except that due to large parcel size, coverages of less than 1% of the total parcel area were removed, rather than 10% threshold used for the other datasets. In addition, all ditches within ditch aggregates were applied rather than only those with recorded diversions. Ditches and ditch service areas may have changed considerably since 1936, and, upon application of the current ditch service area, it was noted that many irrigated parcels do not have a specified water source. This may cause underestimation of irrigated area and consumptive use in the basin in 1936. Therefore, the new 1936 set may need additional evaluation prior to the integration of the new set into Hydrobase and the RGDSS.

3.7.4 Sprinkler Irrigated Parcels

A particular effort was made to ensure that sprinkler areas are accurately represented in the each data set. The 1998 sprinkler boundaries were replaced with equivalent boundaries drawn in 2002, and the higher accuracy delineation generally results in a somewhat smaller delineated area. The following table shows the number and area of all sprinkler systems in Division 3 (total and irrigated/non-fallow) for the year of study. Continued installation of new sprinkler systems can be noted. 134 new sprinklers were installed between 2002 and 2005, although the overall area of these systems did not increase significantly due to the removal of a large number of end-guns and corner systems from existing sprinklers, primarily from the central portion of the valley during this time. It should be noted that a number of the new systems were actually “mini-pivots” or “pie” sprinklers that were small in area and did not add significantly to the total sprinkler areas. A significant number of pivots were fallowed in 2005, and the irrigated area of sprinklers was actually lower in 2005 than in 2002. A number of new sprinkler systems were also noted in the 2006 aerial imagery that was used in a supplementary manner to the 2005 study. Therefore, an estimate of the number of 2006 sprinkler systems was also included.

Table 11. Progression of Development of Sprinkler Systems in Division 3

Year	1998	1998 New	2002	2005	2006	2008
Systems	2290	2290	2434	2568	2588	2644
Systems Irrigated	2252	2252	2368	2476		
Acres	279,194	273,434	285,450	286,384	288,301	291,954
Acres Irrigated	273,466	267,603	276,269	271,796		

An attempt was made to refine sprinkler areas for intermediate years between the study years of 1998, 2002, and 2005 using annual sprinkler maps maintained by the Rio Grande Water Conservation District. These paper maps of center-pivot sprinklers indicate a total of about 60 to 130 systems less than known to exist through the 1998, 2002, and 2005 studies (2,227, 2,304, and 2,445 systems, respectively), and annual documentation when a new system was installed was not sufficiently accurate to enable this refinement. Since 2005, the RGWCD has maintained mapping of sprinkler systems in GIS. The 2008 GIS set did indicate 56 systems that were installed between 2006 and 2008 as noted in the previous table, although the RGWCD set does not include 25 sprinkler systems covering over 2,000 acres noted in the 2005 imagery.

A GIS set was developed that includes the newest delineation for each sprinkler system known to be installed through 2008 and describes time time-period it was installed by 1998, 2002, 2005, 2006, or 2008. The RGDSS model currently considers the number of sprinkler systems to be constant since 1998 with the exception of 2002. This data set could be used to refine the annual sprinkler acreages under each ditch system after 1998 for the model.

4. RESULTS

4.1 Ditch Service Area Statistics

To facilitate the estimation of consumptive use by ditch structure, the area of irrigated parcels that fall within each ditch service area was summarized by crop type for each surface water structure. A list of the acreage associated with each ditch system is contained in Appendix A. Irrigated parcels that are outside of ditch service areas are categorized as ground water only parcels. These parcels were grouped together based upon their location. A total of 721 ditches have been mapped with total overlapping area of 960,865 acres encompassing an area of 854,516 acres when combined together. In 2005, 470,931 irrigated acres are contained within ditch service areas and 43,763 irrigated acres are located outside of ditch service areas.

4.2 Well Use Statistics

In 2005, 4557 of parcels, representing 299,938 acres were served by wells. Of this total, 132 parcels irrigating 7,277 acres were served wells that had been inactivated by 2009, and 61 parcels irrigating 2,547 acres were wells that were not included in the State's list of active irrigation wells.

4.3 Crop Type Statistics

For 2005, a total of 11,728 irrigated parcels were defined, covering 514,694 acres. The number of parcels and total acres of each crop type for 1998, 2002, and 2005 are shown in the following table. Minor crops are indicated as well as changes for the 1998 and 2002 datasets.

Table 12. Crop Type Statistics for 1998, 2002, and 2005 Irrigated Parcels

CROP	2005:		2002:	ACREAGE		1998:	ACREAGE	
	PARCELS	ACREAGE	PARCELS	NEW	OLD	PARCELS	NEW	OLD
Potatoes	**680**	**63,725**	**667**	**73,012**	**73,012**	**732**	**77,490**	**80,064**
Small Grains	**778**	**64,700**	**808**	**76,673**	**76,623**	**1,433**	**112,601**	**114,214**
Barley / Wheat	726	61,134	800	75,942	75,892			
Canola	16	1,590	8	731	731			
Winter Wheat	36	1,976						
Vegetables	**66**	**5,377**	**52**	**5,701**	**5,626**	**81**	**7,337**	**7,583**
Lettuce	54	4,405	30	3,108	3,108			
Carrots	11	929	22	2,593	2,518			
Strawberries	1	42						
Alfalfa	**4,034**	**168,152**	**3,082**	**146,942**	**149,759**	**3,676**	**137,729**	**139,502**
Established	3,701	151,094						
New	333	17,058						
Grass/Pasture	**6,170**	**212,741**	**3,845**	**125,020**	**177,090**	**4,405**	**270,985**	**271,476**
Pasture/Grass Hay	5,836	197,923						
Oat Hay	230	8,309						
Sudan Grass	66	4,069						
Other Cover Crops	38	2,440						
TOTAL	**11,728**	**514,694**	**8,454**	**427,348**	**482,110**	**10,327**	**606,142**	**612,839**

4.4 Irrigation System Type Statistics

Statistics for irrigation system types of irrigated parcels are shown in the following table for years 1998, 2002, and 2005. For sprinklers, numbers are shown as full sprinkler systems rather than numbers of irrigated parcels. For 2005, 271,796 acres within 2476 full sprinkler systems, representing 52.8% of the irrigated acreage, were irrigated by center pivot irrigation systems. The remaining 242,898 acres, representing 47.2% of the irrigated acreage were flood irrigated in 8751 parcels. Although the number of sprinkler systems increased between all years, the irrigated sprinkler area went down between 2002 and 2005 as many end-gun and corner systems were removed and reduced the size of many sprinkler systems.

Table 13. Irrigation System Type Statistics for 1998, 2002, and 2005 Irrigated Parcels

IRRIGATION TYPE	2005:		2002:	ACREAGE		1998:	ACREAGE	
	SYS*	ACREAGE	SYS*	NEW	OLD	SYS*	NEW	OLD
Flood	**8,751**	**242,898**	**5,740**	**151,432**	**200,741**	**7,732**	**338,270**	**340,030**
Sprinkler Irrigated**	**2,476**	**271,796**	**2,368**	**275,917**	**276,207**	**2,252**	**267,872**	**272,709**
Sprinkler Fallow***		14,588		9,534	9,243		5,384	6,485
Sprinklers Total	2,567	286,384	2,434	285,450	285,450	2,290	273,257	279,194

*Note: *SYS. is the number of full sprinkler systems rather than parcels that may be cut from within sprinklers. numbers of irrigated parcels are shown for flood irrigation.*
*** Some irrigated sprinkler systems may include portions of a full sprinkler that are fallowed.*
****The area of sprinkler fallow includes some fallowed portions of irrigated sprinklers.*

4.5 Water Supply Source Statistics

Statistics for water supplies assigned to irrigated parcels are presented in the following table for the new 2005 dataset, as well as old new datasets from 1998 and 2002. In the new 1998, 2002, and 2005 irrigated parcel datasets, there are no parcels without a defined water supply. The proportion of parcels in Division 3 that can be irrigated by groundwater remains relatively constant near 300,000 acres while areas irrigated by surface water fluctuate based on surface water supplies.

Table 14. Water Supply Statistics for 1998, 2002, and 2005 Irrigated Parcels

WATER SUPPLY	2005:		2002:	ACREAGE		1998:	ACREAGE		
	PARCELS	ACREAGE	PARCELS	NEW	OLD	PARCELS	NEW	OLDv1	OLDv2
Ground Water	4557	299,938	4389	312,728	328,859	4,197	325,701	384,253	326,391
Surface Water	11160	470,931	7885	380,949	420,490	9,858	561,020	561,171	556,882
Ground Water Only	568	43,763	569	46,399	56,457	469	45,122	48,506	58,000
Surface Water Only	7171	214,756	4065	114,620	148,088	6,130	280,441	225,424	288,491
Both GW and SW	3989	256,175	3820	266,329	272,402	3,728	280,579	335,747	268,391
TOTAL	**11728**	**514,694**	**8454**	**427,348**	**476,947**	**10,327**	**606,142**	**609,677**	**614,882**

Note: OLDv1(1998)=original dataset provided by Agro Engineering as considered in other result tables.
OLDv2=Current dataset in CDSS with supply modifications as well as sprinklers that did not exist in 1998.

5. CONCLUSIONS

The 2005 Irrigated Lands Assessment was developed to provide a more recent snapshot of irrigated lands within Division 3 for use within the RGDSS model. The purpose of the Irrigated Lands Assessment was to determine the extent (i.e. acreage) and character (i.e. crop type, irrigation system type, and irrigation source) of irrigated parcels within the Rio Grande Basin during the 2005 irrigation season.

The following GIS themes were developed as products of this project:

1. An enhanced ditch service area coverage was produced. Enhancements to the ditch service area concentrated on mapping ditches which had not been defined in prior studies, and on refining the ditch service area for ditches to which no irrigated parcels had previously been assigned.
2. A new irrigated parcel coverage for 2005 was developed. The development of the 2005 Irrigated Lands Assessment required the following procedures. First parcel boundaries were delineated using NAIP aerial photography. Second, parcels were reassessed to ensure that they were actually irrigated during 2005. This assessment used NDVI satellite imagery to differentiate between irrigated versus non-irrigated lands and an evaluation of an available water source from the well assignment and a review of diversion records for surface water sources. Third, a crop classification was performed to determine what crop type was grown on each parcel during 2005. The crop classification involved a manual determination of crop type based upon aerial photography, NDVI satellite imagery, Rio Grande Water Conservation District data, and other Agro Engineering cropping information. Then a multi-spectral supervised classification was performed using a Bayesian classifier that resulted in a crop type probability. A multi-temporal analysis was then performed to combine crop type probabilities across the entire season. Differences between the computer classification and the manual determination were then compared and reassessed in a classification refinement process. Fourth, wells were assigned to parcels using a spatial assignment methodology that had been used in previous evaluations and then refined using a methodology that compared well assignment vectors against the aerial photography. Finally surface water supplies that could be used on each parcel were assigned using a fractional coverage approach.
3. The existing 1936, 1998, and 2002 irrigated land coverages were enhanced so that they provided information consistent between the different time periods. In this process, the new ditch service area enhancements were applied to prior coverages. The time at which center pivot sprinkler irrigation systems were installed was re-evaluated. The enhanced well assignment process was applied to prior coverages. Finally, the threshold used in prior coverages to determine if a parcel was irrigated versus non-irrigated was reconsidered.

The methodologies used to for irrigated lands assessment has improved between the 1998, 2002, and 2005 datasets, and integration into the RGDSS model system of the improved data sets and the 2005 dataset, in particularly, is urged. As part of the integration of current datasets into the RGDSS models, several other tasks related to the RGDSS model system are needed including:

- Re-cut the coverage representing native vegetation using the new irrigated parcel datasets. Potentially, improvements could also be made to the current native vegetation coverage.
- Prepare aggregate structure list represented new and modified ditch aggregate structures
- Prepare new "NoGIS" file list with the six remaining ditches without mapped service areas or have the water commissioners locate where these ditches are located and resolve the uncertainty.
- Integrate progressive change of sprinkler system areas into the ditch area files.
- Remove (*.cds and *.ipy) files that previously "hard-wired" irrigated acreage for such ditches as the Centennial Ditch.
- Integrate new irrigated parcel data sets into model.

Other recommendations for continued improvements of the current GIS data sets or modeling systems include:

- Well data could be further improved using DWR Forms 3.1 and 4, collected through the meter installation and certification process; mapped county assessor data; and well data collected for the groundwater management sub-districts.
- The new 1936 set may need additional evaluation of water supply prior to the integration of the new set into Hydrobase and the RGDSS.

APPENDIX A.

IRRIGATED ACREAGE BY DITCH

DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
-	**TOTAL**	567,061	81,296	606,142	325,701	267,872	427,348	312,728	275,917	514,694	299,938	271,796
-	Groundwater Only Areas	43497	43497	45780	45780	39241	46844	46844	39586	44288	44288	38309
200500	Adams Ditch 1	224		307			235			267		
200505	Alamosa Ditch	792		1213			423			578		
200506	Alder Creek Ditch 1	114		47								
200507	Alder Creek Ditch 2	58		56								
200508	Alder Creek Ditch 3	53		42								
200511	Anaconda Ditch	595		565		81	280		81	491		84
200512	Anderson Ditch	1000	99	710			646			625		
200513	Anna Raber Ditch	167		235			108			150		
200516*	Arroya Eagle and Larrick5	496		235			146			348		
200517	Atencio Ditch	244		350			321			303		
200518	Atencio Ditch 2	111		106			120			115		
200522	Bachman Ditch 2			59			55			59		
200523	Bachman Seitz Ditch			63			14			63		
200524	Barclay	25		14			10			10		
200526	Bellows Creek Ditch 4			21			21			21		
200528	Bauer Ditch	276		354			110			304		59
200529	Bauer Ditch 1	51		32			9			32		
200530	Beiger-Ladd Ditch	23		38			35			37		
200532	Bellows Creek Ditch 2	64		23						16		
200533	Bellows Creek Ditch 3	112		36						36		
200535	Bennett Creek Ditch	68		58			10			54		
200536	Bennett Ditch 1	28		16						20		
200537	Bennett 2	86		44						46		
200541	Bevan D 4	31		31			5			24		
200543	Bevan D 6	15		16						12		
200546	Billings Ditch	2210	78	4446	3303	3303	3925	3311	3302	3417	2693	2693
200551	Breene Myers Ditch	28		25			23			25		
200552	Brey Ditch	66		106						83		
200555	Burns	110		71						81		
200556	Butler Ditch	320		224	122	122	199	122	122	224	120	120
200557	Cadle 1	29		67						47		
200558	Cadle 2	12		30						14		
200559	Cadle Ditch 3	29		28			11			24		
200561	Campbell Bauer Ditch	370		35						35		
200566	Centennial Ditch	5485	54	7204	337	1313	5462	263	1460	6190	362	1781
200568*	Chadwick Ditch 1	59	16	31								
200570	Chadwick Ditch 3	14		13			1			8		
200575	Chicago Ditch	2978	548	2800	422		2180	526		2204	477	
200582	Cochran Pioneer	217	9	169			131			172		
200583	Cole D 1	231		64			68			169		
200585	Cole D 6	39		49						44		
200587	Costilla Ditch	9867	1083	10494	1104	257	3747	907	257	5744	900	241
200588	Davies Bros. Ditch			273			120			271		
200590	Davies Ditch 2			93			10			93		
200595	Del Norte Town Ditch	117	20	82	11		75			78	2	
200597	Ditch 1	307								26		
200599	Ditch 3	196								17		
200606	Mc Neil Dupke	329		383						356		
200611	Dyer Ditch	43		136			27			30		
200614	Ehrowitz Ditch	193		265	92	57	238	78	57	289	83	63
200616	Elliot Ditch			8						8		
200619	Elliott 4	64		75						65		
200620	Elliott 5	11		27			6			22		
200621	Elliott Bevan	31		30						29		
200622	Embargo Ditch	293		284			131			269		
200623*	Commonwealth Ditch Co.	21464	2058	35677	17018	12671	21183	16388	13338	29982	16916	14583
200626	Ewing Ditch 1	80		51			25			48		
200627	Excelsior Ditch	5329	116	7526	65	65	3280	72	65	4564	71	62
200631	San Luis Valley ID (Farmer's Un	37052	4434	51207	48501	48094	48899	48792	48562	43923	43758	43659

*Note: *Ditch aggregate includes diversions from several structures*

DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
200634	Field			39						23		
200636	Fish Ditch	1248	135	1140	23	23	941	23	23	642	19	19
200642	Garden											
200643	Getz No. 3	109		127			13					
200644	Getz Seepage D 4			85						16		
200645	Goose Creek Ditch			22						22		
200647	Grant Ditch 2	78								35		
200649	Grubb Ditch 3	69		71			11					
200650	Grubb Ditch 2	17		36								
200651	Gwinn Creek Ditch			25						25		
200652	Hagadorn	427	63	390		56	143		58	310		60
200655	Hanna 1	48		40			9			34		
200656	Hanna 2	69		75			27			59		
200657	Happy Thought Ditch			11						17		
200669	Hilton Cr River Ditch	136		41						41		
200671	Horner Ydren Ditch	727		720		56	611		56	622		58
200676	Howlett	53		57			9			44		
200677	Hubbard Ditch	296		169	97		144	75		155	88	
200680	Independent D	352		581			249			282		
200681	Independent Ditch #2	1301		1302	65	65	1243	65	117	1368	67	119
200682	James Mcleary	301		332	305		253	244		282	270	
200684	Jemison Bevan 1	69		81			40			56		
200685	Jemison Bevan 2	189		228			115			195		
200686	Jemison 1	6		24			12			17		
200687	Jemison 2	37		52			32			34		
200688	Jemison 3	16					14			14		
200689	Jemison 4	28		64			35			47		
200690	Jemison 7	22		40			27			27		
200691	Jemison 9	19		25			23			24		
200692	Jessup Ditch 1			23						10		
200694	John Anderson Ditch	115		94	22		89	22		105	22	
200695	John R Grant Ditch	218		15						15		
200699	Kane Callan Ditch	398		432	169	77	305	111	96	372	85	103
200702	Kiel Larsen	49		60						47		
200706*	Larrick D 2	903		901	126	238	246	136	118	705	127	239
200709	Larrick 6	176		56						120		
200713	Little Annie	222		203		39	73		39	191		40
200714	Little Danube	285		278			18			219		
200718	Lohr Overflow Seepage D	63										
200720	Lavato	8		15						20		
200721	Mackenzie Ditch 1	39		25								
200729	Mallett	89		86			23			100		
200731	Marajo Ditch	171		174						162		
200733	Martinez D	36		19						12		
200736	Mc Donald Ditch	762	23	769	12	126	583	11	126	652	10	126
200737	McIntosh Arroya Ditch	112		188			129			109		
200742	Meadow Glen Ditch	709		550	27		234	29	29	391	29	30
200744	Mexican	49	5	43			31			39		
200748	Mill Ditch			22						8		
200751	Miners Creek Ditch	311		83						83		
200752	Minor Ditch	1843	68	1693	389	510	969	364	510	1052	383	500
200753	Monte Vista Canal	19722	2008	23258	15757	10161	17325	15399	12066	19203	15177	12832
200754	Montoya 1 2 and 5	60	28	91			66			83		
200755	Montoya 3 and 4	68		79			74			83		
200757	Montoya 6	50		59						56		
200773	New Ditch	480		471			510	70		528	72	
200774	Newton	36		25						32		
200775*	Nichol Ditch	647		471		145	439		142	337		
200776	Norris Ditch			20						13		
200777	Off Ditch	258		428			367			400		
200781	Pace Ditch	128		177			28			145		

*Note: *Ditch aggregate includes diversions from several structures*

DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
200782	Park and Green	213		500	168	168	328	180	180	430	178	178
200783	Parma Ditch	56		278			125			104		
200786	Perkins	169	48	180						157		
200787	Pfeiffer Ditch	152		144			18			150		
200788	Phillips Ditch 1	43		36						36		
200789	Phillips Ditch 2	26		33						33		
200790	Pinos Creek 1	349		392			81			331		
200792	Poole Bachle	10								10		
200794	Poole Fairchild	15		20			9			11		
200795	Poole Jemison	60		69			59			61		
200796	Poole Meadow	40		55			28			36		
200797	Poole Mesa	60		64						45		
200798	Prairie Ditch	13007	3393	18148	16204	15853	16096	16012	15743	15037	14802	14689
200801	Raber Ditch	128		132			91			117		
200810	Rio Grande Ditch #1	863		922	62	15	691	55		761	56	
200811	Rio Grande Piedra Valley	5908	512	6695	875	802	5909	856	938	6030	851	918
200812	Rio Grande Canal	98921	11638	81753	73719	67674	74010	72690	69194	70334	67726	64845
200814	Rio Grande Ditch #2	168		240		49	61		49	113		49
200815	Rio Grande Ditch #4	35		72			34			48		
200816	Rio Grande Lariat Ditch	3362	297	2970	2033	1763	2339	1957	1791	2565	1891	1704
200817	Rio Grande San Luis Ditch	2543	178	3298	1603	1313	2577	1578	1384	2581	1553	1359
200818	Robran	318		298			184			273		50
200819	Rock Creek/Anderson and Cadl	91		85			36			72		
200820	Rough and Ready	1602		795			324			1130		
200824	San Francisco D	149		195						145		
200826	San Jose or Lucero Ditch	348		367	116	116	155	116	116	217	113	113
200829	San Luis Valley Canal	12130	1192	22561	16409	15145	16165	15553	15115	15244	12577	12180
200830	Valdez Ditch 2			11								
200831	Schrader Ditch 1	182		133			8			133		
200832	Schrader Ditch 2	121		72			16			72		
200833	Schuch Schmidt D	192		247	137	60	105	105		123	104	55
200835	Seitz Ditch			12			12			12		
200836	Shaw Ditch 1	153		57			99			113		
200837	Shaw Ditch 2			33			5			33		
200846	Silva Ditch	578		692		56	534		100	561		163
200853	South Farm Meadow D	716	267	560	82		203	158		190	143	
200854	South Fork Highline Ditch	320		174			73			131		
200857	Sprague Ditch	12		28						20		
200863	Spruce Lawn D	132		743			129	11		449	7	
200865	Star Ditch	250	17	406			156	62	62	279		
200867	Valdez Ditch 1			16						10		
200878	Trout Dale Ditch	501		43						29		
200884	Valdez D 1	110		58						59		
200885	Valdez D 2	89		75						83		
200894	Wassen Ditch	333		144						198		
200895	Wason Deep Cr Ditch	323		43								
200896	Wason Ditch	193		47						17		
200901	Weiss	194		202			22			80		
200903	Westside Ditch	2153	293	1881			1266			2041		
200909	Wolf Creek Ditch 1			118						118		
200910	Wolf Creek Ditch 2			187						198		
200913	Woodfern Ditch	136		41						41		
200914	Yarnell	384		192			98			201		
200915	Ziegler Ditch	70		249	216	189	238	219	198	241	218	194
200966	Hall-Voss Ditch	68		66						83		
200967	Cochran Bros 2R			20						34		
200968	Rienau D 2R			23						55		
200969	Macleod D 1R			58						48		
200970	Macleod D 4R			28						31		
200971	Ward D 1R			63						52		
200972	Ward D 2R			58						64		

*Note: *Ditch aggregate includes diversions from several structures*

DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
200973	Ward D 3R			36						41		
200986	Charlesworth Ditch 1R	16		47			17			47		
200987	Fairchild	59		57			60			60		
201000	Voss Seepage Ditch	13					16			19		
201026	Deer Creek Ditch			19						8		
201129	Heath	44		38						31		
201603	Montoya Mexican	529	5	542			446			469		
201676	Closed Basin Canal	856		895			766	72		771	73	
201692	4UR Ditch			78						78		
201705	Atkins/Voss Seepage Pump	238		241		241	258		241	274		253
201710	Pierce Cr Outlaw Ditch			24						24		
201876	Willow Park Feeder Ditch	33	33	44			42			44		
210501	Agua Caliente	133		126			8			18		
210502	Alamos			20						60		
210503	Alamosa Creek Canal	2449	203	4043	3776	3694	3892	3768	3712	3944	3734	3702
210505	Alamosa Spring Creek	545		579	289		273	267		568	286	
210506	Arroya	1082		1344	645	87	793	470	87	1298	463	202
210510	Capulin Ditch	879		835	102	54	456	105	61	634	102	99
210511	Clark	58		113	83		83	83		104	79	
210512	Coddington	947	9	1043			761			1058		
210513	Cottonwood	459		454			192			451		
210514	Cristobal Rivera	206	21	240	63	112	159	69	130	183	69	131
210515	Crowther Bros.			14								
210520	El Viejo	667	21	621	106	309	530	112	452	563	112	451
210521*	Empire-La Jara	7795	364	9751	4089	1712	6062	3055	1955	8859	3756	2601
210523	Eskridge Garret	97		99	44		40	32		83	33	
210525	Flintham Ditch	1484	7	1842	1106	255	1205	928	414	1655	946	471
210526	Gabino Gallegos	608		508	8	41	210	7	99	325	7	109
210527	Gallegos No. 1	172		38			17			20		
210528	Gallegos No. 2	82		98			34			72		
210529	Gallegos 3	223		375			148			266		
210530	Gallegos No. 4	255		162			68			80		
210531	Garcia Ditch No. 1	234		280			156			184		
210532	Garcia #2	325		362	154		370	137		267	132	
210535	H. Louise Shawcroft	7		7			5			6		
210536	Hansen Overflow #3	1192		1501			770			1432		
210537	Hardtack S. Branch	21		22			12			20		
210538	Hardtack N. Branch	178		232	154		203	137		212	131	
210539*	Head Overflow #5	5741	259	6185	409	119	727	354	119	5473	340	124
210543	Jose E Atencio Ditch	82		68			34			46		
210545	Juan De Dios Vigil	57		35			16			11		
210546	Keystone	221		305	209		268	227		250	195	
210548	L.D. Eskridge	129	1	287	254		257	210		241	204	
210549	L. E. Shawcroft and Sons	17		23			35			21		
210551	La Jara Seepage	238		485		127	351			478		129
210552	Le Mita #1	21		56			14			21		
210553	Le Mita #2	56		177			47			68		
210554	Le Mita #3	39		49								
210557	Lower La Jara	441	75	430	107	105	402	161	158	387	109	107
210558*	Lowland	4204	874	4306	1111		1299	474		3522	679	
210559	Mc Cunniff	677		778	255		488	222	128	738	226	131
210560*	Miller-La Jara	1572	75	2285	405		900	444	124	1580	472	80
210564	Morganville	1446		2597	1847	582	1993	1653	990	2084	1627	1183
210565	Murphy Crowther	247		288			229			249		
210566	Nate Garrett	81		99	34		94	45		92	43	
210569	Newcomb Bros.	272		262	192	116	238	192	87	261	187	158
210570	Norland	144	21	287	106	203	221	112	221	238	113	223
210571	North Alamosa	1214		1337	816	120	1214	801	120	1316	729	245
210572	Ortiz	370		374	55		34	26		324	47	36
210579	Pino Real	45		24			5			46		
210581	Ramona	302		342	34		130	45		233	43	

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DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
210582	Reed #1	190		194	72		266	51		202	32	
210583	Reynolds Reed	19	19	15						18		
210584	Reynolds Ditch	42	8	71			125			82		
210585	Rivera	272		147			4			49		19
210586	Romaldo Valdez	67		53						18		
210587	Romero			95			106			129		
210590	Sanco	117		91								
210591	San Jose Ditch No. 1	96		79			23			57		
210592	San Jose #2	40		33								
210593	Scandinavian Ditch	1205	194	1234	952	808	1011	907	821	1162	952	838
210596	South Side Arroya	1531		1981	1126	213	1237	784	106	1334	789	106
210599	Swamp	311		114			84			153		
210600	T.K. Walsh	68		47	8		7	7		44	7	
210601	Terrace Main	3879	81	6036	4919	4199	4866	4718	4754	5122	4924	4965
210602	Union	2455	62	2937	1461	392	1987	1405	363	2849	1418	455
210603	Valley Ditch	188		192	73		86	69	36	93	67	37
210604	Valdez	722		625			128			109		
210606	Weist	147		329	81		321	75		262	60	
210611	Madril	142		89			47			58		
210612	Reed #2	229	86	350	158		368	114	59	383	142	89
210631	Eskridge Garret N Branch	19		22						17		
210644	Dam in the Center of Sec. 14	83	30	78			61			85		
210662	Warren Shawcroft Wildcat	13		19			28			17		
210705	Baker Ditch	28		135						81		
210712	Louise Shawcroft Ditch	60	29	41			47			39		
210717	J.H. Valdez	36		5						4		
213299	Murphy Crowther Wildcat	37		70			63			66		
220500	A.D. Archuleta Ditch	410		441	393	393	413	393	393	433	394	394
220501	Alamo Ditch	1619	667	1502	753		467			1514	967	
220502	An Con	347		560	49	22	42	42	22	481	23	23
220503	Angostura Ditch	92		43						61		
220504	Antonito Ditch	1066		1081	398	450	477	398	450	1088	394	535
220505	Archuleta-Trogillio No. 1	458		534			223			531		
220506*	Arch-Trogillo No 2 (Springs)	942		678			417			579		
220508	Bagwell Ditch	20		42						71		
220509*	Ball Bros. Overflow No. 1	1671		836			31			714		
220513	Bernardo Romero	299		280			44			305		12
220514	Bosque Irrigation Ditch	53		50						58		
220515	Braiden Overflow No. 1	281		365	302		254	239	239	260	235	235
220516	Braiden Overflow No. 2	118		127								
220517	Braiden Overflow No. 3	132		39						63		
220518	Branch Ditch	35		85						91		
220524	Canon Ditch	1088		918	132	158	208	132	158	771	131	245
220525	Carpe and Reekers Canon	96		20						37		
220526	Chacon Ditch No. 1	150		201			47			141		
220527	Chavez Ditch	38		63			59			62		
220528	Christensen Ditch	228		227	215		198	193		216	195	120
220531	Cordova Ditch	98		178						174		
220532	Cottonwood Ditch	362		373	351		307	184		413	108	
220535	East Bend Ditch	285		212						214	62	
220536	East Bend D, No. 2	212		236	93		67			223	86	
220537	Eight Mile Ditch	111		191	13	13	13	13	13	39	13	13
220538	El Coda	1116		1244			787			1130		
220539	El Serrito Ditch	235		252			172			219		
220540	Elledges	210		127			53			151		34
220541	Ephraim	3849	284	4207	3938	507	3326	3241	635	3600	3265	695
220542	Espinoza Springs	18		16			11			10		
220543*	Florida Ditch	334		687	410	410	540	540	540	526	525	525
220544	Fox Creek	71		21						51		
220545	Fox Creek #1	36		10						30		
220546	Fox Creek #2	49		28						35		

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DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
220547	Fuertecitos Ditch	171		313			154			386		
220548	Gabriel Martinez	104		71		25	28		25	69		26
220549	Galvez Ditch	138		146						131		
220553*	Guadalupe Main	1466		1670	39		1033	45		1458	60	
220554	Head's Mill and Irg. D	1430		1516	735	735	791	735	735	1374	739	739
220555	Home Ditch	119		65						107		
220556*	Hughes' Overflow	437		236			82			41		
220559	Island Ditch No. 2	209		152						100		
220560	Island Ditch No. 3	222		181						220		
220561	JF Chacon No. 2	136		130	122	122	122	122	122	124	124	124
220562	JF Chacon No. 3	316		320	237	211	234	231	211	306	212	212
220563	JM Espinoza	125		142			16			112		
220564	Jack's Irrigation Ditch	28		71						65		
220565	Jackson Ditch	90		104	1		1			97		
220568	Jacobs Ditch No. 3			4								
220571*	John W. Floyd Overflow	484		283			17	17	17	196	16	16
220576	La Del Rio	742		715		42	8			477		
220579	Le Duc Ditch	154		111	111		38	38		99	39	
220580	LLano Ditch	654		672			633			718		
220581	Lobato and Cordoba D	83		375	250	250	250	250	250	310	248	248
220583	Lopez Ditch	111		136						136		
220584	Los Ojos No. 1	621	185	903	67		208			760	53	
220585	Los Ojos D. No. 2	88	5	316	159		86	73		173	33	
220586	Los Pinos	242		230			229			251		
220587	Los Sauces	2365		2720			1558			2235		
220589	Lovato Irr. D.	414		486	85		137	137	137	366	192	192
220590	Maes Ditch	20		13								
220591*	Mogote-Northeastern	6431	154	8034	3733	2970	3657	2848	2481	6527	3690	3358
220593*	Manassa, Eastfield, Westfield	17375	194	17988	4535	2086	11563	3981	3179	16067	4197	3887
220597	Martinez D (S.Antonio)	582		545	134	134	134	134	134	493	134	134
220598	Martinez Ditch	431		521			26			544		
220599	Massie Ditch			6								
220600	Mc Carrol Ditch No. 1	140		193			13			184		
220601	McCarroll Ditch No. 2	145		94						125		
220602	Mc Daniels Ditch	39		45						43		
220604	Las Mesitas Ditch	1933		1338		79				1061		266
220605	Mill Ditch	306		344			212			341		
220606	Mogales Valley Ditch	7										
220607	Mountain Ditch	18		19								
220608	New J.B. Romero Ditch	380		30						35		
220611*	Overflow, Vega Grande, Sabine	253		250			99			243		
220614	Poleo Ditch	74		45			41			42		
220615	Punche Ditch	367		302						441		
220616	Richfield Canal	1569	79	2503	1370	371	1772	1215	371	2130	1278	355
220618	Rincones Ditch	557		979	79	77	514	77	77	834	74	74
220619*	Romero	4895	153	3531	1712	1388	3240	2463	2229	2841	1708	1597
220620	Sabine School Section Ditch	100		191			29			165		
220621*	Salazar Ditch	495		677			356			620		
220622	San Carlos Ditch	76		198			267			295		
220624	San Juan/San Rafael Ditch	837		899		26	73		26	799		116
220625	San Rafael Conejos	735		920			169			849		
220626	Sanchez Ditch	306		271			4			263		
220627	Sanford Ditch	2345	121	2913	2721	237	2259	2259	239	2366	2208	470
220628	Santa Rosa	60		73						73		
220629	Santiago D.	231		381			276			424		
220630*	Seledonio Valdez Ir.	3965		4335	154		1643	162	162	4019	163	163
220631	Servietta	713		840	31	31	520	42	42	890	32	32
220632	Cenicero Ditch	998		922			175			864		
220633	Sisneros Ditch	211		144						215		
220634	Smith Bros. Ditch	259		231	41		172	28		229	33	
220635	Star Ditch	129								127	127	127

