RGDSS Memorandum
Phase 6 –Review and Enhancement of Sprinkler Acreage Timeline
Final

TO: File
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SUBJECT: RGDSS Groundwater Model – Phase 6: Review and Enhancement of Sprinkler Acreage Timeline
DATE: 12/4/2015

1. Introduction

A large number of sprinkler irrigation systems were installed in the San Luis Valley in the 1970s and early 1980s although additional sprinklers are still being installed. Within the Rio Grande Decision Support System (RGDSS) StateCU model (used as a preprocessor for the RGDSS groundwater flow model), irrigated acres assigned to structures are divided between sprinkler and flood irrigation types; with and without groundwater wells. The sprinkler and flood irrigation types are assigned different irrigation application efficiencies for use within the consumptive use modeling. A sprinkler acreage timeline was developed in the RGDSS Phase 5 to track the progression of sprinkler acreage through time.

This memorandum describes the review and enhancement to the methodology used to compute the sprinkler acreage timeline used for structures within the RGDSS StateCU model. 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. *Review the Phase 5 methodologies to estimate sprinkler acreages and define needed improvements for Phase 6.*
2. *Refine the delineation of sprinkler irrigated parcels and the timeline for which sprinklers were installed, fallowed, or no longer used using enhanced irrigated parcel datasets and satellite imagery datasets.*
3. *Develop and implement a dynamic methodology to integrate acreages of sprinkler irrigated parcels with and without access to groundwater and consideration for fallow periods into structure acreages used by StateCU.*

2. Previous Efforts

Leonard Rice Consulting Water Engineers (LRE) developed the sprinkler acreage timeline and methodologies used to calculate structure sprinkler acreages for Phase 5 of the RGDSS model. The timeline and methodologies are described in the RGDSS memorandum *Rio Grande Historic Consumptive Use – Annual Irrigation Parameter Time Series* (LRE, E.M. Wilson 2004) that is included as Appendix A of the June 2004 RGDSS Phase 5 report *Historic Crop Consumptive Use Analysis, Rio Grande Decision Support System* (LRE, E.M. Wilson 2004). This memorandum is attached at the end of this document.

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. Enhancements of the sprinkler acreage timeline integrated into model version 6P35 were implemented by Agro Engineering, Inc. and were documented in the section titled “Refinement of Sprinkler Acreage Timeline” in the memorandum *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 2011).

3. Approach

3.1. <u>Review of Sprinkler Acreage Timeline Methodologies</u>

3.1.1. Phase 5 Methodology

The Rio Grande Water Conservancy District (RGWCD) first compiled the locations of sprinkler irrigations systems in the San Luis Valley. Davis Engineering, Inc. prepared maps for the RGWCD that showed the locations of installed sprinklers; although sizes were typically generalized as 120 acre circles. The maps were updated as the RGWCD noted changes to sprinklers during their annual crop investigations. To develop the RGDSS Phase 5 sprinkler acreage timelines, LRE obtained paper copies of the RGWCD maps for 14 years (1975,76,77,78,79,80,82,83,84,89,91,93,96 and 1998).

The first RGDSS mapping of irrigated acreages, crop types, and structure types ("irrigated parcel dataset") was developed for year 1998 by Agro Engineering, Inc., as part of the Consumptive Use and Water Budget component of the RGDSS (Agro Engineering, K.R. Thompson et. al. 2000). The original 1998 irrigated parcel dataset was delineated using satellite imagery with a 5-meter resolution, and the size and location of sprinkler parcels in this dataset were more accurate than what was represented in the RGWCD mapping.