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		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
220636	Stover Ditch	308		329			40			330		
220639	Taos Valley Canal No.3	176		109						96		
220640*	Teodoro No. 1, Jaramillo 1 and 2	665		436						213		
220641	Teodoro No. 2	204		247						202		
220644	Trogillo	243		269	143		234	128		255	128	
220646	Vega Ditch	324		141			9			157		
220651	William Stewart Co. Irr. D.	1443		1173			183			1103	191	
220659	William Jackson Ditch	193		199			42			190		
220664	Broyle's Overflow No. 4	65		59						85		
220692*	Garcia Ditch-R	311		278			245			259		
220829	Canon Irrig. D. APD	30		11						8		
220914	Paine D.	21		16			19			19		
240502	Aban Sanchez Ditch	121		55						41		
240504	Acequia Chiquita	14										
240505	Acequia de los Cedros	89		52			8			40		
240506	Acequia Madre	443		107			2			4		
240507	Acequiacita	99		25						17		
240508	Alamo Ditch	132		71			56			72		
240509	Albert and Vigil Ditch	47		43			18			33		
240510	Alfonso Ditch	15		89			28			62		
240511	Pando Ditch	32		39			33			41		
240512	Antonio Valdez Ditch	118		167			12			177		
240513	Antonio Sanchez Ditch	48		28			28			29		
240514	Arellano Ditch	5										
240516	Association Ditch			18						20		
240519	Canon Ditch 1			60						54		
240520	Canon Valle D									108		
240521	Cerro Canal (Colo. Side)	1186	72	2448	2179	1996	2074	2064	1889	2543	2417	2234
240522	Cerro Ditch	1473	156	1294	205		349	95		624		
240524	Chalifu Ditch	215		68						91		
240525	Chama Ditch Ext.											
240526	Chavez and Quintana Ditch	59		65						42		
240527	Choury Ditch	139		162			107			140		
240528	Clarita Vigil Ditch	78		53			33			49		
240533*	Sanchez Ditch and Res Co.	10093		7859	2247	6026	6764	2261	6433	6691	2154	6628
240540	Emilio Lobato Ditch	53		55			15			54		
240542	Fares Jaquez Ditch	211		252						137		
240543	Felipe Vialpando Ditch	10		40						59		
240544	Francisco Sanchez	197	25	177			84			159		
240545	Frank Mondragon Ditch 1	66		57			56			54		
240546	Gabino Atencio Ditch	102		66			32			105		
240547	Gabriel Medina Ditch 1	52		102			48			53		
240548	Gabriel Medina Ditch 2	13		35						35		
240549	Garcia Ditch	43		40						35		
240550	Guadalupe Sanchez Ditch	223		170			110			158		
240551	Guadalupe Vigil Ditch	343		136			16			124		
240552	Island Ditch	191	32	179			124			172		
240553	J. M. J. Maez Ditch	126		145			153			159		
240554	Jacquez Ditch	83		80			74			82		
240555	Jaroso Ditch	1132		70						76		
240558	Jose M. Sanchez Ditch	40		66			3			63		
240559	Julio Gold Ditch	38		49						38		
240562	Little Rock Ditch	45		13			14			33		
240564	Lobato Ditch 1	20		18			3			19		
240565	Lobato Ditch 2	100		32			22			69		
240566	Lucero Ditch	9		18			83			86		
240570	Mestas Ditch	199		54			48			75		
240571	Mondragon Ditch	69					1			2		
240572	Montez Ditch	30		3								
240573	Cuates Ditch 1	226		120						205		
240574	Cuates Ditch 2	147		89						173		

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		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
240575	Ramon Lucero Ditch	69		60			20			61		
240576	Robert Allen Ditch	186		233			141			153		
240579	Salazar Ditch	166		99			68			72		
240580	Sam Lucero	137		216			211			212		
240581	San Acacio Ditch	1878	235	2467	489	188	1947	127	188	2555	765	864
240583	San Francisco Ditch	1082		873			109			810		
240586	San Luis Peoples Ditch	1625		1604			1245			1356		
240589	San Pedro Ditch	1593		1580			1384			1480		
240592	Torcido Ditch	152		200						211		
240593	Trujillo Ditch	9		8						4		
240594	Vallejos Ditch	1198		913			763			946		
240595	Vallejos Canon Ditch	71		59			9			59		
240598	Vigil Ditch	36		37			32			38		
240599	W. F. Meyer Ditch	694		384						424		
240601	Mondragon and Romero Ditch	226		175			141			185		
240602	Robert Atencio Ditch			31			40			37		
240604	Frank Mondragon Ditch 2	73		79			79			91		
243577*	Eastdale Reservoir	844		478	124	124	215	124	124	419	256	256
250502	Alder Creek Ditch			15			9			14		
250505	Arthur Young Ditch	1642		1279	21		448	8		388	7	
250506	B Clark Ditch			15			9			14		
250507	Baca Grant 4 Irr D 3	212	196	30						18		
250508*	Baca Grant 4 Irr. Ditch 4	288	35	71						38		
250509	Baca Grant 4 Irr. Ditch 5	563	145	322			113					
250513	Baca Grant 4 Irr. Ditch 9	2593		2534			1279			2428		
250516*	Baca Grant 4 Irr. Ditch 12	1380		1552			1174			1863		
250533	Cedar Creek Ditch											
250535	Clark Ditch A	353		352						209		
250541	Clayton Ditch D	212		125			67			119		
250542	Clayton Ditch E	173		100			17			63		
250545	Clayton Old Channel Ditch	100		48						66		
250546	Cody Ditch	127		88						103		
250550	Cottonwood Creek Ditch	622		1552			762			1381		
250551	Daniels Fish Arroya Ditch	125		38								
250552	Daniels Fish Ditch 4	147		60								
250553	Davison Ditch 1	22		60								
250556	Decamp Ditch	132		20			25					
250562	Dorcey Ditch 1			38						10		
250565	Driscoll Ditch											
250568	Ewing Ditch	14		108			26			81		
250569	Ford Ditch 1	123		79						66		
250571*	Garner Ditch 1	177		332		124	152			304		123
250573	Gash Ditch			13	13					34	17	
250577*	Greer Ditch 1	1008		519			381			443		
250583	Hall D 1	347		270			57			297	27	
250588	Henry White Ditch	16										
250589	Heukaufer Ditch 2			4								
250590	Hice Ditch 1	67		199			37			70		
250591	Hice Ditch 2	24					13			18		
250592	Hice Ditch 3	93		61			40			47		
250593*	Hice Ditch 4	91		32			30			25		
250595	Hice Ditch 6	78		49			37			40		
250596	Hice Ditch 7	27		18			13			13		
250597	Hice Ditch 8	24		15			15					
250605	Hopkins Ditch			2								
250606	Hot Springs Creek Ditch	283		392	126	126	218	126	126	140		
250607	Howard and Hall Ditch	240		159						26		
250614	Kennedy D 2	628		166								
250618	Malcolm Ditch			10								
250619	McFarland Ditch A B	324		293			103			179		
250620	McNulty Ditch			52						13		

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DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
250621	Means Ditch 1			12								
250622	Means Ditch 2			21								
250624	Neeland Ditch	111		111						82		
250627	North Ditch	194		718	136	136	311	136	136	469		
250628	Peterson Ditch	1130		517						646		
250631	Richards Ditch 1	147		125			27					
250632	Richards Ditch 2			29						19		
250633	Ridenour Ditch			10			6			6		
250636	Robinson Ditch	197		199	199		160	68		191	72	
250639	Ross Ditch	695		232			119					
250641	San Luis Co. Ditch	739		364	364	364	442	442	442	450	450	450
250642	San Luis Ditch	240		142			79			86		
250646	Schilling Ditch	284		192						24		
250647	Schultz Dittrich D	608		510		124	264		124	489		124
250649	Shellabarger Eaton Ditch	31		140						15		
250650	Shellabarger Home Ditch 1			114								
250652	Shewalter D #1	39		36			20			14		
250653	Shewalter Ditch 2	50		38								
250657	Squires Ditch 1	62										
250659	Steel Creek Ditch	288		103	26		100	28		232	46	
250661	Steel Ditch 2	333		264			104			302		
250662	Stump Ditch	20		19			16			16		
250663	Stump Ditch 1	19		15			13			16		
250664	Stump Ditch 2	15		8			11			11		
250665	Stump Ditch 3	20					15			15		
250666	Stump Ditch 4	10		6			13			13		
250667	Swidensky Ditch											
250669*	Tobler Rominger D	454		429	385	385	385	385	385			
250670	Turner Ditch			29								
250672	Wales D 2	521		290			109			289		
250674	Wales D 4	37								30		
250675*	Wales San Luis Ditch 1	719	393	371			46			239		
250677	Wales Shellabarger Ditch 1	494		569			135			485		
250679*	Wales Travis Ditch	4996		3307	462		1442	70		3459	404	
250680	Wells Kerber Ditch	446		220			85			225		
250683	White Ditch			36			19			15		
250684	Willow Creek Ditch	2134		1636			701			1498		
250685	Barsch Miller Ditch	417		36			14			65		
250686	Cedars Ditch			7								
250689*	Baca Grant Ditch 19-20	606		946			652			917		
250690*	Baca Grant Ditch 24-28	3642		1060			312			1153		
250691	Barsch Ditch 1-2-3	210		33			40			82		
250692	Clayton Ditch ABC	247		124			27			89		
250693*	Clayton Ditch FG	323		136			61			149		
250695	Schultz Dittrich No 14 Ditch	224		170	129		149	107	107	153	101	101
250698*	Hoffman Neidhardt Ditch	2044		1425	371	1425	371	371	371	1439	430	1358
250699*	San Isabel Nash Ditch			709			39			507		
250701	Silver Creek and Silver 2	87		17	11		6	6		31	19	
250702	Bunker Meadow Ditch	103		209			30			189		
250747	1920 D	38		7						18		
250756	Quintana Spg Drng Ovflw D	426		106						24		
250841	Wagner Ditch	36		13								
250847	Amer Ditch 1											
250848	Amer Ditch 2											
250857	Little Kerber Ditch 1			25			9			25		
250858	/LD Ditch 1	43		17			8					
250859	/LD Ditch 2	80		20			3					
260501*	Ashley Proffitt Ditch	717		598	22		107			378		
260504	Baxter Creek D 3			6								
260505	Big Meadow Ditch	839		981			885			901		
260506	Braun Brothers Ditch 1	457		254	254		280	254		263	258	

*Note: *Ditch aggregate includes diversions from several structures*

DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
260510	Campbell Ditch #4	289		137	137		184	184		293	293	
260511	Campbell Ditch #5	946		689	689		457	457		414	414	
260514	Carruthers			133			114			187		
260517	Chase Peyton			228			44			137		
260519	Commodore			135			16			122		
260531	Elwes D #2			73			80			129		
260533	Farrington D #1			55			21			54		
260535	Florence Ditch	192		245			195			190		
260536	Ford Creek			8								
260537	Ford D	40		336						209		
260538	Ford D 1 and 2	326		281			118			210		96
260539	Friese D #1			69			75			71		
260540	Friese D #2			26			74					
260542	Fullerton Ditch 1	694		533			338			479		
260543	Fullerton Ditch 2	107		100						93		
260545*	George Ball Ditch	1787	728	1463	1463		1105	1105		494	494	
260548	Gotthelf Ditch 1	234		249			170			193		97
260551	Harence D 1			45			21			25		
260552	Harence D 2			4								
260553	Harence D 3			11								
260557	Hawkins			112			96			139		
260559	Hearn Ditch	510	234	550	290		331	331	130	431	248	127
260561	Hodding D 1			11								
260562	Hodding D 2			24								
260563	Hodding D #3			20			32			22		
260564	Hodding D #5			49								
260568	Hougland Ditch			73			1			81		
260569	I. L. Gotthelf			28			86			113		
260570	Irwin Ditch	250		159			100			83		
260571	Jacques D	48		51			15					
260572	Jays D	356										
260574	Jeep Scandrett Ditch	350	218	284	92		32	32		52	25	
260583	Laughlin Ditch	67		76			4			59		
260584	Lawrence Ditch 3	286		242			126			181		
260586	Luders D1			37			27			31		
260587	Luders D 2			46			29			31		
260590	McCree			162			155			203		
260591	Malone Ditch	115		147			120			129		
260592	Malone Sullivan	454		536	88		448	75		437	23	
260601	Middle Ditch			72			60			62		
260602	Miely D						30	30				
260603	Mill Ditch	68		59						10		
260605	Monk D #1			190			95			224		
260607	Monk D #2			55			11			49		
260609	Morrison Ditch	162		162						146		
260610	Moses Goff Ditch 1	185		190			80			169		
260611	Moses Goff Ditch 2	98		69			49			61		
260613	Mountfield Ditch	250		341			80			285	119	119
260614	Munro D #1			114			106			130		
260615	Munro D #2			77			86			47		
260616	Nehls Company Ditch	278		232	232		219	219		189	176	107
260619	North Meadow No 779 Ditch									41		
260620	North Meadow No 780 Ditch			17						34		
260621*	Oklahoma Co. Ditch	3840		5100	2290		1082	891		1414	935	
260623	Phillips Ditch #1	567										
260625	Piquet D #1			82			45			58		
260628	Piquet D #13			96			100			90		
260634	Piquet D #3			51						31		
260637	Piquet D #7			174			75			160		
260639	Piquet D #9			46								
260648	Proffitt Company Ditch	247		269	59		60			227	44	

*Note: *Ditch aggregate includes diversions from several structures*

DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
260649	Proffitt McDonough Ditch	316		64						61		
260650	Quartet Ditch	872		734	613		1032	1030		640	640	
260653	Reservoir Enlargement Ditch	440		283	80	176	198	76	122	246	4	170
260654	Roberts Company Ditch	729		315	315		395	395		374	374	
260655*	Russell Company Ditch	267		261	176		21			231	101	40
260658	Russell Ditch 4	581		569			321			486		
260667	Seitz Mc Clure Ashley	181		95	48		57	57		143	52	
260669	Sheep Creek Ditch			16						37		
260670	Sheep Creek No 775 Ditch			10			7			9		
260671	Sheep Creek No 776 Ditch			14			4			4		
260672	Sheep Creek No 777 Ditch			9			13			13		
260673	Sheep Creek No 778 Ditch			19			13			13		
260675	Slane Scandrett Ditch	465		345						95		
260677*	Star Ditch	1186		975			744			879		92
260680	Stubbs Gallegos Ditch	274		255			246			235		
260682	Taylor A Ashley Ditch	132	132	147	147		58	58		45	45	
260686	Tuttle Creek			12								
260690	Van Allen Ditch	186		95	49		25	13		53	53	
260691	Wall Ditch	923		463	242	118	186	186	118	292	261	124
260692	Ward Highline Ditch	33		182			161			176		
260694	Werner B	128		24								
260695	Werner Clark	525	472	39			109	109				
260697*	Woodard Brothers Ditch	513		419	25		203			385	24	
260706	Farrington D #2			34			25			30		
260707	Fullerton Ditch 3	161		151			93			141		
260762	Ward Springs No 5									2		
260767	Ward Springs No 10									24		
260790	Paradise Valley D #1			31								
260791	Paradise Valley D #2			4								
260796	Cordova D			49								
260820	Cabin Spring									2		
260821	Cotton D			11						8		
260822	Hour Ditch			9						5		
260823	Upper Ditch									6		
260824	West Ditch			11								
260827	Joe Alexander Overflow	815		178	178		99	99				
260829	Glenn Alexander Overflow	454										
261099	Sheep Creek Ditch 2			28			43			9		
261100	Sheep Creek Ditch 3									20		
261102	Ortega 1A			6						1		
261103	Ortega D 4			4								
261109	Ortega 1B			2						3		
261110	Ortega D 2			23						9		
261111	Ortega D 3			4								
261114	Ward Highline Ditch - Alt			44						38		
270502	Biedell No. 10	940		897	344	344	428	344	344	803	336	336
270503	Biedell No. 2	58		37						9		
270505	Biehl D			52								
270509	Curby D No. 2			42			24			55		
270513	Dee Bois D No. 1	48		69						89		
270514	Espinosa D			9								
270517	Garcia Ditch	25		29						19		
270518	Green D #1	275		207	207	30	186	186	30	217	195	55
270521	Holland Ditch			160			77			96		
270522	Home Ditch No. 1	1252		1306	284		698	222	118	1402	327	241
270523	Johnnie Smith D 1	1403		800	654		338	338	175	565	560	560
270525	Juan Trujillo D	70		91			14			135		
270526	La Garita Ditch											
270527	La Loma D											
270528	La Magotes D			7						7		
270530	Manuel D No. 1			11						23		

*Note: *Ditch aggregate includes diversions from several structures*

DITCHID	DITCH NAME	1936 Acres		1998 Acres			2002 Acres			2005 Acres		
		Irrig.	GW	Irrig.	GW	Sprk	Irrig.	GW	Sprk	Irrig.	GW	Sprk
270531	Marcelino Martinez Waste	6		20								
270533	McLeod No. 3	12		9			4			4		
270534	McLeod No. 4	32		21	21	21	21	21	21	24	19	19
270535	McLeod No. 5	31		26	23	23	25	23	23	25	22	22
270537	Moody and Head D	6		20								
270538	Omnibus Ditch	377		433			295			484		
270539	Paradise No. 1			13								
270541	Paradise No. 3			4								
270543	Rocky Hill Seepage	1822	147	1300	977	543	923	829	574	825	750	547
270545	Shown D	37		85	62	62	62	62	62	80	61	61
270546	Stewart Ditch #4	44		65			16			53		
270548	Susanna D			27						27		
270549	Torres D			13								
270551	White D			5								
270553	Wilson D #4	37		86	62	62	62	62	62	80	61	61
270554	Wilson D			19								
270566	Cascias D			26								
270604	Navin D	516	516	399	387		570	570		391	391	
270605	Crow Ditch	799	799	188	176		239	239		178	178	
270623	Carnero Gd. Sta. 123			10								
270632	C Ditch			4								
270684	La Magotes D #2	161		196			51			165		
350507	Caldwell Ditch 1			7						7		
350508	Caldwell Ditch 2			9			4			9		
350513	Denton Ditch			2						2		
350514	Denton Ditch 1			9								
350515	Denton Ditch 2			8						8		
350518*	Fred Etter	940		1010	424		394	150	113	1152	607	175
350520	Galloway Ditch			6								
350528	Hull D	1271		967			438			1103		
350532	King Ditch			5			3			5		
350535	Leggitt Ditch			3								
350537	Little Frankie	63		74			43			73		
350538	Los Ojos Ditch	190		117			63			232		
350541	Medano Sand Creek	1616		974			528			1260		
350551	Beckwith D	8		12	10	8	17	14	14	15	13	13
350555*	New North	1272		1088	379		201	134		1206	523	134
350562	Notley Ball Overflow 38.25	902		466						468		
350570*	Aggregation of Trinchera District	11006		17058	12355	10749	13165	11246	10416	16204	12231	11903
350574	South D 2	307		236			325			487		
350575	South D 1	793		499			480			889		
350577	South Urraca Ditch	84		218						130		
350584	Trujillo D	3010		541			217			43		
350585	Urraca Ditch	35		51			29			60		
350594	Seyfried Stribling D	676		728		356				531		119
350595	Calkins D	202		232						163		
350597	Notley Ball Overflow 38.5	100		96						102		
350651	Cooper D			2								
350663*	N. Zapata Cr. Pipeline	1519	266	1101	161	161	319			511	156	156
350664	Wilbur's D	314		45			139	139		250	89	
350702	Rattlesnake Diversion			125	17	68	107	28	67	142	27	105

*Note: *Ditch aggregate includes diversions from several structures*

LIST OF AGGREGATE DITCHES - RGDSS 2005 Irrigated Lands Assessment - Agro Engineering, Inc.

Code	DitchID	Ditch Name Annual Diversion:	1998	2002	2005	Diversion Record Comments
20_MS_1	200516	Arroya Eagle + Larrick 5	515	277	804	
	200613	Eagle D	0	0	0	Water taken in another structure since 1976
	201004	Arroya D	0	0	0	diversions recorded in only 1988
20_MS_2	200623	Empire Cnl	58799	1191	62798	
	201060	Lease,Davis And Bingle D	0	0	0	carried in empire canal, no diversions reported
20_MS_3	200706	Larick D 2	479	109	311	
	200784	Peachy D 1	337	128	661	
	200849	**Smith D 1**	735	116	909	
	200785	**Peachy D 2**	170	62	226	
20_MS_5	200775	**Nichol D**	1341	1374	2002	
	200683	**James Patterson D**	0	0	0	Water taken in another structure since 1988
20_MS_7	200568	**Chadwick D 1**	280	0	0	No diversions since 1998, now SLVWCD water
	200569	**Chadwick D 2**	0	0	0	No diversions since 1996, no remaining right
	200571	**Chadwick D 4**	0	0	0	No diversions since 1996, no remaining right
21_MS_1	210558	Lowland D	1120	0	7407	
	210643	Cat House Dam	277	0	0	since 1998, acreage recorded with lowland ditch
	210576	Overflow D 1 So Branch	1563	0	5138	
	210575	Overflow D 1 No Branch	966	0	3707	
21_MS_2	210539	**Head Overflow D 5**	7797	0	12719	
	210716	**Seaman Flume**	0	0	0	no decreed right
21_MS_3	210521	**Empire Canal-La Jara**	18964	0	18245	
	210522	**Empire Canal-Alamosa**	18858	0	19480	
21_MS_4	210560	**Miller D-La Jara**	2310	0	155	
	210561	**Miller D-Alamosa**	2485	0	4735	
22_MS_1	220509	Ball Bros Overflow No 1	2726	0	3647	
	220510	Ball Bros Overflow No 2	0	0	0	509 is APD, only diversions 67 to 88
22_MS_2	220543	Florida D	901	0	974	
	220617	Riedel D	114	0	483	
22_MS_3	220553	Guadalupe Main	5145	3075	5078	
	220519	Brazo Del Norte D	182	0	604	
22_MS_4	220556	Hughes Overflow No 1	482	0	0	
	220557	Hughes Overflow No 2	0	0	0	Water taken in another structure, diversions 74/07
22_MS_5	220571	John W Floyd Ovrflw No 1	311	0	0	
	220572	John W Floyd Ovrflw No 2	0	0	0	Water taken in another structure, diversion 74
	220573	John W Floyd Ovrflw No 3	0	0	0	Water taken in another structure, diversion 74
22_MS_6	220591	Magote D	4534	0	11625	
	220609	North Eastern D	2921	0	5001	
22_MS_7	220593	Manassa D No 3	23649	13819	32434	
	220596	Manassa Westfield D	1605	0	3584	
	220533	Cruz Chavez D	71	0	0	right transferred to 220593 in 97, no div after 98
	220595	Manassa D	2491	0	3801	
	220653	La Vega De La Servilleta	357	0	0	right transferred to 220593 in 97, no div after 98
22_MS_8	220621	Salazar D	1254	266	1508	
	220511	Becroft Irr D	0	0	245	
	220534	Del Puerticito D	132	93	918	
22_MS_9	220630	Seledonia Valdez Irr Mil	4606	1910	5144	
	220623	San Jose D	5312	1097	4099	
	220647	**Vega Grande D**	173	0	366	
	220648	**William Sabine D No 1**	0	0	489	
22_MS_10	220640	Teodoro D No 1	169	0	195	
	220569	Jaramillo Ovfl D No 1	143	0	0	
	220570	Jaramillo Ovfl D No 2	143	0	0	
22_MS_12	220611	Overflow D	1383	244	1518	
	220650	Vega Grande And Sabine D	179	0	1094	
22_MS_13	220692	**Garcia D-R**	972	244	1143	
	220552	**Garcia D**	1067	480	1404	
22_MS_14	220506	**Archuleta Trogillio No 2**	510	248	543	
	220588	**Lovato D**	284	0	478	
	220708	**Arch-Trogillio Lwr Div 1**	344	126	272	
	220844	**Arch-Trogillio Lwr Div 2**	307	126	284	

Note: total annual diversions between april and october in acre-feet (AF); additions to ditch aggregates shown in bold

LIST OF AGGREGATE DITCHES - RGDSS 2005 Irrigated Lands Assessment - Agro Engineering, Inc.

Code	DitchID	Ditch Name Annual Diversion:	1998	2002	2005	Diversion Record Comments
22_MS_15	220619	**Romero D**	20354	6507	16498	
	220575	**Jose Bonifacio Romero D**	0	0	0	
24_EASTDALE	243577	Eastdale Reservoir No 1	0	0	0	Reservoir storage right (not ditch aggregate?)
	240537	Eastdale 1 Cnl	0	0	0	
	240619	Eastdale Culebra No 1 D	0	0	0	
24_MS_1	240533	Culebra Eastdale D	20719	14606	23037	
	240532	Culebra Cerritos Canal	2554	772	805	
25_MS_1	250516	Baca Grant 4 Irr D 12	1468	198	2123	
	250515	Baca Grant 4 Irr D 11	189	0	165	
	250517	Baca Grant 4 Irr D 13	0	6	129	
25_MS_2	250571	Garner D 1	1361	453	1246	
	250617	Major Cr D	483	77	574	
25_MS_3	250577	Greer D 1	0	0	0	1998, Water taken but no data available
	250578	Greer D 2	0	0	0	1998, Water taken but no data available
	250579	Greer D 3	0	0	0	1998, Water taken but no data available
25_MS_4	250593	Hice D 4	180	4	158	
	250594	Hice D 5	0	9	0	water generally taken
25_MS_5	250675	Wales San Luis D 1	0	0	0	No water available
	250676	Wales San Luis D 2	0	0	0	No water available
25_MS_6	250679	Wales Travis D	869	0	991	
	250501	Abby Shellabarger	0	0	0	diversion 94,01,07
	250582	H H Wales D	70	0	73	
	250648	Shellabarger D 2	0	0	0	Water taken in another structure, no div. since 90
	250678	Wales Shellabarger D 2	1675	69	2836	
	250644	Sanford D	14	0	73	
25_MS_7	250689	Baca Grant 4 Irr D 19-20	1854	427	1160	
	250518	Baca Grant 4 Irr D 19	0	0	0	recorded under 689, no div except 1968
	250519	Baca Grant 4 Irr D 20	0	0	0	Water taken in another structure, no div
25_MS_8	250690	Baca Grant 4 Irr D 24-28	4618	274	3576	
	250520	Baca Grant 4 Irr D 24	0	0	0	Water taken in another structure, only div 75-77
	250521	Baca Grant 4 Irr D 25	0	0	0	Water taken in another structure, only div 75-77
	250522	Baca Grant 4 Irr D 26	0	0	0	Water taken in another structure, only div 75-77
25_MS_9	250698	Hoffman Neidhardt D	4689	2268	7168	
	250548	Cotton Cr Airline D	0	0	0	Water taken in another structure, only div 90
25_MS_10	250699	San Isabel Nash Frazee D	2152	0	1987	
	250623	Nash D	0	0	293	Water taken in another structure, except 58/05
	250640	San Isabel D	0	0	0	Water taken in another structure since 1973
25_MS_11	250669	Tobler Rominger D	460	0	0	No diversions reported since 1998
	250574	General Fuller	0	0	0	No diversions reported
25_MS_12	250693	Clayton D Fg	478	5	175	
	250543	Clayton D F	0	0	0	only diversion in 1951
25_MS_13	250508	**Baca Grant 4 Irr D 4**	233	0	0	
	250512	**Baca Grant 4 Irr D 8**	35	0	0	
26_MS_1	260621	Oklahoma Co D	2508	56	685	
	260681	Sullivan D	0	0	0	when available taken in 621, no reported diversions
	260500	Arroyo D	0	0	0	when available taken in 621, no reported diversions
	260532	Fairplay Arroyo D	0	0	0	when available taken in 621, no reported diversions
	260547	Goodwin D	0	0	0	no reported diversions
	260554	Hartman Bros D 2	0	0	0	no reported diversions, one right transferred to 621
	260555	Hartman Bros D 3	0	0	0	Water taken in another structure, only div 92/93
	260567	Holcomb D	0	0	0	Water taken in another structure, no reported divs
	260597	Means D	0	0	0	when available taken in 621, no div since 1973
	260674	Shore Or Campbell D 3	0	0	0	right transferred to 621, no reported divs
	260676	South 38 D	0	0	0	when available taken in 621, only div 93/94
	260684	Travis D 3	0	0	0	Water taken in another structure, no reported divs
	260696	Wm M Stowe D	0	0	0	when available taken in 621, only div 57
	260700	Zeigler Bros D	0	0	0	when available taken in 621, no reported diversions
26_MS_2	260655	**Russell Company D**	569	3	429	
	260656	Russell D 1	0	0	0	when available taken in 655, no div since 1963
	260657	Russell D 2	0	0	0	when available taken in 655, no reported diversions

Note: total annual diversions between april and october in acre-feet (AF); additions to ditch aggregates shown in bold

LIST OF AGGREGATE DITCHES - RGDSS 2005 Irrigated Lands Assessment - Agro Engineering, Inc.

Code	DitchID	Ditch Name Annual Diversion:	1998	2002	2005	Diversion Record Comments
26_MS_3	260677	Star D	1940	621	2730	
	260612	Moses Goff D 3	0	0	0	water taken in 677, no reported div. since 1987
26_MS_4	260697	Woodard Bro D	997	101	905	
	260698	Woodard D	0	0	0	Water taken in another structure, no reported divs
	260699	Woodard Overflow D	0	0	0	Structure not usable, no reported divs
26_MS_5	260545	George Ball D	1046	0	357	
	260685	Turnbull Luengen D	0	0	0	when available taken in 545, no reported diversions
26_MS_6	260501	**Ashley Proffitt D**	1636	248	2104	
	260809	**Virden Arroyo D**	236	0	0	since 1999 mentioned as tailwater into 501
35_MS_1	350518	Fred Etter D	2055	673	1313	
	350517	East Ridge D	201	57	161	
	350544	Meyer D 1	995	0	925	
	350554	North Middle Island D	206	0	424	
	350556	North East Island D	254	0	447	
	350567	South Bluff D	276	0	272	
	350681	Meyer D	0	0	0	taken at APDs, no reported diversions
35_MS_2	350555	New North D	845	288	881	
	350500	Alamos Altos D	2078	281	983	
	350505	Bridge D	37	7	116	
	350527	Hughes D 1	2043	649	1669	
	350549	Nenninger D	0	0	0	taken at APDs, no reported divs since 1983
	350559	New South D	930	0	527	
35_MS_3	350570	Sangre Cristo Trinchera	9630	267	6137	
	350521	Garland D,Hdgt 1	9980	866	3702	
	350523	Garland D,Hdgt 2	9910	470	11264	
	350529	Indian Creek D	1406	0	0	carrier from indian ck to mtn hm reservoir
	350546	Mill D	17	0	204	
	350560	Newton D 2	3537	446	2524	
	350563	Ojito Creek D	0	0	0	taken at 564, no reported divs since 1973
	350564	Ojito Creek D 1	162	0	153	
	350571	Sangre De Cristo D	316	0	0	
	350579	Trinchera Canal	4373	349	5526	
	350581	Trinchera Garland Canal	10519	1217	4506	
	350582	Trinchera Highline Canal	3261	12	3572	
	350588	Walsen D 1	7070	1426	9394	
	350531	**Juel D**	372	0	0	
	350561	**North Swamp D**	173	52	3169	
	350576	**South Swamp D**	71	14	0	
35_MS_4	350663	N. Zapata Creek Pipeline	0	0	1291	Rocky Mtn Bison Aug Plan Since 1998
	350573	Shady Retreat D	0	0	0	Water taken in another structure, no div. since 1983
	350591	Zapato D	323	0	179	
	350565	Old Hillside D	0	364	0	
	350592	Zapato D 3	0	1305	0	
Deleted:						
20_MS_4	200814	Rio Grande D 2				
	200815	Rio Grande D 4				
20_MS_6	200575	Chicago D				
	200773	New Ditch				
	201676	Closed Basin Project				
22_MS_11	220651	William Stewart Co Irr D				
	220647	Vega Grande D				
	220648	William Sabine D No 1				
25_MS_9	250619	Mcfarland D A B				

Note: total annual diversions between april and october in acre-feet (AF); additions to ditch aggregates shown in bold

Attachment 7

Agro Engineering; Kelley L Thompson. February 19, 2005. *2002 Division 3 Irrigated Lands Assessment and Groundwater Use Evaluation*. Report to Rio Grande Water Conservation District, Colorado Water Conservation Board, Conejos Water Conservancy District, Rio Grande Water Users Association, Alamosa La Jara Water Conservancy District, San Luis Valley Irrigation Well Owners Association, Rio Grande Canal Water Users Association, and Saguache Creek Water Users Association.

FINAL REPORT

2002 Division 3 Irrigated Lands Assessment and Groundwater Use Evaluation

TO: **Rio Grande Water Conservation District**
Colorado Water Conservation Board
Conejos Water Conservancy District
Rio Grande Water Users Association
Alamosa La Jara Water Conservancy District
San Luis Valley Irrigation Well Owners Association
Rio Grande Canal Water Users Association
Saguache Creek Water Users Association

FROM: **Kelley Thompson, P.E.**
Agro Engineering, Inc.

DATE: **February 19, 2005**

Introduction

A study of irrigated lands and water use in the San Luis Valley (Division 3) for the growing season of 2002 was made possible by a joint funding opportunity between the Colorado Water Conservation Board (CWCB), Conejos Water Conservancy District, Rio Grande Water Conservation District (RGWCD), Rio Grande Water Users Association, Alamosa La Jara Water Conservancy District, San Luis Valley Irrigation Well Owners Association, Rio Grande Canal Water Users Association, and Saguache Creek Water Users Association. The study characterizes lands that were irrigated in Division 3 in 2002, and provides a refresh of the irrigated lands assessment for the Rio Grande Decision Support System (RGDSS). In addition, year 2002 provides a unique opportunity to identify parcels, particularly in the southern portion of the valley, that can be irrigated by groundwater, and accurately quantify the present maximum level of ground water usage; as very little surface water was available. The year also provides a unique data set to analyze the relationship between groundwater usage and the change in groundwater storage in the aquifers of the San Luis Valley. The results of the study should give indications on how to bring the water use in the valley more into balance with available water supply. Restated, the goals of the current study were to:

1) Characterize irrigated crops in Division 3 for year 2002. In particular, develop a GIS data set with irrigated parcels, crop classification, and a measure of irrigation water supply for alfalfa and grass/pasture crops that can be used as a 2002 data set for the RGDSS models
2) Identify parcels in Division 3 that can be irrigated by groundwater
3) Approximate groundwater usage in 2002 by parcel

The study was broken into 4 "task" sections. The tasks are as follows:

Task 1. Imagery Acquisition and Processing
Task 2. Parcel Delineation
Task 3. Crop Classification
Task 4. Crop Water Use and Diversion

Task 1. Image Acquisition and Processing

Imagery Acquisition

Ground-truthed crop information was relied upon for crop classification in much of Division 3. However, multiple Landsat satellite images were acquired in order to verify ground-truthed classifications, to classify crops in areas not covered by ground-truthing, to identify parcel boundaries that changed between 1998 and 2002, and to quantify irrigation crop water supply for grass/pasture and alfalfa crops. The U.S. Geological Survey's (USGS) Landsat imagery is relatively cheap, covers large spatial areas, and contains data from seven different radiation wavelengths or "bands". Several methods have been developed to use Landsat's multi-spectral bands to evaluate crop type and vigor. Another advantage of Landsat satellite imagery is image availability. Landsat satellites collect imagery for an area once every 16 days, and this imagery is archived for future purchase. During the study period, imagery was collected by both the Landsat 5 and Landsat 7 satellites (Landsat 7 has since failed), so two images are available every 16 days. Appendix A details more information about Landsat satellite imagery.

Multiple satellite image dates were acquired in order to exploit seasonal crop patterns. June and July images are important for grain, July and August images are important for potatoes, while alfalfa should be the only green field crop in September and October. A seasonal collection of imagery also enables a seasonal examination of crop water use. Two separate Landsat images (east and west) are required to cover the irrigated portions of Division 3. The Missionary Ridge forest fire near Durango and the Million fire near South Fork produced extremely smoky conditions in the San Luis Valley in June through early July of 2002. However, relatively clear and cloud-free image pairs were available near the first of June, mid-July, and mid-August. One clear east image was available in late September, and one clear west image was available in October. The following table details the images that were acquired. Agro Engineering purchased three of these images as part of a different project and provided them for the project.

Table 1. Acquired Landsat imagery

Date	5/31/2002	6/7/2002	7/9/2002	7/18/2002	8/10/2002	8/11/2002	9/20/2002	10/13/2002
Satellite	Landsat7	Landsat7	Landsat7	Landsat7	Landsat7	Landsat5	Landsat7	Landsat7
Location	East	West	West	East	West	East	East	West

The only disadvantage of Landsat imagery is that it has a relatively coarse resolution. Multi-spectral bands have an original resolution of about 30 meters (m) and a processed pixel size of 25m. The 30m resolution is quite suitable for crop classification, but higher resolution imagery was needed for boundary delineation and georeferencing. Agro Engineering provided mosaics of 1m resolution black and white USGS digital ortho-photo quarter-quad (DOQQ) aerial photos from 1998 for all counties in Division 3 except Saguache. DOQQs for areas in Saguache that were irrigated in 1998 were obtained. Agro Engineering also took color digital aerial photos of all irrigated sections in Division 3 during the summer of 2003. The Rio Grande Water Conservation District helped fund this photography. These photos were used to delineate parcels that have changed since 1998; particularly where new center pivot sprinkler systems were installed.

Georeferencing

Although raw images were roughly referenced to the UTM coordinate system using sensor data, the ortho-rectification process used by the USGS does not use any ground control points and spatial accuracy is only on the order of 250m. This is not sufficiently accurate for classification purposes, so the satellite images were re-georeferenced.

The 1m DOQQ imagery was accurately ortho-rectified and georeferenced by the USGS, and was used as a base to orient the Landsat imagery. For the Landsat 7 imagery, the 12.5m resolution panchromatic band (Band 8) was used to find common points in the satellite and DOQQ imagery. The 25m resolution Band 4 was used for the Landsat 5 image. A set of 12 to 14 to/from control points was developed for each image, and a linear, nearest-neighbor transformation was applied. The transformation error averaged 6m for the satellite images (calculated by root mean square (RMS) error). An RMS error of less than 12.5m (one half the pixel resolution of 25m) is considered good for Landsat imagery.

Vegetative

The Normalized Difference Vegetative Index (NDVI) has been used extensively to characterize the density of vegetative biomass using multi-spectral imagery. NDVI is calculated by a normalized ratio of visible red (Landsat Band 3) and near-infrared (Landsat Band 4) radiation. Variations of NDVI have also been used that use visible green (Landsat Band 2) instead of visible red. However, there is some concerns that NDVI results may be influenced by moisture (that effects near-infrared more than visible colors) and soil brightness (that effects visible colors more than near-infrared).

Imagery processing methods were examined that could isolate vegetative characteristics from soil brightness and soil moisture influences. The tasseled cap (TC) transformation is one technique that was developed for this purpose (Kauth and Thomas 1976, Crist and Cicone 1984). The TC transformation uses Principal Component Analysis (PCA) to transform 6 bands of Landsat imagery (Band 6 thermal is not used) that represent somewhat related reflectance characteristics to three different “orthogonal” images that represent independent cover characteristics. The three primary images produced have been called TC greenness, moistness, and brightness. Similar to NDVI, the TC greenness image is related to vegetation characteristics and vegetation biomass. A TC transformation approach using an at-satellite reflectance factor recommended by Huang et al. (2002) was used for the current study. Please see Appendix B for details of the approach and for imagery data used in the calculations.

Both TC greenness and NDVI images were produced. NDVI results vary between -1.0 and 1.0. Greenness image values also have a similar range, but have negative values that extend beyond this range. Therefore, the more standardized range of NDVI is an advantage. However, the TC greenness images displayed a higher contrast between irrigated and non-irrigated lands. TC greenness images and NDVI images from similar dates were compared at locations of overlap. Some slight variation between dates was observed in both sets of images. However, the TC images had much less variation at identical locations than the NDVI images. NDVI was also prepared using at-satellite reflectances. In this case, overlap variation in NDVI was more similar to the TC approach, but appeared to be slightly higher. Therefore, the TC greenness approach using at-satellite reflectances appeared to be the most favorable to increase irrigated / non-irrigated contrast and decrease between scene variability; and was employed for the purposes of this study.

Tasseled Cap composite image

For parcel delineation, an image was needed to indicate which parcels were irrigated at any time during the 2002 growing season. The TC greenness images for east and west image pairs were mosaiced to create one image for the months of June, July, and August. Then, the June, July, and August mosaics were composited as the colors blue, green, and red, respectively. This image was useful for parcel delineation, delineation of crop splits, and crop classification. The color of an irrigated parcel appears bright if vegetation was green during the June, July, and/or August image dates. Fallow areas remain dark and typically have a brownish coloration. The color of the irrigated parcels also provides a good indication of crop type. For example, a parcel that only received irrigation water early in the season (such as grain) will be colored blue or blue green, while a potato crop that was green in July and August will appear as the color yellow (green + red). Alfalfa crops that were well irrigated throughout the summer can appear as the color white (blue + green + red), although a number of other colors are also apparent due to partial water supplies or hay cuttings. Figure 1 displays the TC greenness composite image for most of the irrigated land in Division 3.

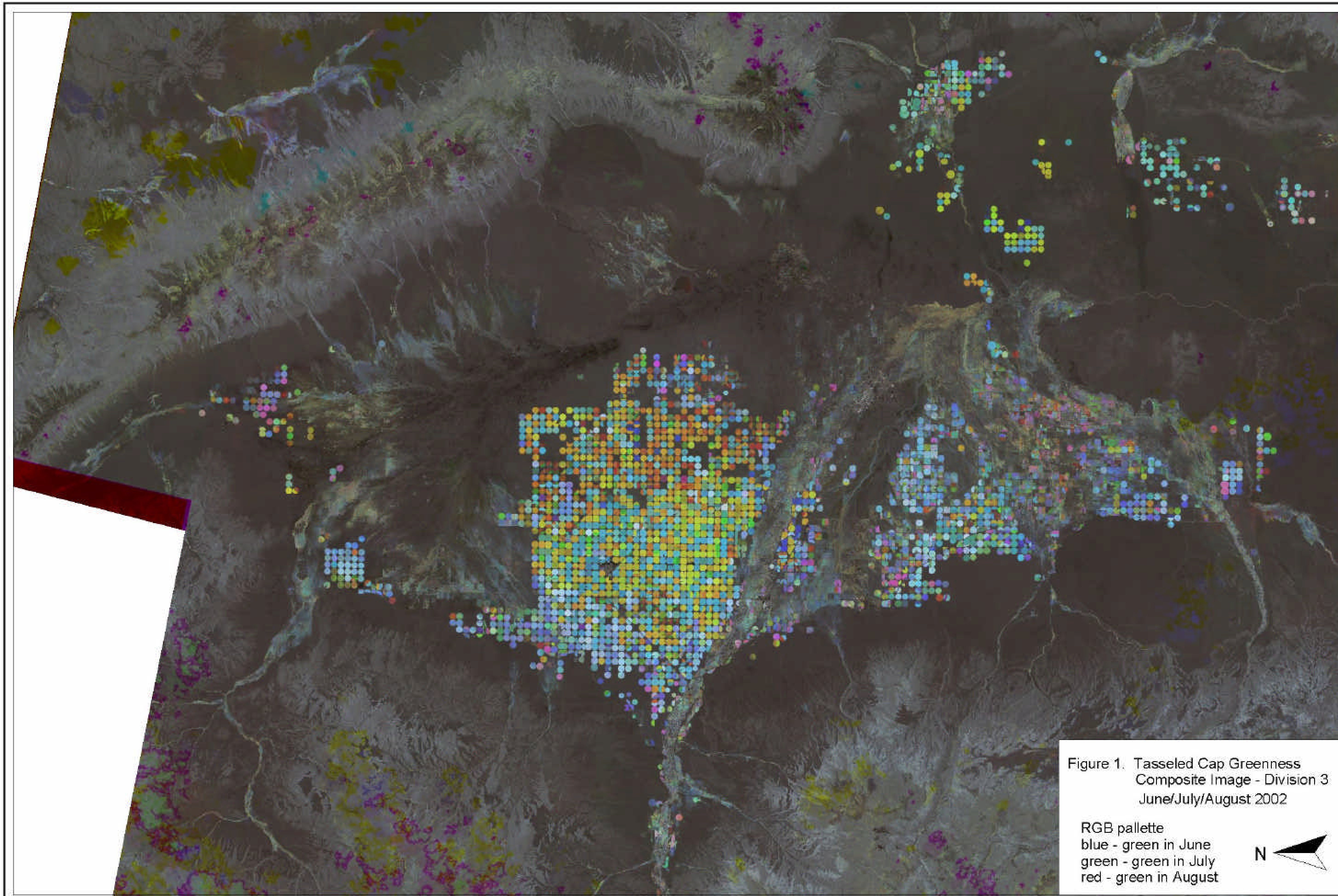


Figure 1. Tasseled Cap Greenness
Composite Image - Division 3
June/July/August 2002

Task 2. Parcel Delineation

For the 1998 RGDSS lands assessment, parcels boundaries were delineated using 5m resolution satellite data. Since the 1998 analysis, the USGS has produced DOQQ imagery that is accurately ortho-rectified and has a 1m resolution. These photos were also taken in 1998, but the additional resolution makes parcel boundaries much more apparent than in the satellite imagery that was used. Parcels drawn with the 1m resolution imagery have more accurate acreages and have better divisions between areas with different cropping or irrigation practices. Therefore, irrigated parcels were re-delineated using the 1998 DOQQs as a base. All parcels in Division 3 using center pivot sprinkler irrigation were delineated even if they appeared fallow in 2002. Flood parcels were delineated when the TC satellite composite image indicated that irrigation water may have been applied to the parcel. Although some parcels that were probably fallow were delineated, most clearly fallow parcels were not. Areas of trees were avoided in parcel delineation to minimize the effect of green leaves on the irrigation water supply evaluation.

The 2002 TC satellite composite image was used to identify irrigated parcels for delineation using the 1998 DOQQs, and to note definite boundary changes between 1998 and 2002. Many parcels did not change between 1998 and 2002. However, newly installed center pivot sprinkler systems, sprinkler systems changes (such as the addition or removal of a corner system tower), or new divisions to flood irrigated parcels were apparent in the satellite imagery. The 2003 color digital aerial photos were used to delineate new parcels that changed between 1998 and 2002. In cases where center pivot irrigation systems were installed, the 2003 photo was georeferenced in GIS to accurately delineate the new parcel. Many end guns and corner towers were removed from center pivot systems during 2003, particularly in areas north of the Rio Grande. However, most newly installed systems did not have end gun or corner tower changes between 2002 and 2003, and changes between 2002 and 2003 rarely posed problems. Sprinkler irrigated fields that were split cropped were visually apparent in the TC satellite composite image, and parcels were split at crop boundaries. The color component of the color photos also aided in the interpretation of parcel boundaries in the black and white DOQQs. The following pictures show examples of a new parcel for a center pivot sprinkler a) detected on the 2002 satellite imagery composite, b) the 2003 color photograph used to redraw the boundary, and c) the new parcel shown on the 1998 DOQQ at which time the parcel was flood irrigated. A total of 9,844 parcels covering 503,569 acres were delineated for year 2002.

Figure 2. Examples of satellite imagery and aerial photography used to delineate parcels

Sprinkler Irrigation Systems

Parcels were noted as sprinkler or flood irrigated using an examination of the DOQQ or color aerial imagery. Of the 9,844 delineated parcels, 7,008 were noted with flood irrigation and 2836 with sprinkler irrigation. This figure includes sprinkler irrigated parcels that were split because of split crops. Parcels for individual sprinkler systems were re-combined, and the parcel delineation indicated a total of 2,436 sprinkler irrigation systems covering 285,731 acres for year 2002. This number does include some sprinkler systems that are still visible in aerial photography but were fallow in 2002 and may no longer be in use. All new sprinkler systems that were installed between 1998 and 2002 were noted in the TC satellite composite image. Many new systems installed in 2003 were also noted by chance during use of the 2003 color aerial photography. These new 2003 systems were also noted and delineated, and information about these systems is useful in a consideration for system numbers in Division 3. But, as they were discovered more by chance and the evaluation was not part of the current scope, some new 2003 systems may not have been discovered. Several small systems that were noted as flood irrigated using the satellite imagery in the 1998 RGDSS were found to actually be sprinkler systems using the higher resolution aerial photography and were not considered “new”. However, it was found that a total of 145 new sprinkler systems were installed between 1998 and 2002, and at least 25 more systems were installed in 2003 in areas that were previously flood irrigated; for a total of 170 new systems covering 14,320 acres.

Many half circle systems are physically split by large canals or power-lines that intersect the quarter section. These systems were delineated separately although they may be indicated as single full circle systems in other documentations of center pivots. Therefore, it is important to note sprinkler size when evaluating the number of sprinkler systems in Division 3. The following table breaks down sprinkler irrigation by system size. In the table, indicated sprinkler acreages are for center pivot sprinkler systems, while all linear sprinkler systems were lumped together. One linear system covered 59 acres, but the remaining 4 systems were relative large and ranged between 140 and 310 acres. Center pivot systems covering between 0 and 40 acres are generally small systems or “mini-pivots” placed in the corners between larger center pivot sprinklers, sprinklers between 40-80 acres are primarily half systems and two such systems often covered a quarter section, while 80 to 220 acre center pivots are often full circle or nearly full circle (windshield wiper) systems that cover full quarter sections or more.

Table 2. Sprinkler irrigation systems by size

SYSTEM SIZE	**1998**		**New 1998-2002**		**New 2003**		**Total New**		**Total in 2003**	
	num	acres	num	acres	num	acres	num	acres	num	acres
0-40 acres	53	1111	23	461	5	107	28	568	81	1679
40-80 acres	178	10837	47	2843	6	363	53	3206	231	14043
80-220 acres	2055	260622	75	8913	14	1633	89	10546	2144	271168
Linear	5	944							5	944
Total	2291	273514	145	12217	25	2103	170	14320	2461	287834

The following table breaks down delineated sprinkler irrigation systems by general area and by water district. The number of sprinkler irrigation systems increased by 17% south and west of the Rio Grande River, 10% in Costilla County, 5% in northern Saguache County, and 2% in the north central portion of the San Luis Valley between 1998 and 2003. Figure 3 shows sprinkler irrigated parcels that were delineated in Division 3 and notes new systems installed between 1998 and 2002 and in 2003.

Table 3. Sprinkler irrigation systems by area

LOCATION	**1998**		**N. 1998-2002**		**New 2003**		**Total New**		**Total in 2003**	
	num	acres	num	acres	num	acres	num	acres	num	acres
North Central Valley Total:	1430	174808	27	1533	3	319	**30**	1852	**1460**	176660
District 20 North of Rio Grande	1068	129395	19	990	0	0	19	990	1087	130386
District 27 Carnero / La Garita	362	45413	8	543	3	319	11	862	373	46274
South of Rio Grande Total:	511	57712	87	8218	20	1628	**107**	9845	**618**	67558
District 20 South of Rio Grande	336	36438	46	3858	6	316	52	4175	388	40612
District 21 Alamosa / La Jara	93	11153	23	2319	12	1050	35	3369	128	14521
District 22 Conejos River	82	10122	18	2041	2	262	20	2302	102	12424
North Saguache County Total:	118	13767	5	438	1	65	**6**	504	**124**	14270
District 25 San Luis Creek	70	8253	4	308	1	65	5	373	75	8626
District 26 Saguache Creek	48	5514	1	130	0	0	1	130	49	5645
Costilla County Total:	232	27227	26	2028	1	91	**27**	2120	**259**	29347
District 24 Culebra Creek	103	12335	7	701	1	91	8	792	111	13127
District 35 Trinchera Creek	129	14892	19	1328	0	0	19	1328	148	16220
TOTAL	2291	273514	145	12217	25	2103	**170**	14320	**2461**	287834

Parcel Identification

For the GIS database, parcels that were delineated for the 1998 irrigated lands assessment were assigned a sequential id starting with the number 10100. As described earlier, parcels were completely redrawn for 2002 using higher resolution photography. Many flood parcels were drawn with different sizes and boundaries than in 1998. Center pivots that were split cropped were divided into separate parcels that may or may not have been similar to splits in 2002. Consequently, it was not feasible to keep the same parcel ids as used in 1998. Therefore, the parcels that were delineated in GIS for 2002 were assigned a new sequential ID beginning with the number 20001.

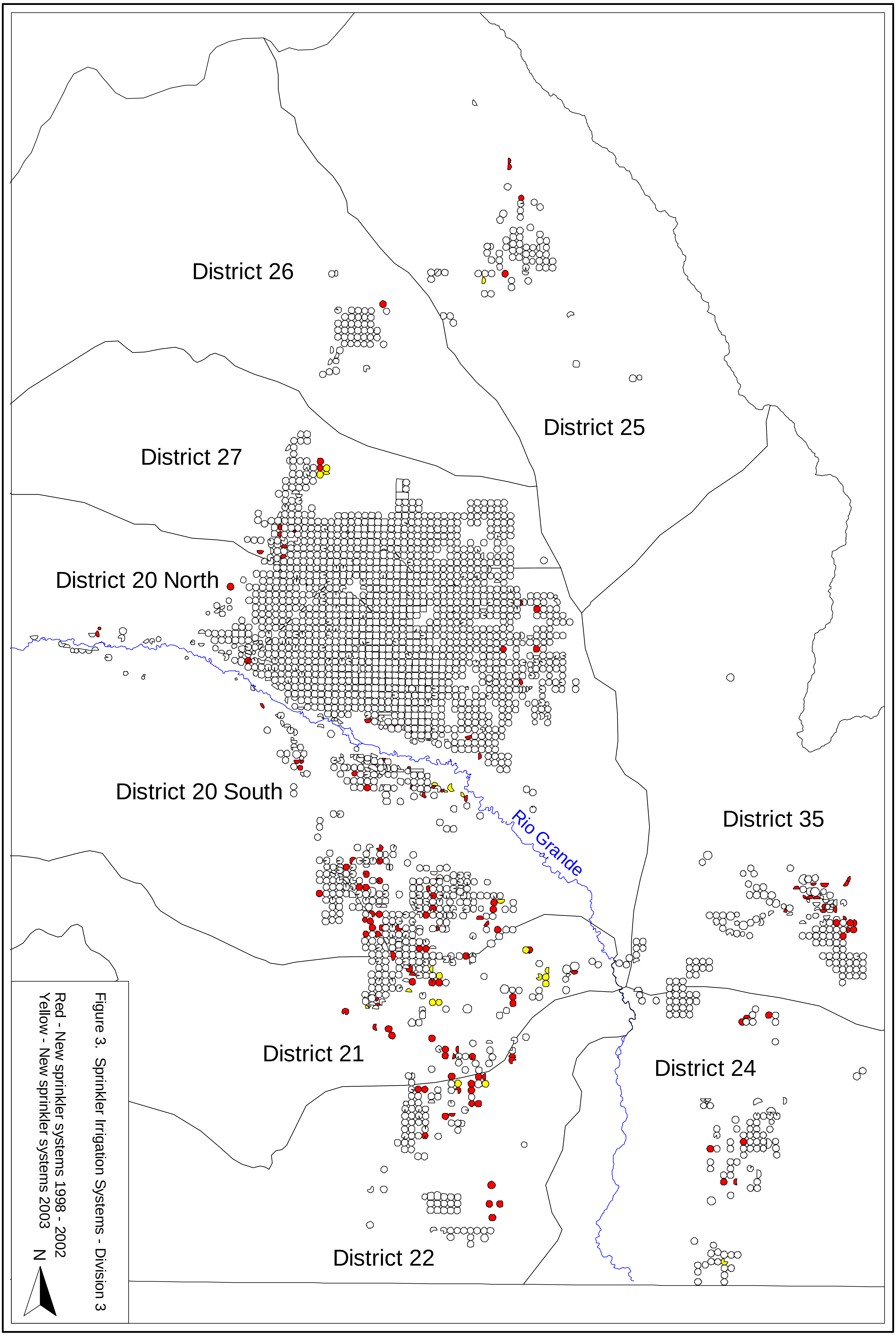


Figure 3. Sprinkler Irrigation Systems - Division 3

Task 3. Crop Classification

Crops types were determined for 2002 parcels using an evaluation of four sources: 1) evaluation of the tasseled gap greenness image and color aerial photos described in section 1, 2) the ground-truthed crop documentation from the Rio Grande Water Conservation District (RGWCD), 3) crop type probability estimates from multi-spectral classifications of all Landsat satellite images, and 4) knowledge of regional cropping practices within Division 3.

The major crop classifications that were used were potatoes, small grains, vegetables, alfalfa, grass/pasture, and fallow. The classification of grass/pasture was named using the same convention as in the 1998 RGDSS. This classification is meant to include irrigated pastures and all hay crops other than alfalfa. The more specific crop types of canola, oat hay, lettuce, and carrots were noted and retained for summary statistics. For water supply calculations, water supply for canola appeared similar to grain and was included as a grain. Since the water supply for oat hay fields appeared to vary widely and it is a hay crop, oat hay was included with the grass/pasture classification rather than grain in order to allow an evaluation of water supply for each field. In the 1998 RGDSS, oat hay was classified as a small grain.

RGWCD Crop Documentation

The Rio Grande Water Conservation District (RGWCD) conducts an annual field investigation to document crops grown on parcels in much of Division 3. Crop types are noted by hand on paper maps. Color aerial photos taken by the Farm Service Agency (FSA) are referenced to document crops in some areas with difficult access. Figure 4 shows townships with crop classifications from the RGWCD that were available for 2002 along with the irrigated parcels that were delineated for 2002. The RGWCD documents the majority of irrigated parcels in Alamosa, Rio Grande, and Conejos Counties; and in southern Saguache County. However, crops are not documented in Costilla County, northern Saguache County, and in Rio Grande County west of Del Norte. For 2002, crop documentation could not be located for township T39N R7E near Monte Vista.

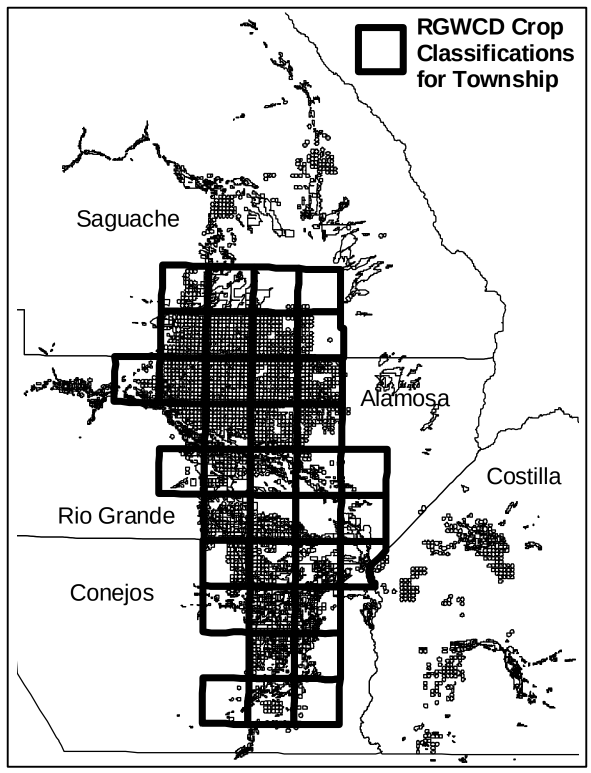


Figure 4. Townships with RGWCD Crop Classifications for 2002

The ground-truthed crop information from the RGWCD was used as the basis for crop classification. The RGWCD crop types were manually entered while observing the colors of the tasseled cap composite image for any obvious crop splits or differences. Of the parcels that were delineated for year 2002, crops on 3150 parcels were noted from the RGWCD maps. An additional 338 parcels were noted by the RGWCD as fallow.

Satellite Imagery Crop Classification

Of the 9844 parcels delineated for 2002, crops for 5355 parcels in Division 3 were not documented by the RGWCD. As mentioned previously, crop classifications could generally be observed using the tasseled cap composite image. In areas under normal center pivot irrigation, potato, grain, and alfalfa crops could generally be distinguished. However, the majority of crops in areas not documented by the RGWCD were grass/pasture, alfalfa, and grain; and distinguishing between these crops using the composite image was difficult. Crop type classification was also difficult in parcels that were irregularly or poorly irrigated. Therefore, a seasonal multi-spectral procedure was developed to classify crops using satellite imagery.

The ground-truthed crop classifications from the RGWCD were used as "training sites" to classify crops using the satellite imagery. For each of the eight satellite images, the median value of imagery pixels from each Landsat band (TM Bands 1,2,3,4,5,7) contained by each delineated parcel was determined. Parcels with crops that were documented by the RGWCD were used to create multispectral signature sets for each image date for potato, grain, alfalfa, and grass/pasture crops. A Bayesian soft classifier process was then used to create probability images for each crop and each satellite image. In other words, for each satellite image, files for potato, grain, alfalfa, and grass/pasture were created that estimated the probability that each parcel contained a particular crop type given the similarity between the spectral characteristics of the parcel on that date to the crop training sets that were developed for that image. The probability images from all dates for each crop were then combined to characterize the relative probability that a parcel was a particular crop given seasonal crop patterns. The crop type with the maximum overall probability was chosen as the most probable crop type for the parcel.

Generally, the RGWCD crop was used for parcels where the crop was documented, while the satellite classification was used for parcels not documented by the RGWCD. Satellite imagery crop classifications were examined on a parcel by parcel basis, and manual adjustments were made using knowledge of crops grown in different parts of the valley, Agro Engineering's client crop database from 2002, and additional examination of 2003 color aerial photos and the tasseled cap greenness images. For example, it is known that potato crops are generally not grown in areas of northern Saguache County or southern Costilla County. Many odd classifications were related to poorly irrigated fields, and it was considered that a poorly irrigated field was most likely grass/pasture or alfalfa. A classification of alfalfa was changed to grass/pasture in areas that appeared, in the 2003 color photos, to be a meadow that had not been plowed or diked. As probabilities were produced for all crops, the crop with the next highest probability was often selected if the first crop did not appear correct.

The following table lists crop acreages mapped for 2002. Total acreages for major crops are shown as well as a breakdown of more specific crop types. Acreages of major crops from the 1998 irrigated lands assessment are also provided for comparison (the area of "user defined as meadow" is listed as fallow). Many areas that were clearly not irrigated were not mapped in 2002. As 1998 was approximately a normal water year, it can be considered that the difference in mapped acreage between 1998 and 2002 can be accounted for by parcels that were clearly not irrigated in 2002. A number of parcels were mapped but designated as fallow including center pivots irrigated fields that were not utilized in 2002. The water supply analysis also indicated a number of mapped alfalfa and grass/pasture parcels that were also not irrigated (see Table 6).

Table 4. 2002 Crop Type Acreages of Mapped Parcels

CROP	PARCELS	2002 ACREAGE	1998 ACREAGE
Potatoes	**667**	**73,012**	80,064
Small Grains	**807**	**76,623**	114,214
Barley / Wheat	799	75,892	
Canola	8	731	
Vegetables	**51**	**5,626**	7,583
Lettuce	30	3,108	
Carrots	21	2,518	
Alfalfa – Total	**3238**	**149,759**	139,502
Grass/Pasture - Total	**4466**	**177,090**	271,476
Fallow	**615**	**21,460**	12,525
TOTAL MAPPED	**9844**	**503,570**	625,364

Note: Grass/pasture includes Oat Hay which was classified as a small grain in 1998

Accuracy Assessment

Parcels with different RGWCD and satellite crop classifications were re-examined. For 44 parcels, the seasonal response of the satellite images as well as the 2003 color photos were such that it appeared reasonably certain that the RGWCD classification was incorrect. On a parcel basis, this would indicate that RGWCD classifications were approximately 98.6% correct. In many cases, the parcel in question was actually a pie or portion of the field that appeared to be cropped differently than the rest of the field. Many of these field portions may not have been visible from the road or vantage point of the ground observer, but the remaining portion of the field was correctly identified. Therefore, the significance of the error in the RGWCD crop types is somewhat overstated. Many parcels were also noted as fallow by the RGWCD. However, spectral response in the tasseled cap greenness image indicated that the parcel may have been irrigated at least once. The satellite classification was used to describe a non-fallow crop type for these parcels. However, the accuracy assessment of 98.6% does not reflect these differences.

For parcels that were documented by the RGWCD, the crop type indicated by the imagery classification was compared to the crop type indicated by the RGWCD. Overall, the classified crop type matched the RGWCD crop type for 90% of the parcels. The crop classification was most successful at classifying potato crops (96%) and was least successful distinguishing alfalfa fields from grass/pasture and grain fields. The classification for sprinkler irrigated crops was more successful than for flood irrigated crops. In addition, the classification process struggled to correctly classify parcels that were poorly irrigated (grain, alfalfa, and grass/pasture).

Therefore, the accuracy of the crop classification is expected to be about 90% in areas not documented by the RGWCD and about 98.6% in areas documented by the RGWCD.

Task 4. Crop Water Use and Diversion

Consumptive Use Calculation

It was considered that the higher value crops of potatoes, small grains, and vegetables were not significantly shorted water in 2002. However, a large portion of alfalfa and grass/pasture crops, particularly those that rely on surface water, were only provided partial water supplies in 2002. The tasseled cap greenness image directly relates to the amount of healthy green biomass on a field. Except for when a hay crop is cut, tasseled cap greenness values also relate to the water supply that a crop has been provided prior to the image. Therefore, after classification of crop type, the apparent consumptive water use for alfalfa and grass/pasture crops was evaluated using the tasseled cap greenness images from the eight satellite images.

The median greenness value for each parcel and for each satellite image date was calculated. The median value was used rather than the average in order to avoid the influence of pixels at the edges of parcels that may appear less irrigated due to averaging within the 25m pixels. The maximum parcel greenness value from each monthly east west image pair was selected, as some parcels overlapped in both the east and west images and some did not, to provide four greenness values characterizing the first week of June, the second weeks of July and August, and the end of September.

The tasseled cap greenness images were examined in conjunction with ditch diversion records to evaluate levels of parcel water supply. The following set of images shows examples of sprinkler irrigated alfalfa fields along with the parcel's median tasseled cap value. It appeared that irrigations were recorded with median tasseled cap greenness values of about 96 to 100. Below, this value, it appeared that parcels were not irrigated. Parcels irrigated with a full water supply appeared to have median tasseled cap values of between 170 and 180. To be conservative (possibly slightly overestimating consumptive use), it was decided that a parcel would be considered irrigated if it had a median greenness value of 96 or greater, and the parcel would be considered to have a full water supply if it had a median greenness value of 160 or greater. The example images were taken from the June satellite image. Levels of irrigation versus greenness value appeared similar for the July and August images as the imagery was normalized. Response appeared slightly less in the late September image, and much less in the October image, but this lower response was more related to the curtailing of irrigations late season rather than an inconsistency in image normalization.

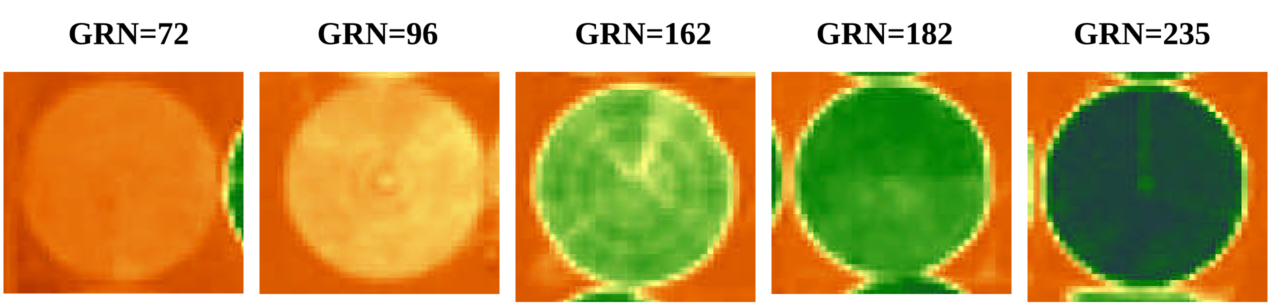


Figure 5. Median Tasseled Cap Greenness Values for Example Alfalfa Fields

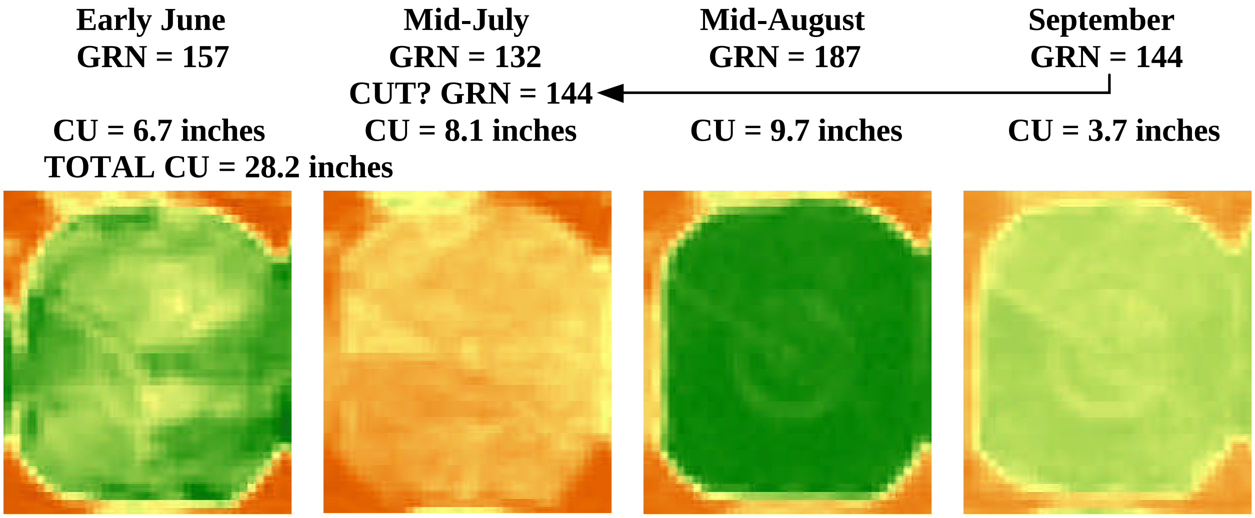
In order to calculate consumptive use and proportion available water supplies, each tasseled cap greenness image was used to represent irrigation supplies during the respective time period. The typical consumptive use pattern of a crop was portioned so that the June image pair represented the consumptive use from the beginning of the season to June 1, the July image from June 1 to July 15, the August image from July 16 to August 30, and the September/October images represented the consumptive use in September and October. The following table indicates the proportions of consumptive use attributed to each image pair. Limited water supplies were not considered for potatoes, grain, and vegetable crops; and consumptive use was calculated irrespective of tasseled cap greenness values. However, the consumptive use attributed to alfalfa and grass/pasture crops by image date was portioned according to greenness values. For median greenness values between 96 and 160, the consumptive use portion was linearly interpolated between an amount equal to about one irrigation and the full water supply amount. The full water supply amount was assigned for greenness values over 160, and zero consumptive use was assigned for values less than 96.

Table 5. Consumptive Use in Inches by Image Date and Tasseled Cap Greenness Value

Image Date	Diversion Considered	Potatoes NA	Grain NA	Canola NA	Carrots NA	Lettuce NA	Alfalfa and Grass/Pasture GRN< 96	= 96	>= 160
Early June	Mar,Apr,May	1	3.5	2	1	1	0	0.75	7
Mid-July	June, ½ July	7.5	9	10	7	9	0	1	10.5
Mid-Aug	½ July, Aug	7.5	5.5	6	7	4	0	1	9.7
Sept/Oct	Sept, Oct	0	0	0	1	0	0	0.5	4.8
Total		16	18	18	16	14	0	3.25	32

Note: For alfalfa and grass/pasture, CU linearly interpolated between median greenness of 96 and 160

Tasseled cap greenness values are not representative of crop consumptive use if the satellite image was taken while hay was cut. In order to attempt to resolve potential problems with hay cuttings, the minimum greenness value was replaced with the next smallest greenness value prior to the calculation of consumptive use for the parcel. The October tasseled cap image had lower greenness values than the late September image. The eastern September image did not cover the northwestern portion of Division 3, so the lower October values did slightly lower consumptive use estimates in this area. Therefore, for hay cuttings, the minimum greenness value in the June, July, and August image was replaced with the next smallest value from these images where the September image was not available, while all four images were considered where the September image was available. This had the effect of slightly raising consumptive use estimates in the northwestern portion of the study area to levels similar to the rest of Division 3. The following figure provides an example of the calculation of consumptive use of an alfalfa field in which it appears that the field was cut during one of the images. The September image was available, so the minimum values of all four images were considered. A table also follows that presents the acreages of alfalfa and other hay and pasture crops by ranges of consumptive use that were calculated from the tasseled cap greenness values.



Note: "GRN" = median value of tasseled cap greenness image within parcel boundary

Figure 6. Example Calculation of Total Consumptive Use for an Alfalfa Field

Table 6. Acreages of Alfalfa and Other Hay Crops by Calculated Consumptive Use

CROP	PARCELS	ACREAGE	1998	AG. STATS*
Alfalfa – Total	**3238**	**149,759**	139,502	
Alfalfa - Irrigated	**3055**	**145,761**		134,000
Consumptive Use = 30-32 inches	111	9,355		
Consumptive Use = 24-30 inches	681	55,610		
Consumptive Use = 16-24 inches	729	35,852		
Consumptive Use = 8-16 inches	873	27,656		
Consumptive Use = 0.5-8 inches	661	17,287		
not irrigated	183	3,998		
Grass/Pasture - Total	**4466**	**177,090**	271,476	
Grass/Pasture - Irrigated	**3041**	**94,168**		86,000
Consumptive Use = 30-32 inches	2	23		
Consumptive Use = 24-30 inches	9	261		
Consumptive Use = 16-24 inches	152	3,708		
Consumptive Use = 8-16 inches	878	21,537		
Consumptive Use = 0.5-8 inches	2000	68,640		
not irrigated	1425	82,922		
TOTAL MAPPED ALL CROPS	**9844**	**503,570**	625,364	
TOTAL IRRIGATED ALL CROPS	**7621**	**395,190**	612,839	
TOTAL IRRIGATED ALL CROPS[2]	**7527**	**393,822**	612,839	

Note: *sum of agricultural statistics for all counties; Ag. stats for Grass/Pasture includes oat hay
[2]includes only parcels with surface or ground water source identified in water use analysis

The majority of alfalfa fields appeared to have had between 24 and 30 inches of consumptive use while the large majority of grass/pasture fields indicated less than 8 inches of consumptive use. Although the average consumptive use for grass/pasture parcels is alarming, the comparison is reasonable as many alfalfa fields have groundwater supplies or are a priority for available surface water supplies while other hay and pasture fields often only have surface water supplies. As indicated in the table, the water supply analysis indicated a number of mapped alfalfa and grass/pasture parcels that were probably not irrigated. Therefore, the analysis indicates that only about 395,190 acres of all crops were irrigated in the San Luis Valley; compared to about 612,839 acres indicated by the irrigated lands assessment in 1998. This would indicate that about 217,649 acres were not irrigated in 2002 due to the extreme drought. The amount of alfalfa and other hay crops reported by the Colorado Agriculture Statistics for year 2002 are also presented in the table. The Agricultural Statistics acreages should be compared to the irrigated acreages of the respective crop rather than total mapped areas. The statistics indicate slightly lower acreages (about 10,000 acres) than determined by the water use analysis, but are quite close. The overestimate may include acres that were poorly irrigated and did not produce hay. Table 5 also lists total irrigated acres without fields for which surface or ground water sources could not be identified. The majority of these fields were grass/pasture fields (1164 acres).

Assignment of Ditch Service Areas

A ditch service area coverage was developed in GIS as part of the 1998 RGDSS. This coverage was developed using USGS topographic maps (digital raster graphics – DRG), so area boundaries are relatively rough. The ditch coverage was adjusted slightly in several areas using the 1m aerial photography when boundaries and boundary problems were apparent. Ditch diversion records that were being referenced as part of the water use supply analysis also indicated several larger changes in ditch service areas. For instance, the Montoya Ditch (200757) was drawn with a service area of 277 acres while the reported acreage in 1998 was 50 acres. The ditch headgate and canal could be observed on the aerial photography, and redrawing the service area to the area that could be served by the canal produced a new service area of 66 acres. Several new ditches were also drawn that were not included in the 1998 RGDSS to serve areas of clearly irrigated parcels using the legal headgate location and indications of canals in the aerial photography. The new service areas should be considered approximate. However, the 1998 RGDSS used groundwater to service some of these areas, and it was apparent that wells were not located in some areas. Consequently, the assignment of available surface water was deemed preferable to a false assignment of groundwater.

In order to assign ditch service to irrigated parcels, the 2002 parcel theme was spatially unioned with the ditch coverage. As the ditch coverage theme contains slight boundary deviations, the boundaries of the ditch areas often slightly overlap small portions of parcels that are probably not in the service area or may not completely cover a parcel that is in the service area. Therefore, coverage of more than 90% or less than 10% of a parcel was rounded to a ditch coverage of 100% and 0%, respectively. Many ditch service areas overlap and create multiple coverages of all or portions of an irrigated parcel. To avoid double-counting acreage, the fractional coverage by each ditch was calculated for each parcel. The process used to calculate these fractions was identical to that used for the 1998 RGDSS irrigated lands assessment. For each parcel, the amount of acres covered by each ditch was summed along with any irrigated acreage not covered by any ditch. Then, the area covered by each ditch was individually divided by this sum to calculate the fractional coverage for each ditch. For example, if two ditches covered a parcel, than each ditch would have a 50% fractional coverage. This represents the fraction of the parcels water requirements supplied by each ditch. The fractioning is based purely on spatial coverage rather than any sort of primary versus supplemental source information on a particular parcel.

Ditch diversion records for year 2002 from the state's Hydrobase database were associated with the service areas prior to the water supply analysis. Several ditch service areas represent an aggregate of several diversion rights, and separate ditch diversion records were summed for aggregate ditch areas. Many ditches listed small diversion amounts for 2002, but water commissioner comments indicated that no water reached farm headgates or that ditch water was used for stock water use only. In this case, the listed diversions were replaced with zero. Several ditches north of the Rio Grande direct the majority of their diversion to ground water recharge rather than to crop irrigation. The Rio Grande Canal was the only northern ditch that recorded a diversion in 2002. The manager of the Rio Grande Canal Water Users Association estimated that 80% of canal diversions were directed to recharge. Therefore, 80% of the Rio Grande Canal diversion was made available to fill crop water needs in the water use analysis.

Assignment of Groundwater Well Service

As part of the 1998 irrigated parcel data set, the state developed a database relating the legal location of permits for agricultural wells to irrigated parcels that could potentially be served by the wells for the 1998 irrigated parcel data set. As parcels were redrawn in 2002 and many parcel boundaries changed, assignments of wells to irrigated parcels had to be recreated for year 2002. The well assignment methodology used for the 1998 data set was followed to create an initial well assignment database. However, following the methodology based assignment; an extensive manual evaluation of the well assignments was conducted using additional resources that were available for the 2002 data set.

The procedure that was used is outlined below. Steps 1 through 6 are identical to the criteria used for the 1998 RGDSS except that flood parcels were only assigned if water use was indicated by the satellite imagery. The specified distance of 0.25 mile or 1320 feet for well proximity was specified by the state. Only wells with a yield of at least 50 gpm and a use designation of irrigation were considered.

1. Where an irrigation well is located within a sprinkler irrigated parcel or within a flood irrigated parcel that has at least minimal water use indicated by tasseled cap satellite greenness images, assign the well to that parcel.

2. When an irrigation well is not assigned in Step 1 above, but is located within 0.25 mile of a parcel served by a sprinkler, assign the well to that parcel.

3. When an irrigation well is not assigned in Steps 1 or 2 above, but is located within 0.25 mile specified distance of a flood irrigated parcel with at least minimal water use indicated by the satellite imagery, assign the well to that parcel.

4. If a center-pivot field is planted with two or more crops resulting in a separate parcel for each crop, assign all wells associated with adjacent portions so that all portions of a complete pivot circle are each served by the same well or wells.

5. For lands irrigated by a sprinkler but not assigned a well in steps 1 through 4 above, assign the closest nearby well with 5 miles.

6. Wells that were manually assigned to parcels from interviews with growers as part of the 1998 RGDSS data set were replicated where still appropriate. Wells assignments that were noted as deleted as a part of grower interviews were deleted when the assignments were still reproduced given the preceeding methodology.

7. All previous well assignments were manually evaluated using an extensive examination of aerial photography and satellite imagery, use of field knowledge of actual well locations and usage from experience with selected clients of Agro Engineering, and results of the water use analysis to distribute available surface water on a parcel by parcel basis.

As mentioned in step 7, the well assignments were evaluated extensively using the additional data that was available in 2002. For many areas that did not have ditch diversions in 2002, well coverage was extended to additional flood irrigated parcels that appeared sufficiently irrigated in the satellite imagery. Well coverage was generally extended or adjusted in the general downslope direction for the area, and many assignments that indicated upslope flow were replaced with downslope assignments. Well coverage was generally deleted for flood parcels that did not appear irrigated. Several areas of sprinklers under senior ditches are known to be served only by surface water rather than wells, so well assignments for these sprinklers were deleted. Well assignments for sprinklers that were not irrigated and did not have a well within the quarter section were generally deleted. In addition, well assignments that crossed roads, large ditches, rivers, streams, or section or quarter section boundaries were generally deleted if the sprinkler was already served by an appropriate well in the same quarter sections or if there were positive indications that the parcel was served entirely by surface water that was available in 2002. Following the parcel by parcel water use analysis, well assignments were extended to parcels for which the satellite imagery indicated consumptive use that was greater than what available ditch diversions could accommodate so long as an appropriate well was located nearby. A GIS layer was produced that details well to parcel matches.

Surface and ground water sources were not identified for 201 parcels. Many of these parcels may be served by an unidentified water source, but the consumptive use analysis indicated little or no water use for the majority of these parcels in 2002. As the RGDSS models require a water source be identified for all parcels, these parcels were deleted in the final GIS coverage.

Calculation of Water Use and Diversion

A computer program was written to calculate water use and diversion for year 2002. The model methodology is similar to the StateCU model used by the RGDSS except that calculations are maintained on a parcel by parcel basis, consumptive use for alfalfa and grass/pasture crops is variable and based on the tasseled cap greenness images, and water use and diversion is compared for 4 periods corresponding to the dates of the satellite imagery. Water efficiency assumptions were made identical to the RGDSS assumptions; a conveyance efficiency of 60% was assumed for losses in all canals, and 50% and 80% application efficiencies were assumed for flood and sprinkler irrigation systems, respectively.

The program begins by calculating consumptive use for each parcel given the methodology described earlier. The diversion requirements for each parcel are calculated by dividing the indicated consumptive use by the appropriate application efficiency. Then, for each ditch service area and for each of the four image periods, the program subtracts conveyance losses and progressively assigns available surface water to groups of parcels in the following priority: 1) sprinkler irrigated parcels with no wells, 2) flood irrigated parcels with no wells, 3) flood irrigated parcels with wells, and 4) sprinkler irrigated parcels with wells. If sufficient surface water is available during the image period for a parcel group, water is portioned to fulfill the diversion requirement for each parcel. However, if there is not sufficient water to fill the needs of all parcels in a group, then parcel diversion requirements are multiplied by the ratio of available surface water to the total diversion requirement of the parcel group. From diversion records, the amount of surface water available for each image period was calculated by summing the recorded diversions for the months represented by the image as detailed in Table 5. Diversions from November through February were not considered in this amount. Following allocation of available surface water, parcels that have wells but do not receive sufficient surface water to meet diversion needs are allocated ground water to fill remaining demand. The following figure shows a schematic of how surface and ground water are allocated in the computer program.

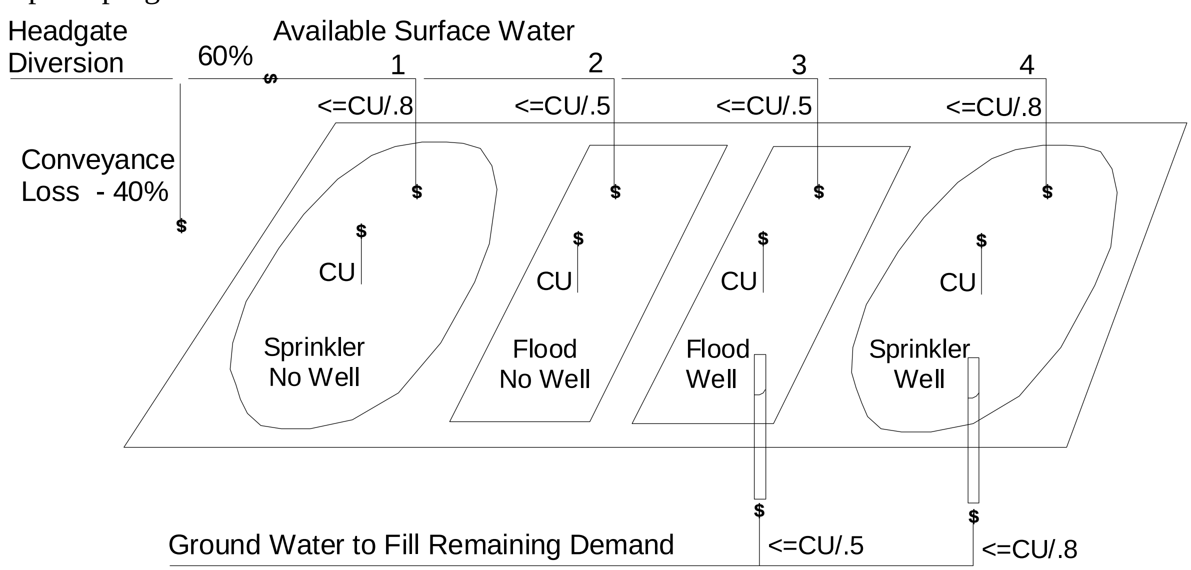


Figure 7. Model schematic for surface and ground water allocation

Fractional ditch coverages were handled by initially assigning only a percentage of the parcels diversion demand less than or equal to the fractional coverage of the ditch depending on if sufficient surface water was available. In year 2002, many ditches did not divert any surface water. The fractional coverages are potentially problematic in modeling if, for example, a fractional coverage by a ditch with no water prevented available surface from another ditch from fulfilling the water requirements of the parcel (i.e. 50% rather than 100%). To overcome this, a second pass was enacted to reassign additional surface water to a parcel if one ditch did have additional available surface water but the other ditches servicing the parcel had not provided sufficient water to fulfill the parcel's water need.

Following the model calculations, files were produced that summarized water use for each parcel as well as for each ditch system. Iterations of the model allowed fine tuning of tasseled cap greenness values versus consumptive use, improvements to the ditch service areas, and identification of additional parcels that were likely served by groundwater.

Results of Water Use Analysis

In order to summarize model results by area, Division 3 was divided into general hydrologic areas as shown in the following figure. The hydrologic areas were defined so as to not divide ditch service areas and do not correspond exactly to water district boundaries.

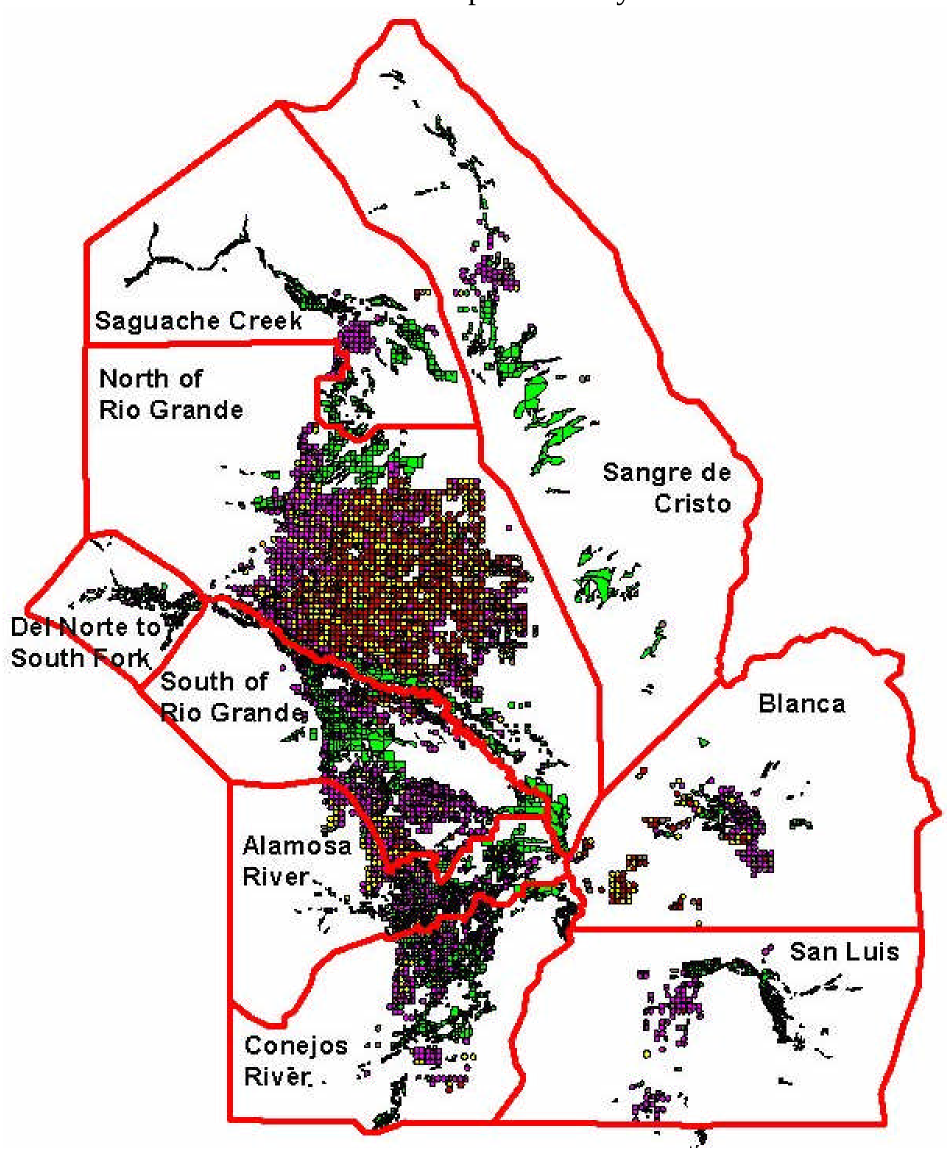


Figure 8. Hydrologic Areas Defined to Summarize Water Use Analysis

The following table summarizes the water use analysis results for each of the hydrologic zones. Water use amounts are summed for each ditch as well as groundwater only areas within each zone. The “2002 irrigated acres” includes only parcels that were determined to be irrigated by the water use analysis. In certain cases, the consumptive use indicated by the tasseled cap imagery analysis was more than could be provided by available surface water diversions assuming the 60% standard conveyance loss. The column “CU Supplied” only details that consumptive use that could be filled given available water sources, while “CU Deficit” indicates the amount of consumptive use that could not be filled. This “CU Deficit” could potentially indicate that additional water was withdrawn from soil moisture or from high water tables or “sub” near water courses, or could potentially be due to ditches that have less conveyance loss than assumed; particularly for ditches with short distances between the diversion point and place of use. Therefore, this deficit could potentially be considered as additional consumptive use beyond the “CU Supplied” value. The “Diversion minus CU” column adds 10% to the “CU Supplied” and subtracts this amount from the 2002 diversion amount. The 10% was added to account for potential evaporation in irrigation application. Therefore, as a sprinkler irrigation system has an 80% application efficiency, this would assume that 10% of the water not used for crop water needs evaporates and the other 10% percolates. The “Diversion minus CU” value is an estimate of the total amount of water in the hydrologic area that was withdrawn from the aquifer systems. The sum of average diversions for all ditches within the areas for all diversion records contained in the state’s Hydrobase database between 1950 and 2002 are included for comparison. It should be noted that if a diversion record was not provided for a ditch between its first year of record and 2002, it was assumed that the ditch did not divert water in that year. The irrigated acres in each zone mapped by the 1998 RGDSS irrigated lands assessment is also included as a reference for a more normal irrigation year.

Table 7. Summary of water use analysis for hydrologic zones.

AREA	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
Saguache Creek	39955	32442	7799	15721	1717	18566	13450	1065	(6996)
North of Rio Grande	345990	265922	54528	187736	9010	333613	270873	1514	(243432)
Del Norte to South Fork	39222	11650	15567	5852	4470	1508	3561	2048	11650
South of Rio Grande	185741	114845	63537	57372	19863	88306	76770	2544	(20910)
Alamosa River	101508	82494	17732	28776	6139	48785	36365	2479	(22270)
Conejos River	217889	108119	49543	37158	16994	40395	38113	2325	7618
San Luis	61390	25004	33842	14643	15788	10722	19018	1198	12922
Blanca	40247	29728	8078	20518	3635	34465	29112	102	(23945)
Sangre de Cristo	51420	42830	13809	14306	1680	12931	10721	958	2016
TOTAL	1083360	713034	264436	382082	79296	589290	497984	14233	(283347)

Note: 2002 Diversion between March and October; Diversion minus CU adds 10% to CU for evaporative losses

The following figures detail the results of the water use analysis by parcel for regions of Division 3. Crop types and the consumptive use “demand” from the analysis of the greenness images are indicated with colors; and labels indicate the consumptive use “supplied” as determined by the water use analysis. Wells and parcels identified with groundwater diversion are also noted. Water use results are summarized by ditch for each hydrologic area in Appendix C.

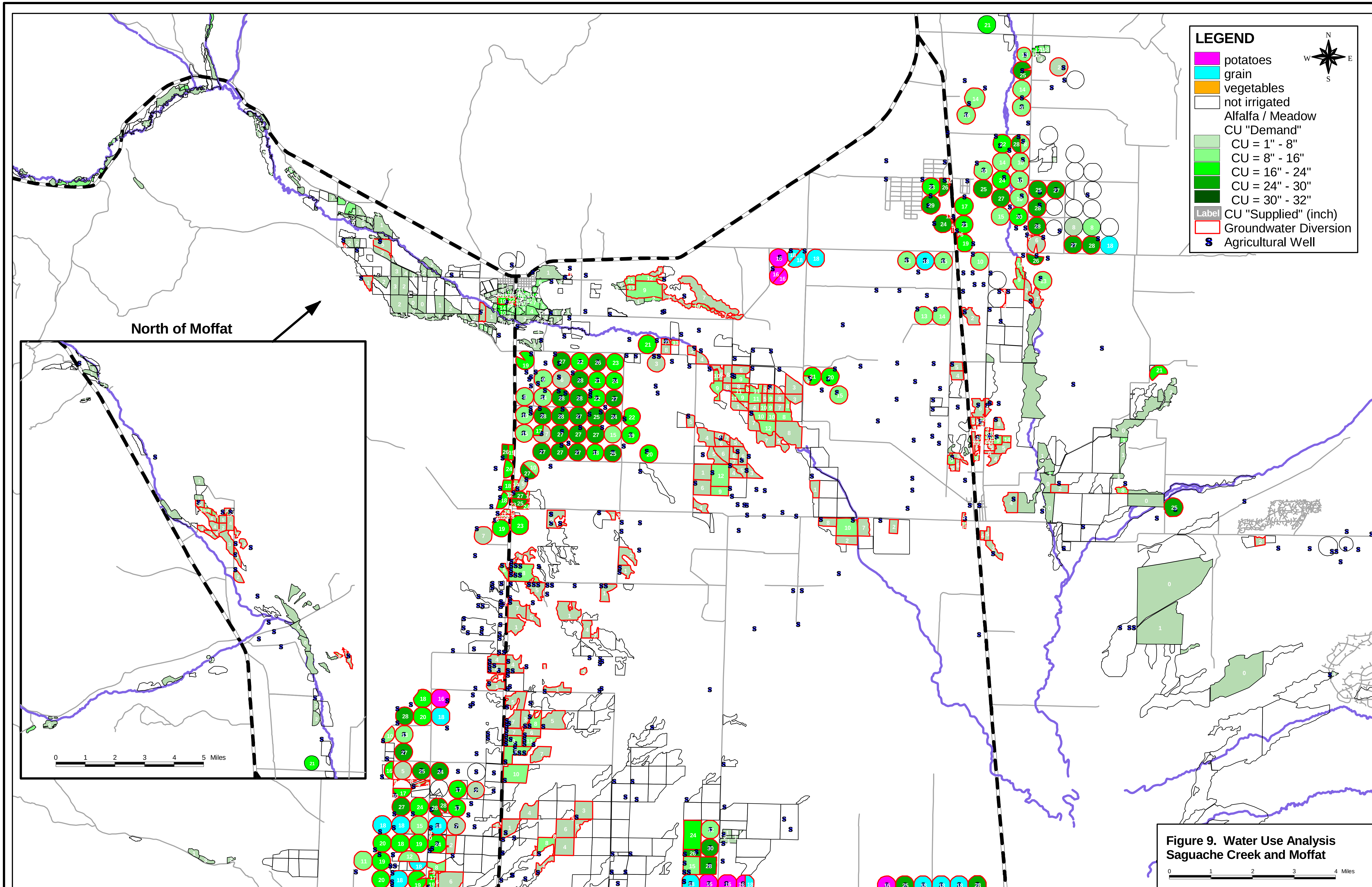


Figure 9. Water Use Analysis
Saguache Creek and Moffat

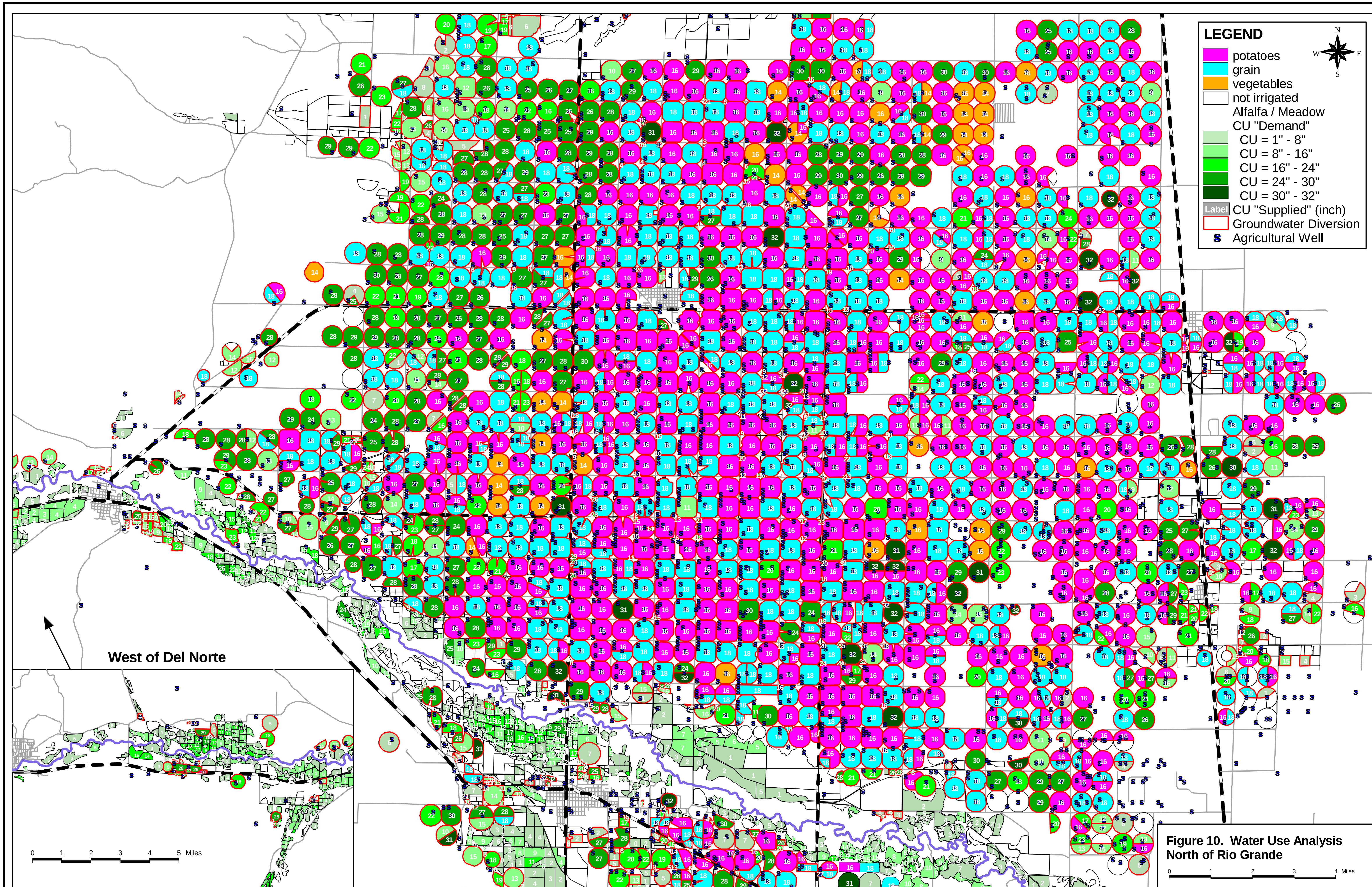


Figure 10. Water Use Analysis North of Rio Grande

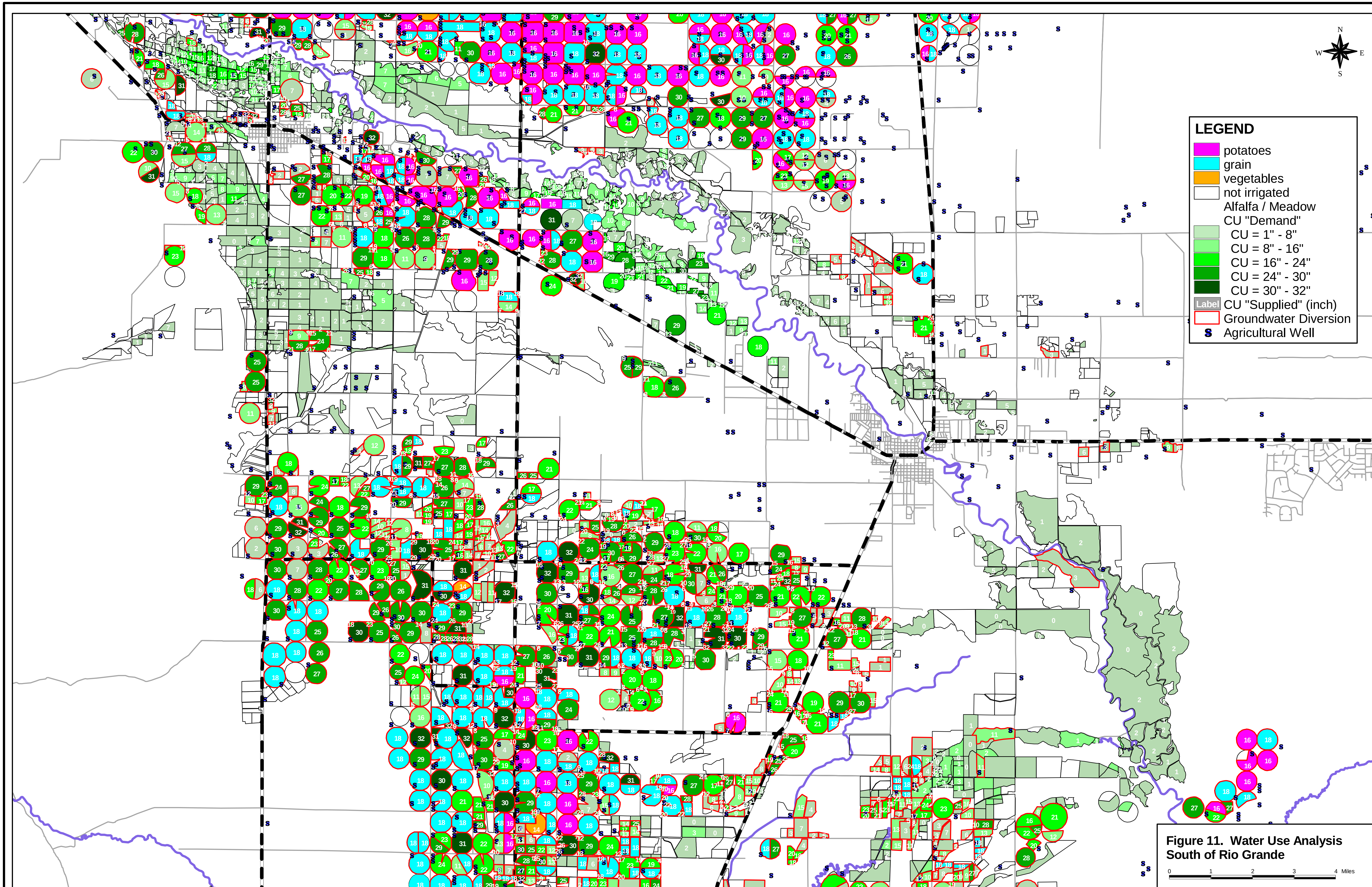


Figure 11. Water Use Analysis South of Rio Grande

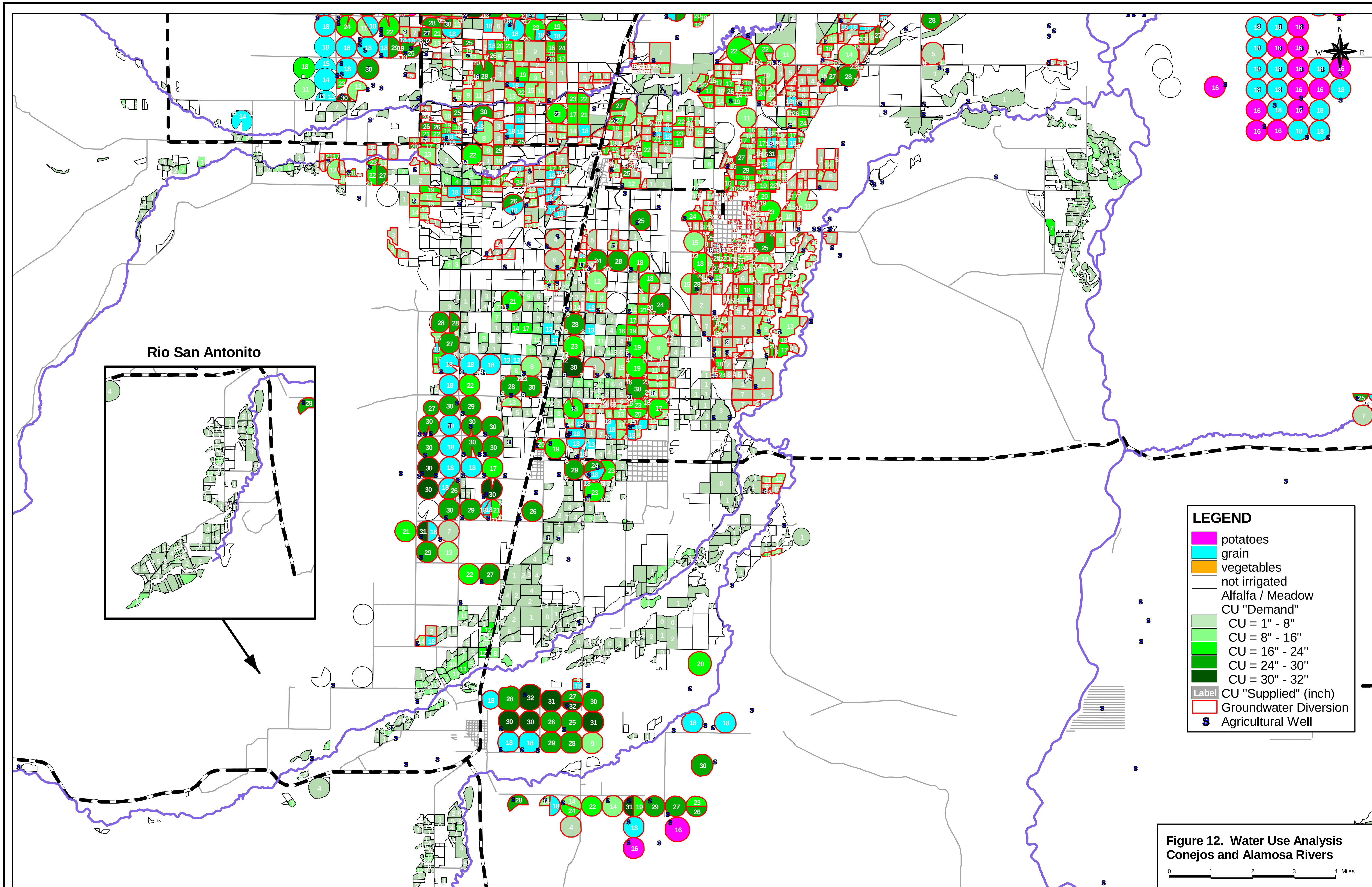


Figure 12. Water Use Analysis Conejos and Alamosa Rivers

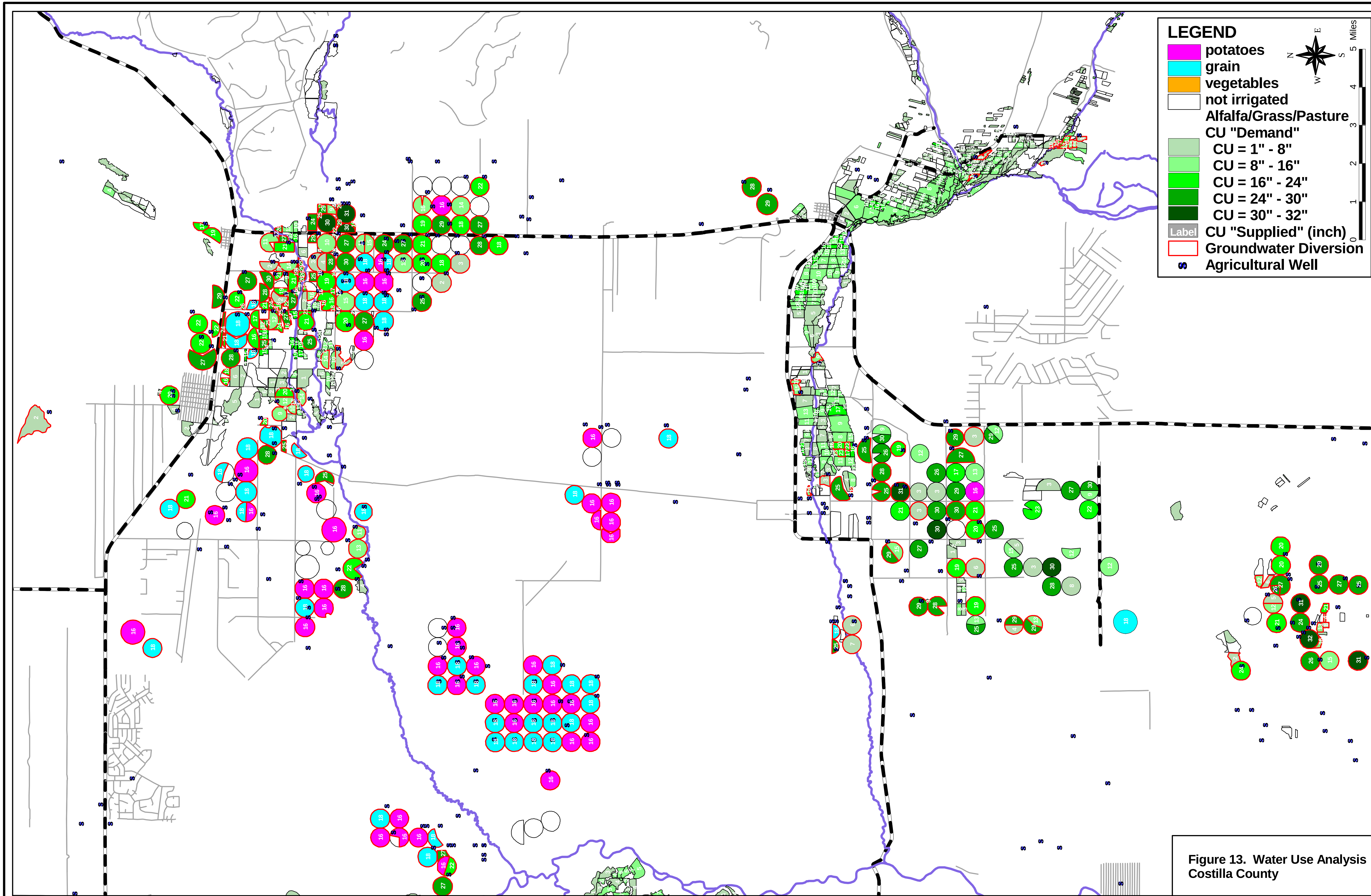


Figure 13. Water Use Analysis
Costilla County

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APPENDIX A

Landsat Satellite Information

The Landsat 5 satellite was launched on March 1, 1984. Although the Landsat 5 satellite was not designed for its current lifespan and slight sensor degradations have occurred, the Landsat 5 sensor is still providing good quality multi-spectral imagery. Unfortunately, Landsat 6 failed shortly after launch. The Landsat 7 satellite was launched on April 15, 1999. Unfortunately, the Landsat 7 satellite sensor failed in May 2003 and is currently providing poor quality imagery. However, fortunately, during the study period of the summer of 2002, high quality imagery is available from both the Landsat 5 and Landsat 7 satellites.

The Landsat 5 satellite provides multi-spectral imagery from its Thematic Mapper (TM) sensor. The TM sensor has 7 multi-spectral bands with an initial pixel resolution of about 30 meter (except for the thermal band with a 60m resolution). The Landsat 7 satellite has an improved sensor called the Enhanced Thematic Mapper (ETM+) sensor. The ETM+ sensor measures the same 7 bands as the TM sensor, but also measures an additional panchromatic band at a higher 15 m resolution. The following table details information about the Landsat TM and ETM+ bands.

Table A.1.1 Landsat TM and ETM+ bands

Band	Color	Wavelength (nanometers)	Resolution (meters)
1	Blue	450- 515	30
2	Green	525-605	30
3	Red	630-690	30
4	Near Infrared	750-900	30
5	Mid Infrared	1550-1750	30
6	Thermal Infrared	10400-12500	60
7	Mid Infrared	2090-2350	30
8 ETM+	Panchromatic	520-900	15

Both satellites are in sun-synchronous orbits at an altitude of 705 km (438 miles). The satellites orbit the earth every 98.9 minutes, making fourteen revolutions around the earth each day. This orbit gives each satellite worldwide coverage as it repeats its path cycle every 16 days.

APPENDIX B

Tasseled Cap Transformation

For Landsat data, TC transformations have been developed based both on digital number (DN) directly from TM data and on a reflectance factor. The DN approach does not account for changing reflectance due to atmospheric or illumination geometry effects, and therefore is not favorable for the comparison between image dates or over large areas. Reflectance factor transformations have been developed for full atmospherically corrected images using ground measurements. Atmospheric correction algorithms have been developed to approximately correct images in the absence of ground measurements. However, in a USGS study, Huang et al. (2002) found that the majority of spectral differences in clear, cloud-free images are due to the sun illumination geometry component. Therefore, in the absence of accurate atmospheric measurements with clear images, Huang et al. recommended a methodology for the use of an at-satellite reflectance factor that accounts for illumination geometry but not full atmospheric correction. Huang et al. studied 2000 sample areas in 10 Landsat 7 ETM+ scenes, and found that the at-satellite reflectance approach produced greenness values that were orthogonally independent to corresponding brightness values; and greenness, moistness, and brightness bands represented over 97% of the spectral variation in the imagery (3 other PCA bands are produced but are generally meaningless). Therefore, the Huang et al. at-satellite reflectance factor approach appeared to be the most appropriate approach for the current study. Huang et al. (2002) proposed the following TC coefficients for use with at-satellite reflectance values.

Table A1. Tasseled cap coefficients for at-satellite reflectance

Index	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Greenness	-0.3344	-0.3544	-0.4556	0.6966	-0.0242	-0.2630
Brightness	0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
Moistness	0.2626	0.2141	0.0926	0.0656	-0.7629	-0.5388

Chander and Markham (2003) and Irish (2000) detail the methodology and sensor data to convert Landsat data to at-satellite reflectance. DN data is first converted to an at-sensor radiance to account for variable sensor sensitivity. The following formula converts Level 1 corrected Landsat data to a spectral radiance (L) in Watts / (square meter*ster*µm) for each band (?) using the calibrated sensor spectral radiance that is scaled to the max and min DN numbers.

$$L_l = \left(\frac{L\max_l - L\min_l}{255} \right) DN + L\min_l$$ (Chander and Markham 2003)

Spectral radiance can then be converted to an at-satellite reflectance (or planetary reflectance) by normalizing for solar irradiances arising from spectral band differences. The following equation calculates planetary reflectance (p) using the earth-sun distance in astronomical units (d), mean solar exo-atmospheric irradiances (ESUN), and the solar zenith angle (?) in degrees.

$$p_l = \frac{p \ L_l \ d^2}{ESUN_l \ \cos(q)}$$ (Chander and Markham 2003)

The following table lists the values of mean solar exo-atmospheric irradiances (ESUN) that were used for the Landsat 7 ETM+ sensor (Irish 2000) and Landsat 5 TM sensor (Chander and Markham 2003).

Table A2. Mean solar exo-atmospheric irradiances (ESUN)

Band	ESUN L7 ETM+ W/(m^2*µm)	ESUN L5 TM W/(m^2*µm)
1	1969	1957
2	1840	1826
3	1551	1554
4	1044	1036
5	225.7	215
7	82.07	80.67

Files with the Landsat 7 ETM+ imagery provided values of Lmin, Lmax, and sun angle. For the Landsat 5 TM image, current accepted values of Lmin and Lmax were taken from Chander and Markham (2003), and the sun angle was determined by use of an archive file from the USGS (USGS 2001). The earth-sun distance was determined by interpolation from a table contained in Irish (2000). The following table details data that were used for converting the study images to values of at-satellite reflectance.

Table A3. Data used for conversion to at-satellite reflectance

Image Date	05/31/02	06/07/02	07/09/02	07/18/02	08/10/02	08/11/02	09/20/02	10/13/02
Lmin B1	-6.2	-6.2	-6.2	-6.2	-6.2	-1.52	-6.2	-6.2
Lmax B1	293.7	191.6	191.6	293.7	191.6	193	293.7	191.6
Lmin B2	-6.4	-6.4	-6.4	-6.4	-6.4	-2.84	-6.4	-6.4
Lmax B2	300.9	196.5	196.5	300.9	196.5	365	300.9	196.5
Lmin B3	-5	-5	-5	-5	-5	-1.17	-5	-5
Lmax B3	234.4	152.9	152.9	234.4	152.9	264	234.4	152.9
Lmin B4	-5.1	-5.1	-5.1	-5.1	-5.1	-1.51	-5.1	-5.1
Lmax B4	241.1	241.1	241.1	241.1	241.1	221	241.1	157.4
Lmin B5	-1	-1	-1	-1	-1	-0.37	-1	-1
Lmax B5	47.57	31.06	31.06	47.57	31.06	30.2	47.57	31.06
Lmin B7	-0.35	-0.35	-0.35	-0.35	-0.35	-0.15	-0.35	-.35
Lmax B7	16.54	10.8	10.8	16.54	10.8	16.5	16.54	10.8
Sun Elev	64.9882	65.3281	63.8768	62.7971	58.9605	58.4	48.3755	41.0121
GMT	17:00	17:00	17:00	17:00	17:00	16:45	17:00	17:00
d	1.01364	1.01464	1.0166	1.01631	1.01385	1.0137	1.00513	0.99859

APPENDIX C

Results of Water Use Analysis by Ditch Grouped by Hydrologic Area

Saguache Creek Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
		Groundwater Only Areas	0	7980	0	7776	0	12788	9606	0	(10566)
260501		Ashley Proffitt Ditch	1776	618	248	97	17	0	9	0	238
260504		Baxter Creek D 3	48	6	0	0	0	0	0	0	0
260505		Big Meadow Ditch	1617	1521	667	470	148	0	68	49	592
260506		Braun Brothers Ditch 1	408	241	3	248	2	332	167	0	(180)
260510		Campbell Ditch #4	86	131	0	184	0	216	108	0	(119)
260511		Campbell Ditch #5	171	421	0	423	0	648	324	0	(356)
260514		Carruthers	211	137	0	0	0	0	0	38	0
260517		Chase Peyton	751	156	323	2	4	0	2	0	321
260519		Commodore	251	135	12	2	0	0	0	0	12
260531		Elwes D #2	204	73	6	39	4	0	2	33	4
260533		Farrington D #1	109	61	0	0	0	0	0	11	0
260535		Florence Ditch	413	250	118	163	28	60	44	25	70
260536		Ford Creek	138	8	0	0	0	0	0	0	0
260537		Ford D	205	285	0	0	0	0	0	10	0
260538		Ford D 1 and 2	989	289	406	49	53	0	27	0	377
260539		Friese D #1	393	97	29	25	11	0	4	13	24
260540		Friese D #2	44	26	0	0	0	0	0	2	0
260542		Fullerton Ditch 1	763	553	63	268	38	0	19	99	43
260543		Fullerton Ditch 2	64	104	0	0	0	0	0	0	0
260545	A	George Ball Ditch	585	1449	0	1027	0	1157	578	0	(636)
260548		Gotthelf Ditch 1	1575	239	592	68	13	0	8	20	583
260551		Harence D 1	105	45	0	0	0	0	0	1	0
260552		Harence D 2	9	4	0	0	0	0	0	0	0
260553		Harence D 3	8	11	0	0	0	0	0	0	0
260557		Hawkins	470	112	171	60	71	0	35	12	132
260559		Hearn Ditch	850	551	132	255	79	339	293	0	(191)
260561		Hodding D 1	199	11	0	0	0	0	0	0	0
260562		Hodding D 2	7	24	0	0	0	0	0	0	0
260563		Hodding D #3	82	20	0	0	0	0	0	23	0
260564		Hodding D #5	178	49	0	0	0	0	0	0	0
260569		I. L. Gotthelf	229	45	0	0	0	0	0	59	0
260570		Irwin Ditch	277	154	0	11	0	0	0	80	(0)
260571		Jacques D	101	152	75	5	4	0	1	0	73
260572		Jays D	152	0	0	0	0	0	0	0	0
260574		Jeep Scandrett Ditch	291	286	0	0	0	0	0	0	0
260583		Laughlin Ditch	78	96	0	0	0	0	0	1	0
260584		Lawrence Ditch 3	1056	243	157	14	16	0	2	0	155
260586		Luders D1	127	185	0	0	0	0	0	22	0
260587		Luders D 2	6	197	0	0	0	0	0	22	0
260590		McCree	428	123	0	0	0	0	0	56	0
260591		Malone Ditch	603	158	338	121	136	0	74	41	257
260592		Malone Sullivan	2773	542	1235	432	587	140	346	73	854
260601		Middle Ditch	264	107	0	0	0	0	0	22	0
260602		Miely D	17	na	0	0	0	0	0	0	0
260603		Mill Ditch	76	55	0	0	0	0	0	0	0
260605		Monk D #1	281	170	0	0	0	0	0	26	0
260607		Monk D #2	97	171	0	0	0	0	0	38	0
260609		Morrison Ditch	640	159	0	0	0	0	0	0	0
260610		Moses Goff Ditch 1	575	187	28	0	0	0	0	0	28
260611		Moses Goff Ditch 2	290	70	0	49	0	8	4	0	(4)
260613		Mountfield Ditch	704	334	210	80	14	0	7	0	202
260614		Munro D #1	243	122	0	0	0	0	0	26	0
260615		Munro D #2	145	115	0	17	0	0	1	4	(1)
260616		Nehls Company Ditch	216	235	8	221	5	293	149	0	(156)
260621	A	Oklahoma Co. Ditch	2881	5100	153	563	92	452	272	0	(146)

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Saguache Creek Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
260623		Phillips Ditch #1	144	na	0	0	0	0	0	0	0
260625		Piquet D #1	259	85	0	0	0	0	0	44	0
260628		Piquet D #13	86	96	19	5	1	0	0	1	18
260634		Piquet D #3	0	68	0	0	0	0	0	0	0
260637		Piquet D #7	59	155	0	0	0	0	0	5	0
260639		Piquet D #9	22	46	7	0	0	0	0	0	7
260648		Proffitt Company Ditch	727	270	28	1	0	0	0	0	28
260649		Proffitt McDonough Ditch	302	70	0	0	0	0	0	0	0
260650		Quartet Ditch	1131	706	145	970	87	1192	644	29	(564)
260653		Reservoir Enlargement Ditch	1970	280	569	76	11	0	5	0	563
260654		Roberts Company Ditch	272	320	0	306	0	428	214	0	(236)
260655		Russell Company Ditch	263	274	2	21	1	0	2	0	0
260658	A	Russel Ditch 4	1096	548	475	164	38	0	19	28	454
260667		Seitz Mc Clure Ashley	210	45	0	0	0	0	0	0	0
260669		Sheep Cr D	209	97	0	0	0	0	0	14	0
260675		Slane Scandrett Ditch	361	333	0	0	0	0	0	0	0
260677	A	Star Ditch	2155	1365	711	480	141	55	98	59	604
260680		Stubbs Gallegos Ditch	885	453	12	136	8	0	16	0	(5)
260682		Taylor A Ashley Ditch	247	148	0	58	0	35	18	0	(19)
260686		Tuttle Creek	28	12	0	0	0	0	0	0	0
260690		Van Allen Ditch	233	144	374	16	17	0	4	0	370
260691		Wall Ditch	595	462	96	118	0	42	34	0	59
260692		Ward Highline Ditch	454	286	21	50	12	0	5	19	15
260694		Werner B	305	na	0	0	0	0	0	0	0
260695		Werner Clark	261	na	0	0	0	0	0	0	0
260697	A	Woodard Brothers Ditch	806	419	101	174	61	0	40	49	57
260706		Farrington D #2	89	29	0	9	0	0	1	7	(1)
260707		Fullerton Ditch 3	427	154	54	65	20	3	11	0	41
260789		Hougland	25	73	0	0	0	0	0	1	0
260790		Paradise Valley D #1	71	31	0	0	0	0	0	0	0
260791		Paradise Valley D #2	43	4	0	0	0	0	0	0	0
260796		Cordova D	36	49	0	0	0	0	0	0	0
260821		Cotton D	18	9	0	0	0	0	0	0	0
260822		Hour Ditch	30	9	0	0	0	0	0	0	0
260823		Upper D	43	10	0	0	0	0	0	0	0
260824		West Ditch	14	4	0	0	0	0	0	0	0
260827		Joe Alexander Overflow	221	178	75	0	0	0	0	0	75
260829		Glenn Alexander Overflow	190	na	136	0	0	0	0	0	136
261102		Ortega 1A	21	6	0	0	0	0	0	0	0
261103		Ortega D 4	16	4	0	0	0	0	0	0	0
261109		Ortega 1B	0	2	0	0	0	0	0	0	0
261110		Ortega D 2	16	23	0	0	0	0	0	0	0
261111		Ortega D 3	13	4	0	0	0	0	0	0	0
270604		Navin D	202	346	0	272	0	277	139	0	(152)
270605		Crow Ditch	137	212	0	130	0	99	50	0	(55)
		TOTAL	39955	32442	7799	15721	1717	18566	13450	1065	(6996)
260545	A	(26_MS_5) Includes 260685 (Turnbull Luengen)									
260621	A	(26_MS_1) Includes structures 260681(Sullivan D), 260500(Arroyo D), 260532(Fairplay Arroyo D), 260547(Goodwin D), 260554(Hartman Bros D2), 260555(Hartman Bros D3), 260567(Holcomb D), 260597(Means D), 260674(Shore or Campbell D3), 260676(South 38 D), 260684(Travis D3), 260696(WM M Stowe D), 260700(Zeigler Bros D)									
260658	A	(26_MS_2) Includes 260656 (Russel D1) and 260657 (Russel D2)									
260677	A	(26_MS_3) Includes structure 260612 (Moses Goff Ditch 3)									
260697	A	(26_MS_4) Includes structures 260698(Woodard D) and 260699(Woodard Overflow D)									

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

North of Rio Grande Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
		Groundwater Only Areas	0	27205	0	24962	0	48543	38405	0	(42245)
200546		Billings Ditch	4560	1194	1194	3452	716	4690	4275	35	(3509)
200556		Butler Ditch	1097	222	753	127	195	0	154	0	584
200575		Chicago Ditch	8622	7277	5211	1814	1084	0	194	342	4997
200582		Cochran Pioneer	983	163	1061	86	159	0	80	0	974
200587		Costilla Ditch	11904	15111	0	2399	0	694	697	353	(767)
200627		Excelsior Ditch	19580	8132	11191	2212	1548	22	712	3	10408
200631		San Luis Valley ID (Farmer's Unio	48327	51350	0	46636	0	85182	67971	14	(74768)
200636		Fish Ditch	1696	1998	1016	596	384	23	202	150	794
200677		Hubbard Ditch	262	169	425	47	46	0	22	0	400
200680		Independent D	1679	576	1544	130	96	0	48	0	1491
200699		Kane Callan Ditch	2457	149	1430	238	262	21	151	26	1264
200736		Mc Donald Ditch	4962	680	5487	438	582	0	331	0	5123
200773		New Ditch	1680	1865	0	510	0	0	75	154	(83)
200798		Prairie Ditch	16605	24696	1273	14610	764	26943	22019	0	(22948)
200812		Rio Grande Canal	177581	87812	20251	72446	2430	139567	112529	177	(103531)
200814	A	Rio Grande Ditch #2	1956	330	821	49	55	0	44	0	773
200829		San Luis Valley Canal	20579	26849	0	14813	0	26462	21247	46	(23372)
200833		Schuch Schmidt D	981	284	305	105	87	3	45	2	255
201676		Closed Basin Canal	5408	3298	0	765	0	0	78	175	(86)
270502		Biedell No. 10	3283	919	1032	344	480	472	761	0	195
270503		Biedell No. 2	226	0	0	0	0	0	0	0	0
270505		Biehl D	142	52	0	0	0	0	0	0	0
270509		Curby D No. 2	71	42	17	0	0	0	0	0	17
270513		Dee Bois D No. 1	170	79	0	0	0	0	0	0	0
270514		Espinosa D	23	9	0	0	0	0	0	0	0
270517		Garcia Ditch	93	34	0	0	0	0	0	0	0
270518		Green D #1	739	418	1	67	1	99	70	0	(75)
270521		Holland Ditch	778	160	133	77	28	0	14	23	117
270522		Home Ditch No. 1	1952	1319	416	81	3	16	10	0	405
270523		Johnnie Smith D 1	189	881	0	113	0	22	18	0	(20)
270525		Juan Trujillo D	308	86	0	0	0	0	0	6	0
270527		La Loma D	46	na	0	0	0	0	0	0	0
270530		Manuel D No. 1	123	1	0	0	0	0	0	0	0
270531		Marcelino Martinez Waste	41	40	0	0	0	0	0	0	0
270533		McLeod No. 3	1022	16	0	4	0	0	1	0	(1)
270534		McLeod No. 4	121	31	0	21	0	28	23	0	(25)
270535		McLeod No. 5	53	40	0	25	0	32	26	0	(28)
270537		Moody and Head D	85	40	0	0	0	0	0	0	0
270538		Omnibus Ditch	2631	431	564	0	0	0	0	0	564
270539		Paradise No. 1	4	13	0	0	0	0	0	0	0
270541		Paradise No. 3	5	4	0	0	0	0	0	0	0
270543		Rocky Hill Seepage	739	1353	54	444	32	576	451	1	(443)
270545		Shown D	744	125	96	62	57	110	111	0	(26)
270546		Stewart Ditch #4	26	62	0	0	0	0	0	7	0
270548		Susanna D	104	27	0	0	0	0	0	0	0
270549		Torres D	30	13	0	0	0	0	0	0	0
270551		White D	195	na	0	0	0	0	0	0	0
270553		Wilson D #4	172	125	0	62	0	110	111	0	(122)
270554		Wilson D	51	19	0	0	0	0	0	0	0
270566		Cascias D	22	26	0	0	0	0	0	0	0
270623		Carnero Gd. Sta. 123	7	10	0	0	0	0	0	0	0
270632		C Ditch	130	na	0	0	0	0	0	0	0
270684		La Magotes D #2	748	187	254	0	0	0	0	0	254
		TOTAL	345990	265922	54528	187736	9010	333613	270873	1514	(243432)
200814	A	(20_MS_4) Includes structure 200815 (Rio Grande 4)									

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Del Norte to South Fork Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
		Groundwater Only Areas	0	1962	0	135	0	395	315	0	(347)
200500		Adams Ditch 1	493	na	0	224	270	0	135	60	(148)
200511		Anaconda Ditch	4037	642	1560	278	224	0	126	13	1422
200522		Bachman Ditch 2	149	na	3	50	2	0	1	32	2
200524		Barclay	184	14	140	8	10	0	5	1	135
200528		Bauer Ditch	1034	354	437	104	63	0	31	16	402
200535		Bennett Creek D	128	58	0	0	0	0	0	2	0
200536		Bennett 1	91	16	0	0	0	0	0	0	0
200537		Bennett 2	93	37	0	0	0	0	0	0	0
200541		Bevan D 4	48	28	2	0	0	0	0	1	2
200543		Bevan D 6	7	12	0	0	0	0	0	0	0
200551		Breene Myers Ditch	213	na	0	23	0	16	8	24	(9)
200588		Davies Bros. Ditch	494	na	93	79	50	0	25	48	65
200590		Davies Ditch 2	362	na	0	0	0	0	0	3	0
200595		Del Norte Town Ditch	1192	261	456	75	42	0	21	6	433
200611		Dyer Ditch	195	90	320	0	0	0	0	0	320
200614		Ehrowitz Ditch	891	271	736	238	233	19	130	82	593
200619		Elliott 4	156	77	0	0	0	0	0	0	0
200620		Elliott 5	23	29	0	0	0	0	0	4	0
200621		Elliott Bevan	34	31	0	1	0	0	0	0	(0)
200622		Embargo Ditch	1043	na	381	215	71	0	36	74	342
200652		Hagadorn	793	408	220	164	118	142	175	25	28
200655		Hanna 1	70	13	0	0	0	0	0	5	0
200656		Hanna 2	93	66	0	0	0	0	0	18	0
200657		Happy Thought	40	11	0	0	0	0	0	0	0
200676		Howlett	65	22	0	0	0	0	0	0	0
200681		Independent Ditch #2	5838	1304	4646	1243	1518	146	899	636	3658
200684		Jemison Bevan 1	213	63	52	29	10	21	15	2	35
200685		Jemison Bevan 2	481	245	97	125	34	0	17	65	79
200686		Jemison 1	114	26	12	17	8	0	5	6	7
200687		Jemison 2	55	34	14	32	9	0	4	20	10
200688		Jemison 3	34	16	0	12	0	0	6	8	(7)
200689		Jemison 4	153	58	92	43	40	0	16	17	75
200690		Jemison 7	63	16	27	13	16	0	6	7	21
200691		Jemison 9	56	18	24	12	14	0	3	7	21
200713		Little Annie	649	223	128	73	27	0	17	15	109
200714		Little Danube	633	282	9	4	1	0	1	2	8
200729		Mallett	229	114	30	23	9	0	4	4	25
200742		Meadow Glen Ditch	2212	428	740	123	119	8	74	15	659
200744		Mexican	92	13	101	20	59	5	16	3	83
200752		Minor Ditch	6630	1443	2464	808	632	406	675	106	1722
200754		Montoya 1 2 and 5	1056	143	275	81	77	0	38	15	232
200755		Montoya 3 and 4	127	45	0	0	0	0	0	35	0
200757		Montoya 6	88	222	0	0	0	0	0	0	0
200776		Norris	37	20	0	0	0	0	0	0	0
200782		Park and Green	842	510	136	328	82	226	231	59	(119)
200786		Perkins	406	180	0	0	0	0	0	0	0
200787		Pfeiffer Ditch	328	71	75	18	13	0	7	7	68
200790		Pinos Creek 1	1683	396	116	100	22	0	11	0	104
200792		Poole Bachle	46	9	0	0	0	0	0	0	0
200794		Poole Fairchild	12	28	0	0	0	0	0	6	0
200795		Poole Jemison	89	62	0	12	0	0	4	38	(4)
200796		Poole Meadow	92	42	0	0	0	0	0	28	0

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Del Norte to South Fork Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
200797		Poole Mesa	56	69	0	0	0	0	0	0	0
200818		Robran	952	310	429	222	106	0	53	97	371
200836		Shaw Ditch 1	189	na	3	0	0	0	0	0	3
200837		Shaw Ditch 2	140	na	155	99	45	0	23	12	130
200854		South Fork Highline Ditch	1319	174	550	31	65	0	32	16	514
200857		Sprague	46	28	0	0	0	0	0	0	0
200914		Yarnell	399	227	0	0	0	0	0	127	0
200986		Charlesworth Ditch 1R	242	na	53	12	4	0	2	0	50
200987		Fairchild	214	66	53	56	32	0	16	45	35
201603		Montoya Mexican	1145	363	511	446	235	27	147	234	349
201705	A	Atkins/Voss Seepage Pump	337	na	427	274	211	97	231	0	173
		TOTAL	39222	11650	15567	5852	4470	1508	3561	2048	11650
201705	A	Includes structure 201000 (Voss Seepage Ditch)									

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

South of Rio Grande Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
		Groundwater Only Areas	0	2991	0	2400	0	5505	4186	0	(4605)
200505		Alamosa Ditch	2095	1214	357	103	24	0	17	80	339
200512		Anderson Ditch	4004	667	4201	562	861	88	463	31	3693
200513		Anna Raber Ditch	466	316	398	108	132	0	66	41	326
200516	A	Arroya Eagle and Larrick5	420	330	277	66	24	0	17	0	259
200517		Atencio Ditch	1756	345	1720	306	575	0	283	36	1408
200518		Atencio Ditch 2	1319	83	817	113	120	0	60	27	751
200552		Brey Ditch	176	104	0	0	0	0	0	0	0
200555		Burns	49	117	0	0	0	0	0	0	0
200557		Cadle 1	154	58	0	0	0	0	0	0	0
200558		Cadle 2	36	70	0	0	0	0	0	0	0
200566		Centennial Ditch	21295	7802	20207	4122	7549	328	4731	179	15003
200583		Cole D 1	232	133	127	0	0	0	0	0	127
200585		Cole D 6	102	49	0	0	0	0	0	0	0
200606		Mc Neil Dupke	404	446	0	0	0	0	0	0	0
200623	A	Commonwealth Ditch Co.	50772	40354	1191	19372	715	38340	28842	612	(30536)
200634		Field	65	19	0	0	0	0	0	0	0
200642		Garden	96	3	0	0	0	0	0	0	0
200643		Getz No. 3	489	315	0	0	0	0	0	0	0
200644		Getz Seepage D 4	466	194	0	0	0	0	0	0	0
200671		Horner Ydren Ditch	2656	699	2839	597	1157	0	637	200	2138
200682		James Mcleary	524	335	122	233	73	428	251	3	(154)
200683		James Patterson Ditch	402	35	0	33	0	0	9	58	(10)
200694		John Anderson Ditch	787	131	262	89	70	47	59	10	197
200702		Kiel Larsen	50	60	0	0	0	0	0	0	0
200706	A	Larrick D 2	686	846	237	136	118	196	241	0	(29)
200709		Larrick 6	67	79	0	0	0	0	0	0	0
200718		Lohr Overflow Seepage D	19	1	0	0	0	0	0	0	0
200720		Lavato	59	15	0	0	0	0	0	0	0
200731		Marajo Ditch	461	176	0	0	0	0	0	0	0
200733		Martinez D	99	19	0	0	0	0	0	0	0
200737		McIntosh Arroya Ditch	829	196	544	131	105	0	53	5	486
200753		Monte Vista Canal	34704	27737	238	15226	0	33036	24545	251	(26761)
200774		Newton	36	54	0	0	0	0	0	0	0
200775		Nichol Ditch	1163	442	1374	337	260	78	200	46	1154
200777		Off Ditch	1427	343	1476	334	483	164	325	110	1119
200781		Pace Ditch	231	158	283	0	0	0	0	0	283
200783		Parma Ditch	647	660	0	0	0	0	0	0	0
200801		Raber Ditch	447	136	355	91	46	0	22	8	331
200810		Rio Grande Ditch #1	4417	913	4736	658	1226	0	610	0	4065
200811		Rio Grande Piedra Valley	17377	8170	9459	5427	3532	1149	2528	536	6678
200815		Rio Grande Ditch #4	755	21	233	34	56	0	28	0	202
200816		Rio Grande Lariat Ditch	9411	3290	481	2151	289	3587	2978	78	(2795)
200817		Rio Grande San Luis Ditch	6857	3519	1733	2449	1040	2668	2748	141	(1290)
200819		Rock Creek/Anderson and Cadle	186	52	39	0	0	0	0	0	39
200820		Rough and Ready	1110	782	951	21	36	0	13	0	937
200824		San Francisco D	327	268	0	0	0	0	0	0	0
200826		San Jose or Lucero Ditch	1040	393	581	148	212	157	286	0	266
200846		Silva Ditch	6323	731	6390	447	788	0	446	0	5899
200853		South Farm Meadow D	328	1055	0	0	0	0	0	17	0
200863		Spruce Lawn D	1205	1669	0	11	0	0	0	2	(0)
200865		Star Ditch	1221	625	0	60	0	0	16	25	(17)
200884		Valdez D 1	128	58	0	0	0	0	0	0	0
200885		Valdez D 2	102	82	0	0	0	0	0	0	0

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South of Rio Grande Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
200901		Weiss	27	204	0	0	0	0	0	26	0
200903		Westside Ditch	3281	1884	1613	462	221	13	112	2	1490
200915		Ziegler Ditch	352	508	252	238	151	443	414	6	(204)
200966		Hall-Voss Ditch	177	65	0	0	0	0	0	0	0
200967		Cochran Bros 2R	68	39	0	0	0	0	0	0	0
200968		Rienau D 2R	40	26	0	0	0	0	0	0	0
200969		Macleod D 1R	142	114	41	0	0	0	0	0	41
200970		Macleod D 4R	32	28	0	0	0	0	0	0	0
200971		Ward D 1R	32	125	0	0	0	0	0	0	0
200972		Ward D 2R	30	83	0	0	0	0	0	0	0
200973		Ward D 3R	35	51	0	0	0	0	0	0	0
201129		Heath	124	74	0	0	0	0	0	0	0
210593		Scandinavian Ditch	923	2284	0	907	0	2080	1581	12	(1739)
		TOTAL	185741	114845	63537	57372	19863	88306	76770	2544	(20910)
200516	A	(20_MS_1) Includes 200613 (Eagle Ditch), and 201004 (Arroya Ditch)									
200623	A	(20_MS_2) Includes structure 201060 (Lease, Davis, and Bingle)									
200706	A	(20_MS_3) Includes structure 200784 (Peachy 1)									

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Alamosa River Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
		Groundwater Only Areas	0	1061	0	1018	0	1684	1202	0	(1323)
210501		Agua Caliente	108	126	0	0	0	0	0	1	0
210502		Alamos	158	39	0	0	0	0	0	0	0
210503		Alamosa Creek Canal	6302	4898	2467	3876	1480	7156	6752	22	(4961)
210505		Alamosa Spring Creek	931	896	0	260	0	671	335	3	(369)
210506		Arroya	1813	1480	0	497	0	1132	647	57	(712)
210510		Capulin Ditch	4782	1479	2692	368	378	246	247	21	2420
210511		Clark	49	115	0	83	0	311	156	0	(171)
210512		Coddington	833	2203	335	134	76	56	45	179	286
210513		Cottonwood	636	522	0	26	0	36	18	27	(20)
210514		Cristobal Rivera	874	789	142	159	85	85	203	15	(81)
210515		Crowther Bros.	84	38	0	0	0	0	0	0	0
210520		El Viejo	5079	1588	3048	528	1167	136	595	66	2394
210521		Commonwealth-La Jara	16839	10985	0	4002	0	7004	4526	680	(4978)
210523		Eskridge Garret	69	177	0	35	0	20	17	3	(19)
210525		Flintham Ditch	1101	1930	0	991	0	2464	1510	23	(1661)
210526		Gabino Gallegos	2622	901	534	155	63	0	108	31	415
210527		Gallegos No. 1	331	38	0	0	0	0	0	0	0
210528		Gallegos No. 2	161	158	19	33	12	0	5	15	14
210529		Gallegos 3	274	319	0	148	0	148	74	0	(81)
210530		Gallegos No. 4	326	284	63	47	34	0	12	20	50
210531		Garcia Ditch No. 1	722	309	907	156	172	0	82	0	817
210532		Garcia #2	496	797	157	203	95	291	197	32	(59)
210535		H. Louise Shawcroft	174	27	0	0	0	0	0	0	0
210536		Hansen Overflow #3	2026	2313	28	99	17	0	8	234	19
210537		Hardtack S. Branch	431	84	0	6	0	0	1	3	(1)
210538		Hardtack N. Branch	768	542	169	166	95	291	190	9	(40)
210539		Head Overflow #5	8177	5132	0	544	0	902	534	6	(588)
210545		Juan De Dios Vigil	287	35	0	0	0	0	0	7	0
210546		Keystone	562	911	0	269	0	588	299	11	(329)
210548		L.D. Eskridge	248	289	0	172	0	451	225	13	(248)
210549		L. E. Shawcroft and Sons	151	61	0	0	0	0	0	27	0
210551		La Jara Seepage	1088	634	1064	206	375	36	153	4	895
210552		Le Mita #1	206	77	51	9	2	0	1	0	50
210553		Le Mita #2	729	186	624	9	2	0	1	0	623
210554		Le Mita #3	116	50	0	0	0	0	0	0	0
210557		Lower La Jara	724	1183	0	310	0	529	366	23	(402)
210558	A	Lowland	5356	4531	0	954	0	1391	728	182	(801)
210559		Mc Cunniff	1957	815	564	450	296	429	445	104	74
210560		Miller-La Jara	3127	2639	0	706	0	1335	767	57	(844)
210564		Morganville	1146	2205	0	1541	0	3743	2468	62	(2715)
210565		Murphy Crowther	418	557	44	168	27	193	105	29	(71)
210566		Nate Garrett	461	364	0	75	0	97	54	17	(60)
210569		Newcomb Bros.	574	595	11	226	6	370	257	15	(272)
210570		Norland	859	968	0	221	0	136	348	22	(382)
210571		North Alamosa	1187	1608	0	1135	0	2110	1158	8	(1274)
210572		Ortiz	1141	542	0	26	0	20	13	0	(15)
210579		Pino Real	70	23	10	0	0	0	0	0	10
210581		Ramona	941	747	0	99	0	122	73	20	(81)
210582		Reed #1	680	537	138	258	83	201	128	95	(2)
210583		Reynolds Reed	776	89	36	0	0	0	0	0	36
210584		Reynolds Ditch	560	336	0	68	0	51	36	19	(40)
210585		Rivera	129	306	0	2	0	0	0	0	(1)

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Alamosa River Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
210586		Romaldo Valdez	334	53	0	0	0	0	0	0	0
210587		Romero	471	105	218	79	26	0	13	11	204
210590		Sanco	7	91	0	0	0	0	0	0	0
210591		San Jose Ditch No. 1	650	119	17	23	10	0	9	0	7
210592		San Jose #2	137	60	0	0	0	0	0	0	0
210596		South Side Arroya	988	3451	0	1088	0	1853	1039	72	(1143)
210599		Swamp	170	206	0	5	0	0	0	32	(0)
210600		T.K. Walsh	135	156	0	0	0	0	0	0	0
210601		Terrace Main	9488	6480	2318	4739	1391	9012	8133	0	(6629)
210602		Union	2244	3619	0	1556	0	3033	1730	51	(1903)
210603		Valley Ditch	999	310	77	86	18	85	66	0	4
210604		Valdez	3861	662	1650	39	23	0	12	2	1637
210606		Weist	81	326	0	231	0	122	61	0	(67)
210611		Madril	59	172	0	25	0	0	6	14	(6)
210612		Reed #2	620	1195	347	331	208	203	179	74	151
210631		Eskridge Garret N Branch	28	34	0	0	0	0	0	0	0
210644		Dam in the Center of Sec. 14	801	482	0	39	0	0	4	13	(5)
210662		Warren Shawcroft Wildcat	30	49	0	0	0	0	0	22	0
210705		Baker Ditch	124	94	0	13	0	12	6	0	(7)
210716		Seaman Ditch	577	5240	0	84	0	28	15	9	(17)
210717		J.H. Valdez	17	na	0	0	0	0	0	0	0
213299		Murphy Crowther Wildcat	32	72	0	0	0	0	0	17	0
		TOTAL	101508	82494	17732	28776	6139	48785	36365	2479	(22270)
210558	A	(21_MS_1) Includes structure 210643 (Cathouse Dam),210576 (Overflow D1-S. Branch), and 210575 (Overflow D2, N.Branch)									

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Conejos River Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
		Groundwater Only Areas	0	1310	0	1283	0	2580	2047	0	(2252)
220500		A.D. Archuleta Ditch	105	901	0	413	0	943	947	9	(1042)
220501		Alamo Ditch	1446	1506	244	290	82	0	26	70	216
220502		An Con	984	1039	0	42	0	112	84	0	(92)
220503		Angostura Ditch	748	47	0	0	0	0	0	0	0
220504		Antonito Ditch	3607	2254	0	450	0	711	634	0	(697)
220505		Archuleta-Trogillio	965	681	32	134	19	0	8	67	23
220506		Arch-Trogillo No 2 (Springs)	736	539	248	200	72	0	34	80	211
220508		Bagwell Ditch	246	41	0	0	0	0	0	0	0
220509	A	Ball Bros. Overflow No. 1	2920	836	0	0	0	0	0	7	0
220513		Bernardo Romero	577	299	23	12	3	0	1	16	21
220514		Bosque Irrigation Ditch	155	100	0	0	0	0	0	0	0
220515		Braiden Overflow No. 1	1166	384	0	239	0	449	359	0	(395)
220516		Braiden Overflow No. 2	254	252	0	0	0	0	0	0	0
220517		Braiden Overflow No. 3	345	7	0	0	0	0	0	0	0
220518		Branch Ditch	746	113	0	0	0	0	0	0	0
220524		Canon Ditch	5473	1484	237	173	142	190	216	0	(1)
220525		Carpe and Reekers Canon	301	20	0	0	0	0	0	0	0
220526		Chacon Ditch No. 1	715	391	0	39	0	0	8	15	(9)
220527		Chavez Ditch	353	63	0	0	0	0	0	21	0
220528		Christensen Ditch	184	263	0	198	0	399	199	0	(219)
220531		Cordova Ditch	507	228	0	0	0	0	0	0	0
220532		Cottonwood Ditch	1222	658	0	249	0	341	174	16	(192)
220535		East Bend Ditch	1293	212	0	0	0	0	0	0	0
220536		East Bend D, No. 2	301	237	0	52	0	56	28	0	(31)
220537		Eight Mile Ditch	852	186	0	13	0	0	1	0	(1)
220538		El Coda	6170	1287	3939	647	387	0	194	48	3726
220539		El Serrito Ditch	621	354	167	178	29	0	13	42	152
220540		Elledges	499	127	27	17	3	0	2	0	25
220541		Ephraim	4384	4376	514	3228	309	4899	2934	0	(2713)
220542		Espinoza Springs	158	39	80	20	3	0	2	5	78
220543	A	Florida Ditch	1433	706	0	540	0	937	750	0	(825)
220544		Fox Creek	118	na	0	0	0	0	0	0	0
220545		Fox Creek #1	171	na	0	0	0	0	0	0	0
220546		Fox Creek #2	23	na	0	0	0	0	0	0	0
220547		Fuertecitos Ditch	1467	387	0	0	0	0	0	58	0
220548		Gabriel Martinez	456	168	82	28	26	0	9	0	72
220549		Galvez Ditch	500	219	0	0	0	0	0	0	0
220553	A	Guadalupe Main	8029	1808	3226	930	1057	0	525	209	2648
220554		Head's Mill and Irg. D	11112	2219	1529	788	918	1769	1778	12	(427)
220555		Home Ditch	269	81	0	0	0	0	0	0	0
220556	A	Hughes' Overflow	591	417	0	0	0	0	0	0	0
220559		Island Ditch No. 2	277	131	0	0	0	0	0	0	0
220560		Island Ditch No. 3	24	173	0	0	0	0	0	0	0
220561		JF Chacon No. 2	627	254	0	122	0	252	246	0	(271)
220562		JF Chacon No. 3	577	654	0	231	0	606	566	0	(623)
220563		JM Espinoza	891	139	0	0	0	0	0	11	0
220564		Jack's Irrigation Ditch	376	73	0	0	0	0	0	0	0
220565		Jackson Ditch	489	248	0	1	0	0	0	0	(0)
220568		Jacobs Ditch No. 3	1	4	0	0	0	0	0	0	0
220571	A	John W. Floyd Overflow	595	272	0	17	0	32	26	0	(29)
220576		La Del Rio	2706	1102	0	3	0	0	0	2	(0)
220579		Le Duc Ditch	398	111	0	0	0	0	0	0	0
220580		LLano Ditch	4661	695	4069	567	473	0	216	0	3832
220581		Lobato and Cordoba D	607	160	0	250	0	675	540	0	(594)

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Conejos River Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
220583		Lopez Ditch	195	140	0	0	0	0	0	0	0
220584		Los Ojos No. 1	1913	1283	0	0	0	0	0	18	0
220585		Los Ojos D. No. 2	604	491	0	0	0	0	0	42	0
220586		Los Pinos	1617	275	704	199	93	0	64	30	634
220587		Los Sauces	9399	2720	3054	1431	815	0	408	376	2606
220589		Lovato Irr. D.	2218	513	0	137	0	424	339	0	(373)
220590		Maes Ditch	164	11	0	0	0	0	0	0	0
220591	A	Mogote-Northeastern	15264	13245	0	3350	0	4532	5052	48	(5557)
220593	A	Manassa, Eastfield, Westfield	27723	18553	14537	10586	7389	7407	9333	328	4271
220597		Martinez D (S.Antonio)	2171	679	0	134	0	398	318	0	(350)
220598		Martinez Ditch	938	597	0	0	0	0	0	9	0
220599		Massie Ditch	85	6	0	0	0	0	0	0	0
220600		Mc Carrol Ditch No. 1	948	190	47	0	0	0	0	0	47
220601		McCarroll Ditch No. 2	181	80	0	0	0	0	0	0	0
220602		Mc Daniels Ditch	471	125	0	0	0	0	0	0	0
220604		Las Mesitas Ditch	5021	1540	0	0	0	0	0	0	0
220605		Mill Ditch	616	340	129	151	10	0	6	47	123
220606		Mogales Valley Ditch	174	na	0	0	0	0	0	0	0
220607		Mountain Ditch	62	na	0	0	0	0	0	0	0
220608		New J.B. Romero Ditch	467	37	126	0	0	0	0	0	126
220611		Overflow, Vega Grande, Sabine	1315	349	244	68	1	0	3	21	241
220614		Poleo Ditch	101	89	0	0	0	0	0	0	0
220615		Punche Ditch	1042	304	0	0	0	0	0	0	0
220616		Richfield Canal	3717	4711	264	1712	158	2869	1752	69	(1663)
220618		Rincones Ditch	2640	1143	673	216	50	41	47	10	621
220619		Romero	15733	10913	7088	3018	4253	4132	4818	49	1788
220620		Sabine School Section Ditch	766	201	0	0	0	0	0	26	0
220621	A	Salazar Ditch	1455	686	359	95	18	0	9	69	349
220622		San Carlos Ditch	158	198	0	13	0	0	3	79	(3)
220624		San Juan/San Rafael Ditch	5129	1699	66	43	35	0	14	0	51
220625		San Rafael Conejos	2936	1273	183	126	47	0	16	65	166
220626		Sanchez Ditch	2036	271	21	0	0	0	0	0	21
220627		Sanford Ditch	4466	3180	0	2278	0	5062	2658	0	(2924)
220628		Santa Rosa	149	144	0	0	0	0	0	0	0
220629		Santiago D.	2577	432	573	134	18	0	9	14	563
220630	A	Seledonio Valdez Ir.	8342	4537	3007	826	201	233	314	151	2661
220631		Servietta	5388	2149	2001	401	285	49	165	3	1820
220632		Cenicero Ditch	3159	921	1562	30	5	0	2	0	1559
220633		Sisneros Ditch	247	143	0	0	0	0	0	0	0
220634		Smith Bros. Ditch	421	227	17	172	10	104	57	52	(46)
220635		Star Ditch	347	125	0	0	0	0	0	0	0
220636		Stover Ditch	415	353	0	0	0	0	0	20	0
220639		Taos Valley Canal No.3	4326	109	0	0	0	0	0	0	0
220640	A	Teodoro No. 1, Jaramillo 1 and 2	769	371	0	0	0	0	0	0	0
220641		Teodoro No. 2	983	281	22	0	0	0	0	0	22
220644		Trogillo	875	268	176	234	40	165	102	33	64
220646		Vega Ditch	828	149	27	2	1	0	1	1	26
220651	A	William Stewart Co. Irr. D.	1752	1175	0	183	0	28	30	18	(33)
220659		William Jackson Ditch	63	201	0	0	0	0	0	6	0
220664		Broyle's Overflow No. 4	356	73	0	0	0	0	0	0	0
220692		Garcia Ditch-R	645	303	244	245	44	0	22	41	220
220829		Canon Irrig. D. APD	63	15	0	0	0	0	0	0	0
220914		Paine D.	29	46	0	19	0	0	1	12	(2)
		TOTAL	217889	108119	49543	37158	16994	40395	38113	2325	7618

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Conejos River Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
220509	A	(22_MS_1) Includes structure 220510 (Ball Gros Overflow No 2)									
220543	A	(22_MS_2) Includes structure 220617 (Riedel D)									
220553	A	(22_MS_3) Includes structure 220519 (Brazo Del Norte D)									
220556	A	(22_MS_4) Includes structure 220557 (Hughs Overflow NO 2)									
220571	A	(22_MS_5) Includes structures 220572 (JW Floyd Overflow 2) and 220573 (GW Floyd Overflow 3)									
220591	A	(22_MS_6) Includes structure 220609 (North Eastern D)									
220593	A	(22_MS_7) Includes structure 220596 (Manassa Westfield D), 220533 (Cruz Chavez D) and 220595 (Manassa Eastfield D). Also,									
220621	A	(22_MS_8) Includes structures 220511 (Becroft Irr D) and 220534 (Del Puerticito D)									
220630	A	(22_MS_9) Includes structure 220623 (San Jose D)									
220640	A	(22_MS_10) Includes structure 220569 (Jaramillo Oflow D 1) and 220570 (Jarmaillo Oflow D 2)									
220651	A	(22_MS_11) Includes structure 220647 (Vega Grande D) and 220648 (William Sabine D No 1)									

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San Luis Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
		Groundwater Only Areas	0	1162	0	303	0	843	673	0	(740)
240502		Aban Sanchez Ditch	292	55	0	0	0	0	0	0	0
240504		Acequia Chiquita	156	0	0	0	0	0	0	0	0
240505		Acequia de los Cedros	185	59	0	0	0	0	0	0	0
240506		Acequia Madre	337	na	213	0	0	0	0	0	213
240507		Acequiacita	203	na	8	0	0	0	0	0	8
240508		Alamo Ditch	254	na	0	0	0	0	0	0	0
240509		Albert and Vigil Ditch	131	43	0	0	0	0	0	5	0
240511		Pando Ditch	191	39	0	0	0	0	0	4	0
240512		Antonio Valdez Ditch	519	157	0	0	0	0	0	0	0
240513		Antonio Sanchez Ditch	149	28	0	0	0	0	0	2	0
240514		Arellano Ditch	110	7	0	0	0	0	0	0	0
240516		Association Ditch	196	17	0	0	0	0	0	0	0
240519		Canon Ditch 1	231	60	0	0	0	0	0	0	0
240520		Canon Valle D	253	89	0	0	0	0	0	9	0
240521		Cerro Canal (Colo. Side)	418	2472	0	2043	0	5026	3930	1	(4323)
240522		Cerro Ditch	5476	1208	967	8	0	0	1	127	966
240524		Chalifu Ditch	759	68	0	0	0	0	0	0	0
240525		Chama Ditch Ext.	8	na	0	0	0	0	0	0	0
240526		Chavez and Quintana Ditch	254	68	0	0	0	0	0	0	0
240527		Choury Ditch	479	162	320	10	19	0	9	0	309
240528		Clarita Vigil Ditch	243	53	0	0	0	0	0	4	0
240533	A	Sanchez Ditch and Res Co.	19726	7951	15378	6708	9227	3903	10441	0	3893
240540		Emilio Lobato Ditch	175	56	0	8	0	0	1	1	(1)
240542		Fares Jaquez Ditch	205	252	0	0	0	0	0	0	0
240543		Felipe Vialpando Ditch	185	50	0	0	0	0	0	0	0
240544		Francisco Sanchez	836	270	570	59	44	40	33	1	533
240545		Frank Mondragon Ditch 1	154	130	0	32	0	34	17	34	(19)
240546		Gabino Atencio Ditch	257	64	0	0	0	0	0	16	0
240547		Gabriel Medina Ditch 1	85	58	0	0	0	0	0	9	0
240548		Gabriel Medina Ditch 2	47	45	0	0	0	0	0	12	0
240549		Garcia Ditch	196	46	0	0	0	0	0	0	0
240550		Guadalupe Sanchez Ditch	538	170	0	0	0	0	0	1	0
240551		Guadalupe Vigil Ditch	409	131	0	11	0	0	1	4	(1)
240552		Island Ditch	182	294	0	42	0	40	29	19	(32)
240553		J. M. J. Maez Ditch	307	229	96	132	21	17	38	90	54
240554		Jacquez Ditch	232	70	0	14	0	31	15	9	(17)
240555		Jaroso Ditch	615	70	0	0	0	0	0	0	0
240558		Jose M. Sanchez Ditch	215	66	0	0	0	0	0	1	0
240559		Julio Gold Ditch	196	49	0	0	0	0	0	0	0
240562		Little Rock Ditch	70	5	0	0	0	0	0	0	0
240564		Lobato Ditch 1	115	19	0	0	0	0	0	3	0
240565		Lobato Ditch 2	118	32	0	0	0	0	0	0	0
240566		Lucero Ditch	31	17	0	0	0	0	0	32	0
240570		Mestas Ditch	496	54	0	0	0	0	0	8	0
240571		Mondragon Ditch	324	1	0	0	0	0	0	0	0
240572		Montez Ditch	24	na	0	0	0	0	0	0	0
240573		Cuates Ditch 1	885	115	239	0	0	0	0	0	239
240574		Cuates Ditch 2	390	86	0	0	0	0	0	0	0
240575		Ramon Lucero Ditch	204	59	0	0	0	0	0	8	0
240576		Robert Allen Ditch	293	166	0	38	0	0	5	4	(5)
240579		Salazar Ditch	1019	99	305	59	74	0	37	0	264
240580		Sam Lucero	74	204	0	44	0	0	15	142	(16)
240581		San Acacio Ditch	5615	2373	5523	1781	2723	313	1651	0	3707

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San Luis Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
240583		San Francisco Ditch	2570	743	644	0	0	0	0	20	644
240586		San Luis Peoples Ditch	4181	1665	4145	1251	1938	0	962	127	3087
240589		San Pedro Ditch	4725	1382	3245	1207	1276	0	621	269	2562
240592		Torcido Ditch	445	200	142	0	0	0	0	0	142
240593		Trujillo Ditch	102	na	0	0	0	0	0	0	0
240594		Vallejos Ditch	2322	845	1317	616	444	9	202	151	1095
240595		Vallejos Canon Ditch	204	50	0	0	0	0	0	2	0
240598		Vigil Ditch	140	37	0	0	0	0	0	12	0
240599		W. F. Meyer Ditch	1213	384	679	0	0	0	0	0	679
240601		Mondragon and Romero Ditch	244	132	0	57	0	141	70	4	(77)
240602		Robert Atencio Ditch	149	30	52	40	23	0	11	17	39
240604		Frank Mondragon Ditch 2	3	85	0	8	0	4	2	38	(2)
243577	A	Eastdale Reservoir	33	473	0	171	0	322	253	12	(279)
		TOTAL	61390	25004	33842	14643	15788	10722	19018	1198	12922
240533	A	(24_MS_1) Includes structure 240532 (Culebra Cerritos Ditch)									
243577	A	(24_EASTDALE) Includes structure 240537 (Eastdale Ditch 1) and 240619 (Eastdale Culebra No 1)									

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Blanca Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
		Groundwater Only Areas	0	7221	0	7134	0	12897	10274	0	(11301)
350518	A	Fred Etter	3424	1001	730	339	124	142	197	47	514
350551		Beckwith D	77	188	91	92	55	94	98	0	(17)
350555	A	New North	3721	1087	1612	38	5	0	2	0	1609
350562		Notley Ball Overflow 38.25	530	601	0	0	0	0	0	0	0
350571	A	Aggregation of Trinchera District	28134	17302	5100	12273	3060	20809	17986	54	(14684)
350594		Seyfried Stribling D	1645	813	0	0	0	0	0	0	0
350597		Notley Ball Overflow 38.5	210	93	0	0	0	0	0	0	0
350651		Cooper D	75	2	0	0	0	0	0	0	0
350664		Wilbur's D	204	45	0	236	0	72	36	0	(40)
350702		Rattlesnake Diversion	2225	1375	545	405	391	450	520	0	(27)
		TOTAL	40247	29728	8078	20518	3635	34465	29112	102	(23945)
350518	A	(35_MS_1) Includes structure 350517(East Ridge D), 350544(Meyer D1), 350554(North Middle Island D), 350556(North East Island D), 350567(South Bluff D), 350681(Meyer D)									
350555	A	(35_MS_2) Includes structure 350500(Alamosa Altos D), 350505(Bridge D), 350527(Hughes D1), 350549(Nenninger D), 350559(New South D									
350571	A	(35_MS_3) Includes all Trinchera District Aggregations 350521(Garland D, HDGT 1), 350523(Garland D, HDGT 2), 350529(Indian Creek D), 350546(Mill D), 350560(Newton D 2), 350563(Ojito Creek D), 350564(Ojito Creek D 1), 350570(Sangr Cristo Tinchera), 350579(Trinchera Canal), 350581(Trinchera Garland Canal), 350582(Trinchera Highline Canal), 350588(Walsen D1), 350531(Juel D)									

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Sangre de Cristo Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
		Groundwater Only Areas	0	7050	0	6984	0	11525	8748	0	(9623)
250502		Alder Creek Ditch	83	43	0	0	0	0	0	0	0
250505		Arthur Young Ditch	1120	983	178	500	107	231	169	0	(7)
250506		B Clark Ditch	130	31	2	7	1	0	1	0	2
250507		Baca Grant 4 Irr D 3	361	17	0	0	0	0	0	0	0
250508		Baca Grant 4 Irr. Ditch 4	271	86	0	0	0	0	0	0	0
250509		Baca Grant 4 Irr. Ditch 5	223	319	0	41	0	16	8	0	(9)
250513		Baca Grant 4 Irr. Ditch 9	1056	2970	223	1306	97	0	43	72	176
250516	A	Baca Grant 4 Irr. Ditch 12	1080	1593	203	807	93	0	52	101	146
250533		Cedar Creek Ditch	44	na	0	0	0	0	0	0	0
250535		Clark Ditch A	598	1051	68	169	41	82	62	11	0
250541		Clayton Ditch D	309	147	10	0	0	0	0	7	10
250542		Clayton Ditch E	271	140	0	0	0	0	0	0	0
250545		Clayton Old Channel Ditch	318	48	0	0	0	0	0	0	0
250546		Cody Ditch	146	93	0	0	0	0	0	0	0
250550		Cottonwood Creek Ditch	4323	2459	951	15	10	0	5	0	946
250551		Daniels Fish Arroya Ditch	170	38	0	0	0	0	0	0	0
250552		Daniels Fish Ditch 4	112	76	0	0	0	0	0	0	0
250553		Davison Ditch 1	15	59	0	0	0	0	0	0	0
250556		Decamp Ditch	32	33	44	0	0	0	0	0	44
250562		Dorcey Ditch 1	56	38	0	0	0	0	0	0	0
250565		Driscoll Ditch	20	na	0	0	0	0	0	0	0
250568		Ewing Ditch	117	205	0	54	0	0	0	4	(0)
250569		Ford Ditch 1	118	92	0	0	0	0	0	0	0
250571	A	Garner Ditch 1	1317	332	531	12	9	0	5	0	526
250573		Gash Ditch	68	13	68	0	0	0	0	0	68
250577	A	Greer Ditch 1	328	515	0	0	0	0	0	206	0
250583		Hall D 1	637	262	99	68	3	0	1	13	98
250588		Henry White Ditch	52	na	0	0	0	0	0	0	0
250589		Heukaufer Ditch 2	125	4	0	0	0	0	0	0	0
250590		Hice Ditch 1	60	172	0	2	0	0	0	0	(0)
250591		Hice Ditch 2	29	24	0	0	0	0	0	0	0
250592		Hice Ditch 3	99	58	5	29	2	0	2	1	4
250593	A	Hice Ditch 4	83	36	12	2	1	0	0	0	12
250595		Hice Ditch 6	64	64	44	48	9	0	4	1	40
250596		Hice Ditch 7	26	23	0	0	0	0	0	0	0
250597		Hice Ditch 8	71	18	65	15	3	0	1	0	64
250605		Hopkins Ditch	31	2	0	0	0	0	0	0	0
250606		Hot Springs Creek Ditch	1108	266	656	92	165	0	82	4	565
250607		Howard and Hall Ditch	158	156	0	0	0	0	0	0	0
250614		Kennedy D 2	335	166	0	0	0	0	0	0	0
250618		Malcolm Ditch	29	12	0	0	0	0	0	0	0
250620		McNulty Ditch	65	na	0	0	0	0	0	0	0
250621		Means Ditch 1	23	12	0	0	0	0	0	0	0
250622		Means Ditch 2	61	28	0	0	0	0	0	0	0
250627		North Ditch	444	975	0	156	0	37	19	13	(21)
250628		Peterson Ditch	970	521	0	14	0	15	8	0	(8)
250631		Richards Ditch 1	81	133	0	0	0	0	0	0	0
250632		Richards Ditch 2	23	28	0	0	0	0	0	0	0
250633		Ridenour Ditch	268	na	99	0	0	0	0	0	99
250637		Robinson Reese Ditch	216	241	0	189	0	146	73	0	(80)
250639		Ross Ditch	232	232	0	120	0	189	94	0	(104)
250641		San Luis Co. Ditch	371	373	0	429	0	618	554	0	(609)
250642		San Luis Ditch	139	141	0	14	0	0	0	3	(0)

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Sangre de Cristo Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
250646		Schilling Ditch	239	192	0	0	0	0	0	0	0
250647		Schultz Dittrich D	1308	464	1402	137	355	3	227	0	1152
250650		Shellabarger Home Ditch 1	397	454	0	0	0	0	0	0	0
250652		Shewalter D #1	19	40	17	20	4	0	2	0	15
250653		Shewalter Ditch 2	31	37	0	0	0	0	0	0	0
250657		Squires Ditch 1	63	4	0	0	0	0	0	0	0
250659		Steel Creek Ditch	232	111	0	9	0	13	6	9	(7)
250661		Steel Ditch 2	660	298	641	0	0	0	0	0	641
250662		Stump Ditch	27	19	0	0	0	0	0	0	0
250663		Stump Ditch 1	34	27	0	0	0	0	0	0	0
250666		Stump Ditch 4	11	9	0	0	0	0	0	0	0
250667		Swidensky Ditch	5	na	0	0	0	0	0	0	0
250669	A	Tobler Rominger D	210	2	0	0	0	0	0	0	0
250670		Turner Ditch	76	29	0	0	0	0	0	0	0
250672		Wales D 2	676	265	634	109	46	0	23	0	608
250674		Wales D 4	100	60	0	0	0	0	0	0	0
250675	A	Wales San Luis Ditch 1	212	401	0	32	0	0	1	2	(1)
250677		Wales Shellabarger Ditch 1	936	348	0	0	0	0	0	19	0
250679	A	Wales Travis Ditch	2959	3122	69	680	41	29	34	84	32
250680		Wells Kerber Ditch	169	215	237	18	6	0	3	0	234
250683		White Ditch	128	43	0	0	0	0	0	21	0
250684		Willow Creek Ditch	2840	1766	580	710	48	0	24	26	553
250685		Barsch Miller Ditch	157	170	0	0	0	0	0	0	0
250686		Cedars Ditch	182	7	0	0	0	0	0	0	0
250689	A	Baca Grant Ditch 19-20	1741	408	427	0	0	0	0	0	427
250690	A	Baca Grant Ditch 24-28	4272	1190	274	0	0	0	0	0	274
250691		Barsch Ditch 1-2-3	138	73	0	95	0	25	13	0	(14)
250692		Clayton Ditch ABC	364	166	0	0	0	0	0	7	0
250693	A	Clayton Ditch FG	282	153	5	50	3	0	1	24	4
250695		Schultz Dittrich No 14 Ditch	1100	195	932	107	24	0	19	0	911
250698	A	Hoffman Neidhardt Ditch	3532	1453	2360	371	437	0	350	0	1975
250699	A	San Isabel Nash Ditch	1983	707	0	0	0	0	0	0	0
250701		Silver Creek and Silver 2	97	18	0	0	0	0	0	3	0
250702		Bunker Meadow Ditch	292	128	1	36	1	0	0	3	1
250747		1920 D	208	2	0	0	0	0	0	0	0
250756		Quintana Spg Drng Ovflw D	0	105	0	0	0	0	0	0	0
250841		Wagner Ditch	47	8	0	0	0	0	0	0	0
250847		Amer Ditch 1	65	na	0	0	0	0	0	0	0
250848		Amer Ditch 2	25	na	0	0	0	0	0	0	0
250858		/LD Ditch 1	205	24	3	9	2	0	1	0	2
250859		/LD Ditch 2	128	25	2	3	1	0	0	0	2
270526		La Garita Ditch	520	na	0	0	0	0	0	0	0
350513		Denton D	133	na	3	0	0	0	0	0	3
350528		Hull D	1234	2115	1032	37	25	0	6	0	1025
350532		King Ditch	124	41	83	0	0	0	0	0	83
350537		Little Frankie	133	272	0	171	0	0	14	0	(16)
350541		Medano Sand Creek	329	2134	0	37	0	0	6	75	(7)
350574		South D 2	159	236	182	428	90	0	45	88	132
350575		South D 1	1131	936	0	0	0	0	0	147	0
350584		Trujillo D	1256	546	0	0	0	0	0	13	0
350595		Calkins D	252	232	0	0	0	0	0	0	0
350663	A	N. Zapata Cr. Pipeline	1512	1202	1669	171	57	0	14	0	1653
		TOTAL	51420	42830	13809	14306	1680	12931	10721	958	2016

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Sangre de Cristo Area by Ditch - 2002 Water Use Evaluation

Ditch ID		Ditch Name	1950-2002 Diversion (ac-ft)	1998 Irrigated Acres	2002 Diversion (ac-ft)*	2002 Irrigated Acres	Farm SW Diversion (ac-ft)	GW Diversion (ac-ft)	CU Supplied (ac-ft)	CU Deficit (ac-ft)	Diversion minus CU (ac-ft)*
250516	A	(25_MS_1) Includes structure 250515 (Baca Grant 4 D 11) and 250517 (Baca Grant 4 D 13)									
250571	A	(25_MS_2) Includes structure 250617 (MAJOR CR D)									
250577	A	(25_MS_3) Includes structure 250578 (GREER D 1) and 250579 (GREER D 2)									
250593	A	(25_MS_4) Includes structure 250594 (Hice D 5)									
250669	A	(25_MS_11) Includes structure 250704 (GENERAL FULLER)									
250675	A	(25_MS_5) Includes structure 250676 (WALES SAN LUIS D 2)									
250679	A	(25_MS_6) Includes structure 250501 (Abby Shellabarger), 250582 (HH Wales D), 250648 (Shallabarger D2), 250678 (Wales Shellabarger D2), and 250644 (Sanford D)									
250689	A	(25_MS_7) Includes structure 250518 (Baca Grant 4 D 19) and 250519 (Baca Grant 4 D 20)									
250690	A	(25_MS_8) Includes structures 250520 (Baca Grant 4 D 24), 250521 (Baca Grant 4 D 25), and 250522 (Baca Grant 4 D 26)									
250693	A	(25_MS_12) Includes structure 250543 (Clayton D)									
250698	A	(25_MS_9) Includes structures 250548 (Cotton Cr. Airline Ditch) and 250619 (Cfarland D A B)									
250699	A	(25_MS_10) Includes structures 250623 (Nash D) and 250640 (San Isabel D)									
350663	A	(35_MS_4) Includes structures 350573 (Shady Retread D), 350591 (Zapato D), 350565 (Old Hillside), and 350592 (Zapato D 3)									

Note: 2002 Diversion between March and October / Diversion minus CU adds 10% to CU for evaporative losses

Attachment 8

Chander, G., B.L. Markham, and D.L. Helder. 2009. *Summary of Current Radiometric Calibration Coefficients for Landsat MSS, TM, ETM+, and EO-1 ALIS Sensors.* Remote Sensing of the Environment 113 (2009) 893-903.

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Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors

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ABSTRACT

This paper provides a summary of the current equations and rescaling factors for converting calibrated Digital Numbers (DNs) to absolute units of at-sensor spectral radiance, Top-Of-Atmosphere (TOA) reflectance, and at-sensor brightness temperature. It tabulates the necessary constants for the Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), and Advanced Land Imager (ALI) sensors. These conversions provide a basis for standardized comparison of data in a single scene or between images acquired on different dates or by different sensors. This paper forms a needed guide for Landsat data users who now have access to the entire Landsat archive at no cost.

1. Introduction

The Landsat series of satellites provides the longest continuous record of satellite-based observations. As such, Landsat is an invaluable resource for monitoring global change and is a primary source of medium spatial resolution Earth observations used in decision-making (Fuller et al., 1994; Townshend et al., 1995; Goward & Williams, 1997; Vogelmann et al., 2001; Woodcock et al., 2001; Cohen & Goward, 2004; Goward et al., 2006; Masek et al., 2008; Wulder et al., 2008). To meet observation requirements at a scale revealing both natural and human-induced landscape changes, Landsat provides the only inventory of the global land surface over time on a seasonal basis (Special issues on Landsat, 1984, 1985, 1997, 2001, 2003, 2004, 2006). The Landsat Program began in early 1972 with the launch of the first satellite in the series. As technological capabilities increased, so did the amount and quality of image data captured by the various sensors onboard the satellites. Table 1 presents general information about each Landsat satellite.

Landsat satellites can be classified into three groups, based on sensor and platform characteristics. The first group consists of Landsat 1 (L1), Landsat 2 (L2), and Landsat 3 (L3), with the Multispectral Scanner (MSS) sensor and the Return Beam Vidicon (RBV) camera as payloads on a "NIMBUS-like" platform. The spatial resolution of the MSS sensor was approximately 79 m (but often processed to pixel size of 60 m), with four bands ranging from the visible blue to the Near-Infrared (NIR) wavelengths. The MSS sensor on L3 included a fifth band in the thermal infrared wavelength, with a spectral range from 10.4 to 12.6 μm. The L1–L3 MSS sensors used a band-naming convention of MSS-4, MSS-5, MSS-6, and MSS-7 for the blue, green, red, and NIR bands, respectively (Markham & Barker, 1983). This designation is obsolete, and to be consistent with the TM and ETM+ sensors, the MSS bands are referred to here as Bands 1–4, respectively.

The second group includes Landsat 4 (L4) and Landsat 5 (L5), which carry the Thematic Mapper (TM) sensor, as well as the MSS, on the Multimission Modular Spacecraft. This second generation of Landsat satellites marked a significant advance in remote sensing through the addition of a more sophisticated sensor, improved acquisition and transmission of data, and more rapid data processing at a highly automated processing facility. The MSS sensor was included to provide continuity with the earlier Landsat missions, but TM data quickly became the primary source of information used from these satellites because the data offered enhanced spatial, spectral, radiometric, and geometric performance over data from the MSS sensor. The TM sensor has a spatial resolution of 30 m for the six reflective bands and 120 m for the thermal band. Because there are no onboard recorders on these sensors, acquisitions are limited to real-time downlink only.

The third group consists of Landsat 6 (L6) and Landsat 7 (L7), which include the Enhanced Thematic Mapper (ETM) and the Enhanced Thematic Mapper Plus (ETM+) sensors, respectively. No MSS sensors were included on either satellite. Landsat 6 failed on

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Table 1
General information about each Landsat satellite.

Satellite	Sensors	Launch date	Decommission	Altitude km	Inclination degrees	Period min	Repeat cycle days	Crossing time (a.m.)
Landsat 1	MSS and RBV	July 23, 1972	January 7, 1978	920	99.20	103.34	18	9:30
Landsat 2	MSS and RBV	January 22, 1975	February 25, 1982	920	99.20	103.34	18	9:30
Landsat 3	MSS and RBV	March 5, 1978	March 31, 1983	920	99.20	103.34	18	9:30
Landsat 4	MSS and TM	July 16, 1982	June 30, 2001	705	98.20	98.20	16	9:45
Landsat 5	MSS and TM	March 1, 1984	Operational	705	98.20	98.20	16	9:45
Landsat 6	ETM	October 5, 1993	Did not achieve orbit					
Landsat 7	ETM+	April 15, 1999	Operational	705	98.20	98.20	16	10:00
EO-1	ALI	November 21, 2000	Operational	705	98.20	98.20	16	10:01

launch. The L7 ETM+ sensor has a spatial resolution of 30 m for the six reflective bands, 60 m for the thermal band, and includes a panchromatic (pan) band with a 15 m resolution. L7 has a 378 gigabit (Gb) Solid State Recorder (SSR) that can hold 42 min (approximately 100 scenes) of sensor data and 29 h of housekeeping telemetry concurrently (L7 Science Data User's Handbook[2]).

The Advanced Land Imager (ALI) onboard the Earth Observer-1 (EO-1) satellite is a technology demonstration that serves as a prototype for the Landsat Data Continuity Mission (LDCM). The ALI observes the Earth in 10 spectral bands; nine spectral bands have a spatial resolution of 30 m, and a pan band has a spatial resolution of 10 m.

The Landsat data archive at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center holds an unequaled 36-year record of the Earth's surface and is available at no cost to users via the Internet (Woodcock et al., 2008). Users can access and search the Landsat data archive via the EarthExplorer (EE)[3] or Global Visualization Viewer (GloVis)[4] web sites. Note that the Landsat scenes collected by locations within the International Ground Station (IGS) network may be available only from the particular station that collected the scene.

2. Purpose

Equations and parameters to convert calibrated Digital Numbers (DNs) to physical units, such as at-sensor radiance or Top-Of-Atmosphere (TOA) reflectance, have been presented in a "sensor-specific" manner elsewhere, e.g., MSS (Markham & Barker, 1986, 1987; Helder, 1993), TM (Chander & Markham, 2003; Chander et al., 2007a), ETM+(Handbook[2]), and ALI (Markham et al., 2004a). This paper, however, tabulates the necessary constants for all of the Landsat sensors in one place defined in a consistent manner and provides a brief overview of the radiometric calibration procedure summarizing the current accuracy of the at-sensor spectral radiances obtained after performing these radiometric conversions on standard data products generated by U.S. ground processing systems.

3. Radiometric calibration procedure

The ability to detect and quantify changes in the Earth's environment depends on sensors that can provide calibrated (known accuracy and precision) and consistent measurements of the Earth's surface features through time. The correct interpretation of scientific information from a global, long-term series of remote-sensing products requires the ability to discriminate between product artifacts and changes in the Earth processes being monitored (Roy et al., 2002). Radiometric characterization and calibration is a prerequisite for creating high-quality science data, and consequently, higher-level downstream products.

3.1. MSS sensors

Each MSS sensor incorporates an Internal Calibrator (IC) system, consisting of a pair of lamp assemblies (for redundancy) and a rotating shutter wheel. The shutter wheel includes a mirror and a neutral density filter that varies in transmittance with rotation angle. The calibration system output appears as a light pulse at the focal plane that rises rapidly and then decays slowly. This pulse is referred to as the calibration wedge (Markham & Barker, 1987). The radiometric calibration of the MSS sensors is performed in two stages. First, raw data from Bands 1–3 are "decompressed" or linearized and rescaled to 7 bits using fixed look-up tables. The look-up tables are derived from prelaunch measurements of the compression amplifiers. Second, the postlaunch gain and offset for each detector of all four bands are individually calculated by a linear regression of the detector responses to the samples of the in-orbit calibration wedge with the prelaunch radiances for these samples. A reasonable estimate of the overall calibration uncertainty of each MSS sensor at-sensor spectral radiances is ±10%, which was the specified accuracy for the sensor (Markham & Barker, 1987). In most cases, the ground processing system must apply an additional step to uncalibrate the MSS data because a number of MSS scenes were archived as radiometrically corrected products. The previously calibrated archived MSS data must be transformed back into raw DNs using the coefficients stored in the data before applying the radiometric calibration procedure. Studies are underway to evaluate the MSS calibration consistency and provide post-calibration adjustments of the MSS sensors so they are consistent over time and consistent between sensors (Helder, 2008).

3.2. TM sensors

The TM sensor includes an onboard calibration system called the IC. The IC consists of a black shutter flag, three lamps, a cavity blackbody, and the optical components necessary to get the lamp and blackbody radiance to the focal plane. The lamps are used to calibrate the reflective bands, and the blackbody is used to calibrate the thermal band. Historically, the TM radiometric calibration procedure used the detector's response to the IC to determine radiometric gains and offsets on a scene-by-scene basis. Before launch, the effective radiance of each lamp state for each reflective band's detector was determined such that each detector's response to the internal lamp was compared to its response to an external calibrated source. The reflective band calibration algorithm for in-flight data used a regression of the detector responses against the prelaunch radiances of the eight lamp states. The slope of the regression represented the gain, while the intercept represented the bias. This algorithm assumed that irradiance of the calibration lamps remained constant over time since launch. Any change in response was treated as a change in sensor response, and thus was compensated for during processing. On-orbit data from individual lamps indicated that the lamps were not particularly stable. Because there was no way to validate the lamp radiances once in orbit, the prelaunch measured radiances were the only metrics available for

[2] http://landsathandbook.gsfc.nasa.gov/handbook.html.
[3] http://earthexplorer.usgs.gov.
[4] http://glovis.usgs.gov.

Table 2
MSS spectral range, post-calibration dynamic ranges, and mean exoatmospheric solar irradiance ($ESUN_\lambda$).

MSS sensors ($Q_{calmin}=0$ and $Q_{calmax}=127$)							
Band	Spectral range	Center wavelength	$LMIN_\lambda$	$LMAX_\lambda$	$G_{rescale}$	$B_{rescale}$	$ESUN_\lambda$
Units	μm		W/(m² sr μm)		(W/m² sr μm)/DN	W/(m² sr μm)	W/(m² μm)
L1 MSS (NLAPS)							
1	0.499–0.597	0.548	0	248	1.952760	0	1823
2	0.603–0.701	0.652	0	200	1.574800	0	1559
3	0.694–0.800	0.747	0	176	1.385830	0	1276
4	0.810–0.989	0.900	0	153	1.204720	0	880.1
L2 MSS (NLAPS)							
1	0.497–0.598	0.548	8	263	2.007870	8	1829
2	0.607–0.710	0.659	6	176	1.338580	6	1539
3	0.697–0.802	0.750	6	152	1.149610	6	1268
4	0.807–0.990	0.899	3.66667	130.333	0.997373	3.66667	886.6
L3 MSS (NLAPS)							
1	0.497–0.593	0.545	4	259	2.007870	4	1839
2	0.606–0.705	0.656	3	179	1.385830	3	1555
3	0.693–0.793	0.743	3	149	1.149610	3	1291
4	0.812–0.979	0.896	1	128	1.000000	1	887.9
L4 MSS (NLAPS)							
1	0.495–0.605	0.550	4	238	1.842520	4	1827
2	0.603–0.696	0.650	4	164	1.259840	4	1569
3	0.701–0.813	0.757	5	142	1.078740	5	1260
4	0.808–1.023	0.916	4	116	0.881890	4	866.4
L5 MSS (NLAPS)							
1	0.497–0.607	0.552	3	268	2.086610	3	1824
2	0.603–0.697	0.650	3	179	1.385830	3	1570
3	0.704–0.814	0.759	5	148	1.125980	5	1249
4	0.809–1.036	0.923	3	123	0.944882	3	853.4

Note 1: In some cases, the header file may have different rescaling factors than provided here. In these cases, the user should use the header file information that comes with the product. Table 1 (Markham & Barker, 1986, 1987) provides a summary of the band-specific $LMIN_\lambda$ and $LMAX_\lambda$ rescaling factors that have been used at different times and by different systems for the ground processing of MSS data.

the regression procedure. Recent studies[5] (Thome et al., 1997a, 1997b; Helder et al., 1998; Markham et al., 1998; Teillet et al., 2001, 2004; Chander et al., 2004a) indicate that the regression calibration did not actually represent detector gains for most of the mission. However, the regression procedure was used until 2003 to generate L5 TM data products and is still used to generate L4 TM products. The calibration uncertainties of the L4 TM at-sensor spectral radiances are ±10%, which was the specified accuracy for the sensor (GSFC specification, 1981).

The L5 TM reflective band calibration procedure was updated in 2003 (Chander & Markham, 2003) to remove the dependence on the changing IC lamps. The new calibration gains implemented on May 5, 2003, for the reflective bands (1–5, 7) were based on lifetime radiometric calibration curves derived from the detectors' responses to the IC, cross-calibration with ETM+, and vicarious measurements (Chander et al., 2004a). The gains were further revised on April 2, 2007, based on the detectors' responses to pseudo-invariant desert sites and cross-calibration with ETM+ (Chander et al., 2007a). Although this calibration update applies to all archived and future L5 TM data, the principal improvements in the calibration are for data acquired during the first eight years of the mission (1984–1991), where changes in the sensor gain values are as much as 15%. The radiometric scaling coefficients for Bands 1 and 2 for approximately the first eight years of the mission have also been changed. Along with the revised reflective band radiometric calibration on April 2, 2007, an sensor offset correction of 0.092 W/(m² sr μm), or about 0.68 K (at 300 K), was added to all L5 TM thermal band (Band 6) data acquired since April 1999 (Barsi et al., 2007). The L5 TM radiometric calibration uncertainty of the at-sensor spectral radiances is around 5% and is somewhat worse for early years, when the sensor was changing more rapidly, and better for later years (Helder et al., 2008). The L4 TM reflective bands and the thermal band on both the TM sensors continue to be calibrated using the IC. Further updates to improve the thermal band calibration are being investigated, as is the calibration of the L4 TM.

3.3. ETM+ sensor

The ETM+ sensor has three onboard calibration devices for the reflective bands: a Full Aperture Solar Calibrator (FASC), which is a white painted diffuser panel; a Partial Aperture Solar Calibrator (PASC), which is a set of optics that allows the ETM+ to image the Sun through small holes; and an IC, which consists of two lamps, a blackbody, a shutter, and optics to transfer the energy from the calibration sources to the focal plane. The ETM+ sensor has also been calibrated vicariously using Earth targets such as Railroad Valley (Thome, 2001; Thome et al., 2004) and cross-calibrated with multiple sensors (Teillet et al., 2001, 2006, 2007; Thome et al., 2003; Chander et al., 2004b, 2007b, 2008). The gain trends from the ETM+ sensor are regularly monitored on-orbit using the onboard calibrators and vicarious calibration. The calibration uncertainties of ETM+ at-sensor spectral radiances are ±5%. ETM+ is the most stable of the Landsat sensors, changing by no more than 0.5% per year in its radiometric calibration (Markham et al., 2004b). The ETM+ radiometric calibration procedure uses prelaunch gain coefficients populated in the Calibration Parameter File (CPF). These CPFs, issued quarterly, have both an "effective" and "version" date. The effective date of the CPF must match the acquisition date of the scene. A CPF version is active until a new CPF for that date period supersedes it. Data can be processed with any version of a CPF; the later versions have more refined parameters, as they reflect more data-rich post-acquisition analysis.

The ETM+ images are acquired in either a low-or high-gain state. The goal of using two gain settings is to maximize the sensors' 8-bit radiometric resolution without saturating the detectors. For all bands,

[5] Radiometric performance studies of the TM sensors have also led to a detailed understanding of several image artifacts due to particular sensor characteristics (Helder & Ruggles, 2004). These artifact corrections (such as Scan-Correlated Shift [SCS], Memory Effect [ME], and Coherent Noise [CN]), along with detector-to-detector normalization (Helder et al., 2004), are necessary to maintain the internal consistency of the calibration within a scene.

Table 3
TM spectral range, post-calibration dynamic ranges, and mean exoatmospheric solar irradiance ($ESUN_\lambda$).

TM Sensors (Q_{calmin} = 1 and Q_{calmax} = 255)							
Band	Spectral range	Center wavelength	$LMIN_\lambda$	$LMAX_\lambda$	$G_{rescale}$	$B_{rescale}$	$ESUN_\lambda$
Units	μm		W/(m² sr m)		(W/m² sr m)/DN	W/(m² sr m)	W/(m² m)
L4 TM (NLAPS)							
1	0.452 – 0.518	0.485	-1.52	152.10	0.602431	-1.52	1983
2	0.529 – 0.609	0.569	-2.84	296.81	1.175098	-2.84	1795
3	0.624 – 0.693	0.659	-1.17	204.30	0.805765	-1.17	1539
4	0.776 – 0.905	0.841	-1.51	206.20	0.814549	-1.51	1028
5	1.568 – 1.784	1.676	-0.37	27.19	0.108078	-0.37	219.8
6	10.42 – 11.66	11.040	1.2378	15.3032	0.055158	1.2378	N/A
7	2.097 – 2.347	2.222	-0.15	14.38	0.056980	-0.15	83.49
L4 TM (LPGS)							
1	0.452 – 0.518	0.485	-1.52	163	0.647717	-2.17	1983
			-1.52	171	0.679213	-2.20	
2	0.529 – 0.609	0.569	-2.84	336	1.334016	-4.17	1795
3	0.624 – 0.693	0.659	-1.17	254	1.004606	-2.17	1539
4	0.776 – 0.905	0.841	-1.51	221	0.876024	-2.39	1028
5	1.568 – 1.784	1.676	-0.37	31.4	0.125079	-0.50	219.8
6	10.42 – 11.66	11.040	1.2378	15.3032	0.055376	1.2378	N/A
7	2.097 – 2.347	2.222	-0.15	16.6	0.065945	-0.22	83.49
L5 TM (LPGS)							
1	0.452 – 0.518	0.485	-1.52	169	0.671339	-2.19	1983
			-1.52	193	0.765827	-2.29	
2	0.528 – 0.609	0.569	-2.84	333	1.322205	-4.16	1796
			-2.84	365	1.448189	-4.29	
3	0.626 – 0.693	0.660	-1.17	264	1.043976	-2.21	1536
4	0.776 – 0.904	0.840	-1.51	221	0.876024	-2.39	1031
5	1.567 – 1.784	1.676	-0.37	30.2	0.120354	-0.49	220.0
6	10.45 – 12.42	11.435	1.2378	15.3032	0.055376	1.18	N/A
7	2.097 – 2.349	2.223	-0.15	16.5	0.065551	-0.22	83.44

Note 1: The $Q_{calmin} = 0$ for data processed using NLAPS. The $Q_{calmin} = 1$ for data processed using LPGS.
Note 2: The $LMIN_\lambda$ is typically set to a small negative number, so a "zero radiance" target will be scaled to a small positive DN value, even in the presence of sensor noise (typically 1 DN or less [1 sigma]). This value is usually not changed throughout the mission.
Note 3: In mid-2009, the processing of L4 TM data will transition from NLAPS to LPGS. NLAPS used IC-based calibration. The L4 TM data processed by LPGS will be radiometrically calibrated using a new lifetime gain model procedure and revised calibration parameters. Use the header file information that comes with the product and the above rescaling factors will not be applicable. The numbers highlighted in grey are the revised ($LMAX_\lambda = 163$) post-calibration dynamic ranges for L4 TM Band 1 data acquired between July 16, 1982 (launch), and August 23, 1986.
Note 4: The radiometric scaling coefficients for L5 TM Bands 1 and 2 for approximately the first eight years (1984–1991) of the mission were changed to optimize the dynamic range and better preserve the sensitivity of the early mission data. The numbers highlighted in grey are the revised ($LMAX_\lambda = 169, 333$) post-calibration dynamic ranges for L5 TM Band 1 and 2 data acquired between March 1, 1984 (launch), and December 31, 1991 (Chander et al., 2007a).

the low-gain dynamic range is approximately 1.5 times the high-gain dynamic range. Therefore, low-gain mode is used to image surfaces with high brightness (higher dynamic range but low sensitivity), and high-gain mode is used to image surfaces with low brightness (lower dynamic range but high sensitivity).

All of the ETM+ acquisitions after May 31, 2003, have an anomaly caused by the failure of the Scan Line Corrector (SLC), which compensated for the forward motion of the spacecraft so that all the scans were aligned parallel with each other. The images with data loss are referred to as SLC-off images, whereas images collected prior to

Table 4
ETM+ spectral range, post-calibration dynamic ranges, and mean exoatmospheric solar irradiance ($ESUN_\lambda$).

L7 ETM+ Sensor ($Q_{calmin} = 1$ and $Q_{calmax} = 255$)							
Band	Spectral range	Center wavelength	$LMIN_\lambda$	$LMAX_\lambda$	$G_{rescale}$	$B_{rescale}$	$ESUN_\lambda$
Units	μm		W/(m² sr μm)		(W/m² sr μm)/DN	W/(m² sr μm)	W/(m² μm)
Low gain (LPGS)							
1	0.452–0.514	0.483	−6.2	293.7	1.180709	−7.38	1997
2	0.519–0.601	0.560	−6.4	300.9	1.209843	−7.61	1812
3	0.631–0.692	0.662	−5.0	234.4	0.942520	−5.94	1533
4	0.772–0.898	0.835	−5.1	241.1	0.969291	−6.07	1039
5	1.547–1.748	1.648	−1.0	47.57	0.191220	−1.19	230.8
6	10.31–12.36	11.335	0.0	17.04	0.067087	−0.07	N/A
7	2.065–2.346	2.206	−0.35	16.54	0.066496	−0.42	84.90
PAN	0.515–0.896	0.706	−4.7	243.1	0.975591	−5.68	1362
High Gain (LPGS)							
1	0.452–0.514	0.483	−6.2	191.6	0.778740	−6.98	1997
2	0.519–0.601	0.560	−6.4	196.5	0.798819	−7.20	1812
3	0.631–0.692	0.662	−5.0	152.9	0.621654	−5.62	1533
4	0.772–0.898	0.835	−5.1	157.4	0.639764	−5.74	1039
5	1.547–1.748	1.648	−1.0	31.06	0.126220	−1.13	230.8
6	10.31–12.36	11.335	3.2	12.65	0.037205	3.16	N/A
7	2.065–2.346	2.206	−0.35	10.80	0.043898	−0.39	84.90
PAN	0.515–0.896	0.706	−4.7	158.3	0.641732	−5.34	1362

Table 5
ALI spectral range, post-calibration dynamic ranges, and mean exoatmospheric solar irradiance ($ESUN_\lambda$).

EO-1 ALI Sensor ($Q_{calmin}=1$ and $Q_{calmax}=32767$)							
Band	Spectral range	Center wavelength	$LMIN_\lambda$	$LMAX_\lambda$	$G_{rescale}$	$B_{rescale}$	$ESUN_\lambda$
Units	μm		$W/(m^2$ sr μm)		$(W/m^2$ sr μm)/DN	$W/(m^2$ sr μm)	$W/(m^2$ μm)
PAN	0.480–0.690	0.585	−2.18	784.2	0.024	−2.2	1724
1P	0.433–0.453	0.443	−3.36	1471	0.045	−3.4	1857
1	0.450–0.515	0.483	−4.36	1405	0.043	−4.4	1996
2	0.525–0.605	0.565	−1.87	915.5	0.028	−1.9	1807
3	0.633–0.690	0.662	−1.28	588.5	0.018	−1.3	1536
4	0.775–0.805	0.790	−0.84	359.6	0.011	−0.85	1145
4P	0.845–0.890	0.868	−0.641	297.5	0.0091	−0.65	955.8
5P	1.200–1.300	1.250	−1.29	270.7	0.0083	−1.3	452.3
5	1.550–1.750	1.650	−0.597	91.14	0.0028	−0.6	235.1
7	2.080–2.350	2.215	−0.209	29.61	0.00091	−0.21	82.38

All EO-1 ALI standard Level 1 products are processed through the EO-1 Product Generation System (EPGS).

the SLC failure are referred to as SLC-on images (i.e., no data gaps exist). The malfunction of the SLC mirror assembly resulted in the loss of approximately 22% of the normal scene area (Storey et al., 2005). The missing data affects most of the image, with scan gaps varying in width from one pixel or less near the center of the image to 14 pixels along the east and west edges of the image, creating a repeating wedge-shaped pattern along the edges. The middle of the scene, approximately 22 km wide on a Level 1 product, contains very little duplication or data loss. Note that the SLC failure has no impact on the radiometric performance with the valid pixels.

3.4. ALI sensor

The ALI has two onboard radiometric calibration devices: a lamp-based system and a solar-diffuser with variable irradiance controlled by an aperture door. In addition to its onboard calibrators, ALI has the ability to collect lunar and stellar observations for calibration purposes. The ALI radiometric calibration procedure uses a fixed set of detector-by-detector gains established shortly after launch and biases measured shortly after each scene acquisition by closing the ALI's shutter. The calibration uncertainties of the ALI at-sensor spectral radiances are ±5% (Mendenhall & Lencioni, 2002). The ALI sensor is well-behaved and stable, with changes in the response being less than 2% per year even early in the mission, and averaging, at most, slightly more than 1% per year over the full mission (Markham et al., 2006).

4. Conversion to at-sensor spectral radiance (Q_{cal}-to-L_λ)

Calculation of at-sensor spectral radiance is the fundamental step in converting image data from multiple sensors and platforms into a physically meaningful common radiometric scale. Radiometric calibration of the MSS, TM, ETM+, and ALI sensors involves rescaling the raw digital numbers (Q) transmitted from the satellite to calibrated digital numbers (Q_{cal})[6], which have the same radiometric scaling for all scenes processed on the ground for a specific period.

During radiometric calibration, pixel values (Q) from raw, unprocessed image data are converted to units of absolute spectral radiance using 32-bit floating-point calculations. The absolute radiance values are then scaled to 7-bit (MSS, $Q_{calmax}=127$), 8-bit (TM and ETM+, $Q_{calmax}=255$), and 16-bit (ALI, $Q_{calmax}=32767$) numbers representing Q_{cal} before output to distribution media. Conversion from Q_{cal} in Level 1 products back to at-sensor spectral radiance (L_λ) requires knowledge of the lower and upper limit of the original rescaling factors. The following equation is used to perform the Q_{cal}-to-L_λ conversion for Level 1 products:

$$L_\lambda = \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax} - Q_{calmin}}\right)(Q_{cal} - Q_{calmin}) + LMIN_\lambda$$

or

$$L_\lambda = G_{rescale} \times Q_{cal} + B_{rescale} \quad \text{where :} \tag{1}$$

$$G_{rescale} = \frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax} - Q_{calmin}}$$

$$B_{rescale} = LMIN_\lambda - \left(\frac{LMAX_\lambda - LMIN_\lambda}{Q_{calmax} - Q_{calmin}}\right)Q_{calmin}$$

where

$L_\lambda=$ Spectral radiance at the sensor's aperture [$W/(m^2$ sr μm)]
$Q_{cal}=$ Quantized calibrated pixel value [DN]
$Q_{calmin}=$ Minimum quantized calibrated pixel value corresponding to $LMIN_\lambda$ [DN]
$Q_{calmax}=$ Maximum quantized calibrated pixel value corresponding to $LMAX_\lambda$ [DN]
$LMIN_\lambda=$ Spectral at-sensor radiance that is scaled to Q_{calmin} [$W/(m^2$ sr μm)]
$LMAX_\lambda=$ Spectral at-sensor radiance that is scaled to Q_{calmax} [$W/(m^2$ sr μm)]
$G_{rescale}=$ Band-specific rescaling gain factor [$(W/(m^2$ sr μm))/DN]
$B_{rescale}=$ Band-specific rescaling bias factor [$W/(m^2$ sr μm)]

Historically, the MSS and TM calibration information is presented in spectral radiance units of $mW/(cm^2$ sr μm). To maintain consistency with ETM+ spectral radiance, units of $W/(m^2$ sr μm) are now used for MSS and TM calibration information. The conversion factor is 1:10 when converting from $mW/(cm^2$ sr μm) units to $W/(m^2$ sr μm). Tables 2, 3, 4, and 5 summarize the spectral range, post-calibration dynamic ranges[7] ($LMIN_\lambda$ and $LMAX_\lambda$ scaling parameters and the corresponding rescaling gain [$G_{rescale}$] and rescaling bias [$B_{rescale}$] values), and mean exoatmospheric solar irradiance ($ESUN_\lambda$) for the MSS, TM, ETM+, and ALI sensors, respectively.

[6] These are the DNs that users receive with Level 1 Landsat products.

[7] The post-calibration dynamic ranges summarized in Tables 2–5 are only applicable to Landsat data processed and distributed by the USGS EROS Center. The IGSs may process the data differently, and these rescaling factors may not be applicable. "Special collections," such as the Multi-Resolution Land Characteristics Consortium (MRLC) or Global Land Survey (GLS), may have a different processing history, so the user needs to verify the respective product header information.

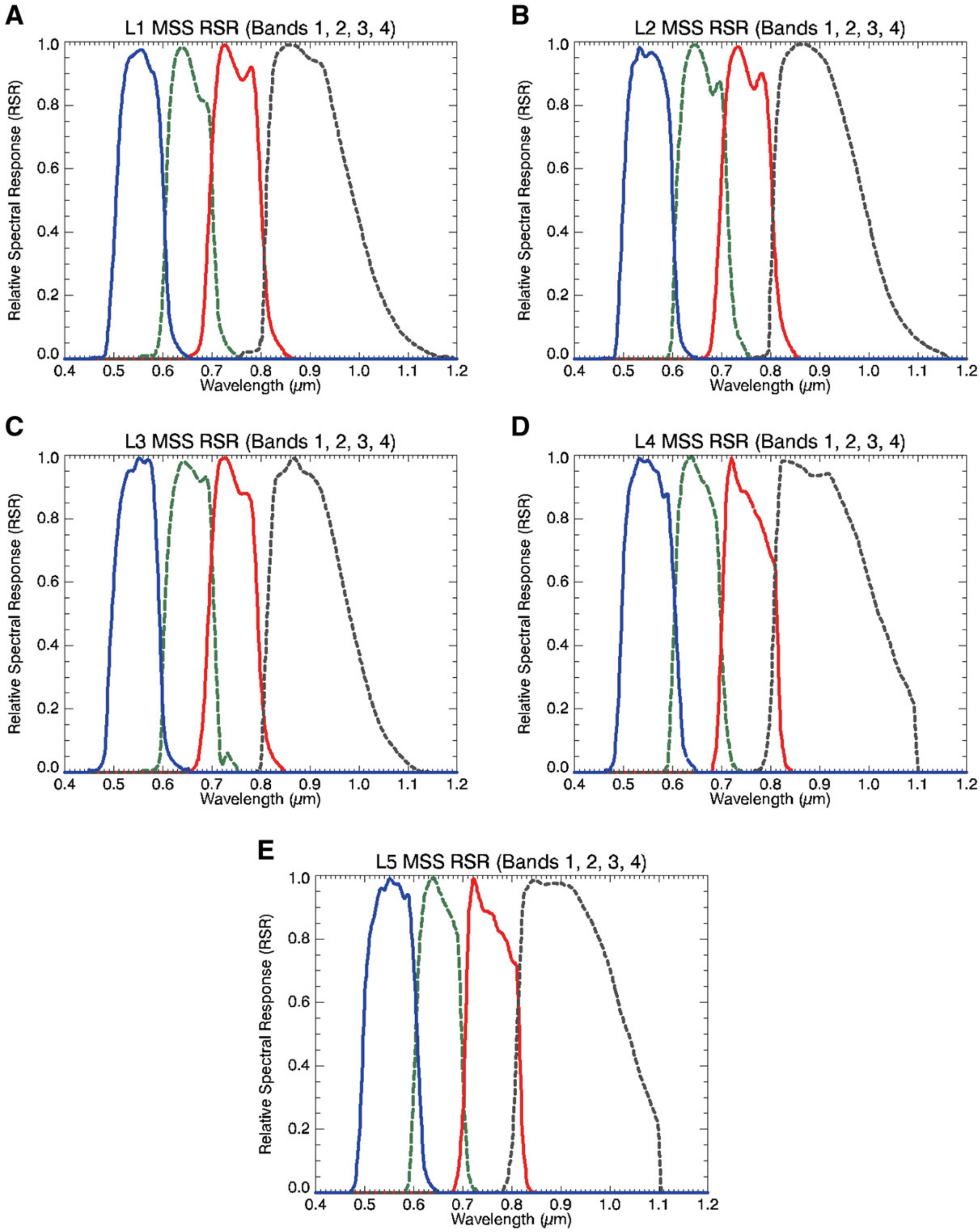

Fig. 1. Comparison of the solar reflective bands RSR profiles of L1–5 MSS sensors.

Tables 2–5 give the prelaunch "measured" (as-built performance) spectral ranges. These numbers are slightly different from the original filter specification. The center wavelengths are the average of the two spectral range numbers. Figs. 1 and 2 show the Relative Spectral Response (RSR) profiles of the Landsat MSS (Markham & Barker, 1983), TM (Markham & Barker, 1985), ETM+(Handbook[2]), and ALI (Mendenhall & Parker, 1999) sensors measured during prelaunch characterization. The ETM+ spectral bands were designed to mimic the standard TM spectral bands 1–7. The ALI bands were designed to mimic the six standard ETM+ solar reflective spectral bands 1–5, and 7; three new bands, 1p, 4p, and 5p, were added to more effectively address atmospheric interference effects and specific applications. The ALI band numbering corresponds with the ETM+ spectral bands. Bands not present on the ETM+ sensor are given the "p," or prime, designation. MSS spectral bands are significantly different from TM and ETM+ spectral bands.

The post-calibration dynamic ranges are band-specific rescaling factors typically provided in the Level 1 product header file. Over the life of the Landsat sensors, occasional changes have occurred in

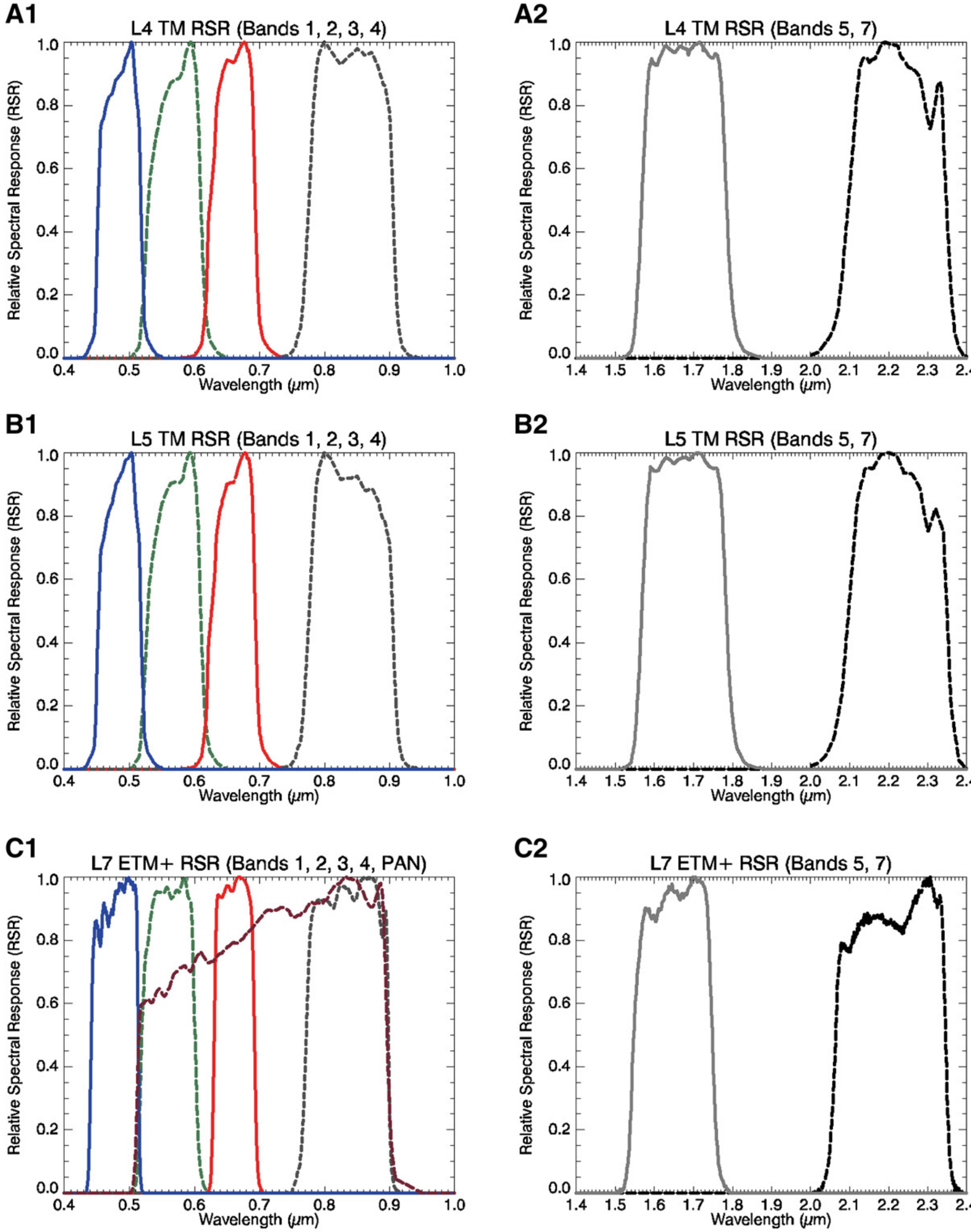

Fig. 2. Comparison of the solar reflective bands RSR profiles of L4 TM, L5 TM, L7 ETM+, and EO-1 ALI sensors.

the post-calibration dynamic range. Future changes are anticipated, especially in the MSS and TM data, because of the possible adjustment of the calibration constants based on comparisons to absolute radiometric measurements made on the ground. In some cases, the header file may have different rescaling factors than provided in the table included here. In these cases, the user should use the header file information that comes with the product.

Two processing systems will continue to generate Landsat data products: the Level 1 Product Generation System (LPGS) and the National Land Archive Production System (NLAPS). Starting December 8, 2008, all L7 ETM+ and L5 TM (except Thematic Mapper-Archive [TM-A][8] products) standard Level 1 products are processed through the LPGS, and all L4 TM and MSS standard Level 1 products are processed through the NLAPS. The Landsat Program is working toward transitioning the processing of all Landsat data to LPGS (Kline, personal

8 A small number of TM scenes were archived as radiometrically corrected products known as TM-A data. The TM-A data are archived on a scene-by-scene basis (instead of intervals). The L4 and L5 TM-A scenes will continue to be processed using NLAPS (with $Q_{calmin}=0$), which attempts to uncalibrate the previously applied calibration and generates the product using updated calibration procedures. Note that approximately 80 L4 TM and approximately 13,300 L5 TM scenes are archived as TM-A data, with acquisition dates ranging between Sept.1982 and Aug. 1990.

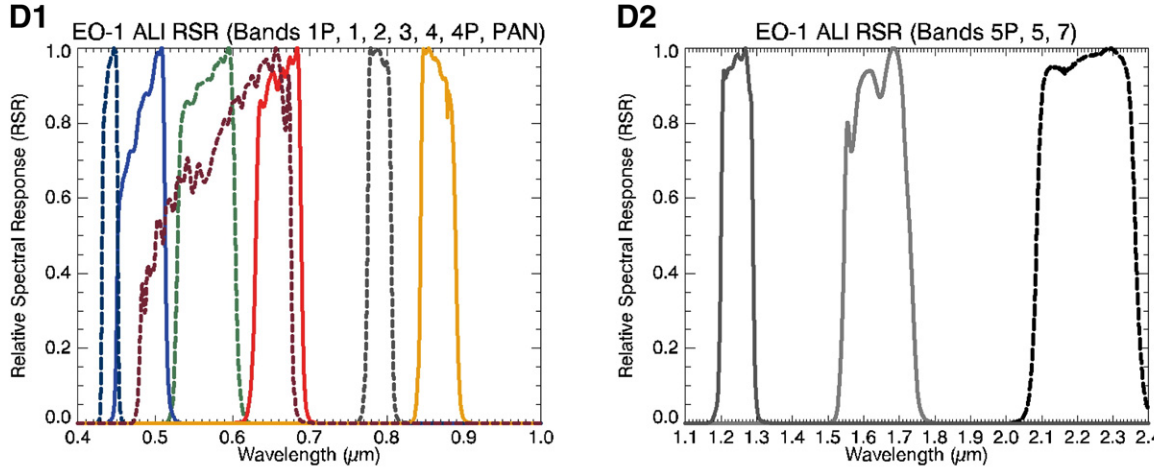

Fig. 2 *(continued)*.

communication). In mid-2009, the processing of L4 TM data will transition from NLAPS to LPGS. The scenes processed using LPGS include a header file (.MTL), which lists the $LMIN_\lambda$ and $LMAX_\lambda$ values but not the rescaling gain and bias numbers. The scenes processed using NLAPS include a processing history work order report (.WO), which lists the rescaling gain and bias numbers but not the $LMIN_\lambda$ and $LMAX_\lambda$.

The sensitivity of the detector changes over time, causing a change in the detector gain applied during radiometric calibration. However, the numbers presented in Tables 2–5 are the rescaling factors, which are the post-calibration dynamic ranges. The $LMIN_\lambda$ and $LMAX_\lambda$ are a representation of how the output Landsat Level 1 data products are scaled in at-sensor radiance units. Generally, there is no need to change the $LMIN_\lambda$ or $LMAX_\lambda$ unless something changes drastically on the sensor. Thus, there is no time dependence for any of the rescaling factors in Tables 2–5.

5. Conversion to TOA reflectance (L_λ-to-ρ_P)

A reduction in scene-to-scene variability can be achieved by converting the at-sensor spectral radiance to exoatmospheric TOA reflectance, also known as in-band planetary albedo. When comparing images from different sensors, there are three advantages to using TOA reflectance instead of at-sensor spectral radiance. First, it removes the cosine effect of different solar zenith angles due to the time difference between data acquisitions. Second, TOA reflectance compensates for different values of the exoatmospheric solar irradiance arising from spectral band differences. Third, the TOA reflectance corrects for the variation in the Earth–Sun distance between different data acquisition dates. These variations can be significant geographically and temporally. The TOA reflectance of the Earth is computed according to the equation:

$$\rho_\lambda = \frac{\pi \cdot L_\lambda \cdot d^2}{\mathrm{ESUN}_\lambda \cdot \cos\theta_s} \tag{2}$$

where

$\rho_\lambda=$ Planetary TOA reflectance [unitless]
$\pi=$ Mathematical constant equal to ~3.14159 [unitless]
$L_\lambda=$ Spectral radiance at the sensor's aperture [W/(m^2 sr μm)]
$d=$ Earth–Sun distance [astronomical units]
$\mathrm{ESUN}_\lambda=$ Mean exoatmospheric solar irradiance [W/(m^2 μm)]
$\theta_s=$ Solar zenith angle [degrees[9]]

Note that the cosine of the solar zenith angle is equal to the sine of the solar elevation angle. The solar elevation angle at the Landsat scene center is typically stored in the Level 1 product header file (.MTL or .WO) or retrieved from the USGS EarthExplorer or GloVis online interfaces under the respective scene metadata (these web sites also contain the acquisition time in hours, minutes, and seconds). The TOA reflectance calculation requires the Earth–Sun distance (d). Table 6 presents d in astronomical units throughout a year generated using the Jet Propulsion Laboratory (JPL) Ephemeris[10] (DE405) data. The d numbers are also tabulated in the Nautical Almanac Office.

The last column of Tables 2–5 summarizes solar exoatmospheric spectral irradiances (ESUN_λ) for the MSS, TM, ETM+, and ALI sensors using the Thuillier solar spectrum (Thuillier et al., 2003). The Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) recommends[11] using this spectrum for applications in optical-based Earth Observation that use an exoatmospheric solar irradiance spectrum. The Thuillier spectrum is believed to be the most accurate and an improvement over the other solar spectrum. Note that the CHKUR solar spectrum in MODTRAN 4.0 (Air Force Laboratory, 1998) was used previously for ETM+(Handbook[2]) and TM (Chander & Markham, 2003), whereas the Neckel and Lab (Neckel & Labs, 1984) and Iqbal (Iqbal, 1983) solar spectrums were used for MSS and TM solar irradiance values (Markham & Barker, 1986). The primary differences occur in Bands 5 and 7. For comparisons to other sensors, users need to verify that the same solar spectrum is used for all sensors.

6. Conversion to at-sensor brightness temperature (L_λ-to-T)

The thermal band data (Band 6 on TM and ETM+) can be converted from at-sensor spectral radiance to effective at-sensor brightness temperature. The at-sensor brightness temperature assumes that the Earth's surface is a black body (i.e., spectral emissivity is 1), and includes atmospheric effects (absorption and emissions along path). The at-sensor temperature uses the prelaunch calibration constants given in Table 7. The conversion formula from the at-sensor's spectral radiance to at-sensor brightness temperature is:

$$T = \frac{K2}{ln\left(\frac{K1}{L_\lambda} + 1\right)} \tag{3}$$

where:

$T=$ Effective at-sensor brightness temperature [K]
$K2=$ Calibration constant 2 [K]

[9] Note that Excel, Matlab, C, and many other software applications use radians, not degrees, to perform calculations. The conversion from degrees to radians is a multiplication factor of pi/180.

[10] http://ssd.jpl.nasa.gov/?horizons.

[11] CEOS-recommended solar irradiance spectrum, http://wgcv.ceos.org.

Table 6
Earth–Sun distance (d) in astronomical units for Day of the Year (DOY).

DOY	d	DOY	d	DOY	d	DOY	d	DOY	d	DOY	d
1	0.98331	61	0.99108	121	1.00756	181	1.01665	241	1.00992	301	0.99359
2	0.98330	62	0.99133	122	1.00781	182	1.01667	242	1.00969	302	0.99332
3	0.98330	63	0.99158	123	1.00806	183	1.01668	243	1.00946	303	0.99306
4	0.98330	64	0.99183	124	1.00831	184	1.01670	244	1.00922	304	0.99279
5	0.98330	65	0.99208	125	1.00856	185	1.01670	245	1.00898	305	0.99253
6	0.98332	66	0.99234	126	1.00880	186	1.01670	246	1.00874	306	0.99228
7	0.98333	67	0.99260	127	1.00904	187	1.01670	247	1.00850	307	0.99202
8	0.98335	68	0.99286	128	1.00928	188	1.01669	248	1.00825	308	0.99177
9	0.98338	69	0.99312	129	1.00952	189	1.01668	249	1.00800	309	0.99152
10	0.98341	70	0.99339	130	1.00975	190	1.01666	250	1.00775	310	0.99127
11	0.98345	71	0.99365	131	1.00998	191	1.01664	251	1.00750	311	0.99102
12	0.98349	72	0.99392	132	1.01020	192	1.01661	252	1.00724	312	0.99078
13	0.98354	73	0.99419	133	1.01043	193	1.01658	253	1.00698	313	0.99054
14	0.98359	74	0.99446	134	1.01065	194	1.01655	254	1.00672	314	0.99030
15	0.98365	75	0.99474	135	1.01087	195	1.01650	255	1.00646	315	0.99007
16	0.98371	76	0.99501	136	1.01108	196	1.01646	256	1.00620	316	0.98983
17	0.98378	77	0.99529	137	1.01129	197	1.01641	257	1.00593	317	0.98961
18	0.98385	78	0.99556	138	1.01150	198	1.01635	258	1.00566	318	0.98938
19	0.98393	79	0.99584	139	1.01170	199	1.01629	259	1.00539	319	0.98916
20	0.98401	80	0.99612	140	1.01191	200	1.01623	260	1.00512	320	0.98894
21	0.98410	81	0.99640	141	1.01210	201	1.01616	261	1.00485	321	0.98872
22	0.98419	82	0.99669	142	1.01230	202	1.01609	262	1.00457	322	0.98851
23	0.98428	83	0.99697	143	1.01249	203	1.01601	263	1.00430	323	0.98830
24	0.98439	84	0.99725	144	1.01267	204	1.01592	264	1.00402	324	0.98809
25	0.98449	85	0.99754	145	1.01286	205	1.01584	265	1.00374	325	0.98789
26	0.98460	86	0.99782	146	1.01304	206	1.01575	266	1.00346	326	0.98769
27	0.98472	87	0.99811	147	1.01321	207	1.01565	267	1.00318	327	0.98750
28	0.98484	88	0.99840	148	1.01338	208	1.01555	268	1.00290	328	0.98731
29	0.98496	89	0.99868	149	1.01355	209	1.01544	269	1.00262	329	0.98712
30	0.98509	90	0.99897	150	1.01371	210	1.01533	270	1.00234	330	0.98694
31	0.98523	91	0.99926	151	1.01387	211	1.01522	271	1.00205	331	0.98676
32	0.98536	92	0.99954	152	1.01403	212	1.01510	272	1.00177	332	0.98658
33	0.98551	93	0.99983	153	1.01418	213	1.01497	273	1.00148	333	0.98641
34	0.98565	94	1.00012	154	1.01433	214	1.01485	274	1.00119	334	0.98624
35	0.98580	95	1.00041	155	1.01447	215	1.01471	275	1.00091	335	0.98608
36	0.98596	96	1.00069	156	1.01461	216	1.01458	276	1.00062	336	0.98592
37	0.98612	97	1.00098	157	1.01475	217	1.01444	277	1.00033	337	0.98577
38	0.98628	98	1.00127	158	1.01488	218	1.01429	278	1.00005	338	0.98562
39	0.98645	99	1.00155	159	1.01500	219	1.01414	279	0.99976	339	0.98547
40	0.98662	100	1.00184	160	1.01513	220	1.01399	280	0.99947	340	0.98533
41	0.98680	101	1.00212	161	1.01524	221	1.01383	281	0.99918	341	0.98519
42	0.98698	102	1.00240	162	1.01536	222	1.01367	282	0.99890	342	0.98506
43	0.98717	103	1.00269	163	1.01547	223	1.01351	283	0.99861	343	0.98493
44	0.98735	104	1.00297	164	1.01557	224	1.01334	284	0.99832	344	0.98481
45	0.98755	105	1.00325	165	1.01567	225	1.01317	285	0.99804	345	0.98469
46	0.98774	106	1.00353	166	1.01577	226	1.01299	286	0.99775	346	0.98457
47	0.98794	107	1.00381	167	1.01586	227	1.01281	287	0.99747	347	0.98446
48	0.98814	108	1.00409	168	1.01595	228	1.01263	288	0.99718	348	0.98436
49	0.98835	109	1.00437	169	1.01603	229	1.01244	289	0.99690	349	0.98426
50	0.98856	110	1.00464	170	1.01610	230	1.01225	290	0.99662	350	0.98416
51	0.98877	111	1.00492	171	1.01618	231	1.01205	291	0.99634	351	0.98407
52	0.98899	112	1.00519	172	1.01625	232	1.01186	292	0.99605	352	0.98399
53	0.98921	113	1.00546	173	1.01631	233	1.01165	293	0.99577	353	0.98391
54	0.98944	114	1.00573	174	1.01637	234	1.01145	294	0.99550	354	0.98383
55	0.98966	115	1.00600	175	1.01642	235	1.01124	295	0.99522	355	0.98376
56	0.98989	116	1.00626	176	1.01647	236	1.01103	296	0.99494	356	0.98370
57	0.99012	117	1.00653	177	1.01652	237	1.01081	297	0.99467	357	0.98363
58	0.99036	118	1.00679	178	1.01656	238	1.01060	298	0.99440	358	0.98358
59	0.99060	119	1.00705	179	1.01659	239	1.01037	299	0.99412	359	0.98353
60	0.99084	120	1.00731	180	1.01662	240	1.01015	300	0.99385	360	0.98348
										361	0.98344
										362	0.98340
										363	0.98337
										364	0.98335
										365	0.98333
										366	0.98331

$K1=$ Calibration constant 1 [W/(m^2 sr μm)]
$L_\lambda=$ Spectral radiance at the sensor's aperture [W/(m^2 sr μm)]
ln= Natural logarithm

The ETM+ Level 1 product has two thermal bands, one acquired using a low gain setting (often referred to as Band 6 L; useful temperature range of 130–350 K) and the other using a high gain setting (often referred to as Band 6H; useful temperature range of 240–320 K). The noise equivalent change in temperature (NEΔT) at 280 K for ETM+ high gain is 0.22 and for low gain is 0.28. The TM Level 1 product has only one thermal band (there is no gain setting on the TM sensor), and the thermal band images have a useful temperature

Table 7
TM and ETM+ thermal band calibration constants.

Constant	K1	K2
Units	W/(m^2 sr μm)	Kelvin
L4 TM	671.62	1284.30
L5 TM	607.76	1260.56
L7 ETM+	666.09	1282.71

range of 200–340 K. The NEΔT at 280 K for L5 TM is 0.17–0.30 (Barsi et al., 2003).

7. Conclusion

This paper provides equations and rescaling factors for converting Landsat calibrated DNs to absolute units of at-sensor spectral radiance, TOA reflectance, and at-sensor brightness temperature. It tabulates the necessary constants for the MSS, TM, ETM+, and ALI sensors in a coherent manner using the same units and definitions. This paper forms a needed guide for Landsat data users who now have access to the entire Landsat archive at no cost. Studies are ongoing to evaluate the MSS calibration consistency and provide post-calibration adjustments of the MSS sensors so they are consistent over time and consistent between sensors. Further updates to improve the TM and ETM+ thermal band calibration are being investigated, as is the calibration of the L4 TM.

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Appendix A

Table A1
To maintain consistency, all Landsat scenes are based on the following naming convention.

Format Example:	Sensor Examples:
LXSPPPRRRYYYYDDDGSIVV	LM10170391976031AAA01(MSS)
L = Landsat	LT40170361982320XXX08 (TM)
X = Sensor	LE70160392004262EDC02 (ETM+)
S = Satellite	
PPP = Worldwide Reference System (WRS) Path	
RRR = WRS Row	
YYYY = Year	
DDD = Day of Year	
GSI = Ground Station Identifier *	
VV = Version	
*Ground Stations Identifiers-Data received at these sites are held at EROS	
AAA = North American site unknown	GNC = Gatineau, Canada
ASA = Alice Springs, Australia	LGS = EROS, SD, USA, Landsat 5 data acquired by
FUI = Fucino, Italy (Historical)	EROS beginning July 1, 2001
GLC = Gilmore Creek, AK, US	MOR = Moscow, Russia
HOA = Hobart, Australia	MLK = Malinda, Kenya
KIS = Kiruna, Sweden	IKR = Irkutsk, Russia
MTI = Matera, Italy	CHM = Chetumal, Mexico
EDC = Receiving site unknown	XXO = Receiving site unknown
PAC = Prince Albert, Canada	XXX = Receiving site unknown

Table A2
Standard Level 1 product specifications.

Product Type – Level 1T (Terrain Corrected)
Pixel Size – 15/30/60 meters
Output format – GeoTIFF
Resampling Method – Cubic Convolution (CC)
Map Projection – Universal Transverse Mercator (UTM)
Polar Stereographic for Antarctica
Image Orientation – Map (North Up)
Distribution – File Transfer Protocol (FTP) Download only

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