To develop the sprinkler acreage timeline, LRE extracted sprinkler parcels from the original 1998 irrigated parcel dataset and compared the sprinklers to the 1998 RGWCD sprinkler mapping. The original 1998 irrigated parcel dataset did not include fallow parcels. LRE added a number of sprinklers parcels that were shown in the RGWCD mapping into a modified 1998 irrigated parcel dataset. Most of the added sprinkler parcels had originally been determined to be fallow while several had been designated flood irrigated. This modified irrigated parcel dataset was subsequently used in RGDSS Phase 5. The revised 1998 sprinkler dataset was compared to the RGWCD sprinkler mapping for 1996 and sprinkler parcels were removed if not in the RGWCD mapping to create a new sprinkler dataset for 1996. In this way, sprinkler datasets were progressively developed for each preceding year with an available RGWCD map using the parcel delineations from the 1998 irrigated parcel dataset. A few sprinkler parcels that were removed before 1998 were also added in earlier datasets.

A Geographic Information System (GIS) based ArcView script was used to associate sprinkler parcels to ditch structures. A BASIC language program was developed that summarized the sprinkler acreage for each ditch system for each year. Linear interpolation was used to estimate sprinkler acreages for years without RGWCD mapping. Sprinkler installation was described as generally starting around 1970 in the San Luis Valley, so sprinkler datasets for 1971 through 1974 were interpolated from zero in 1970.

The above processes resulted in a file with total annual sprinkler acres by structure. For the StateCU model, irrigated acreages are defined in the StateCU irrigation parameter (IPY) file which defines four acreage types for structures; acreages for flood and sprinkler irrigation types and with and without access to groundwater wells. The RGDSS data management process that builds the IPY file (using the "StateDMI" software) first determines total structure acres with and without groundwater wells. The sprinkler acreage was distributed between acreage with and without groundwater by the following logic:

a) GWsprinkler = minimum (sprinkler acres, GWtotal)
b) GWflood = GWtotal - GWsprinkler
c) SWsprinkler = minimum (sprinkler acres - GWsprinkler with groundwater, SWtotal)
d) SWflood = SWtotal - SWsprinkler

3.1.2. Issues with Phase 5 sprinkler acreage timeline for use in Phase 6

In Phase 6, enhancements were made to the irrigated parcel datasets as described in the RGDSS memorandum titled *Phase 6 - Enhancement of Irrigated Parcel Datasets* (RGDSS, K. Thompson, 2015) In Phase 6, new irrigated parcel datasets were developed for years 2002, 2005, 2009, and 2010; and the 1998 irrigated parcel dataset was refined. Parcels in the 1998 dataset were re-delineated using 1m aerial photography and the irrigated status of each parcel was re-evaluated using satellite imagery similarly to the newer datasets. Parcels determined as fallow in 1998 were not included in the 1998 dataset even if they were sprinkler irrigated in other datasets. Several parcel irrigation type designations were modified.

Through the PRT's meeting process, it was identified that the Phase 5 sprinkler acreage timeline when initially used with Phase 6 refined data for the years with irrigated parcel datasets showed noticeable discontinuities. Table 1 compares Phase 5 and Phase 6 sprinkler acreages and highlights this differences for the basin and for several of the largest structures for years with irrigated parcel datasets.

Table 1. Comparison of Phase 5 and Phase 6 Sprinkler Acreages for Selected Structures

Source	Year	Total Basin Sprinkler Acres			Rio Grande Canal Sprinkler Acres			Farmers Union Canal Sprinkler Acres			Monte Vista Canal System Sprinkler Acres		
		SW	GW	Total	SW	GW	Total	SW	GW	Total	SW	GW	Total
Phase 5 GIS*	1998	5482	270028	275510	962	71201	72163	123	47096	47219	274	10921	11195
Phase 5 Timeline	1998	5724	238301	244025	0	71159	71159	328	47096	47424	0	10123	10123
Phase 6 GIS	1998	14049	254571	268620	407	67315	67723	131	45970	46101	261	9646	9907
Phase 6 GIS	2002	11788	264261	276049	124	68679	68803	131	46267	46397	261	11204	11465
Phase 6 GIS	2005	16761	255559	272320	178	64375	64553	125	41531	41656	321	12074	12395
Phase 6 GIS	2009	18373	264001	282374	454	65546	66000	125	43310	43435	442	12826	13268
Phase 6 GIS	2010	18269	263413	281682	366	65636	66001	244	42859	43103	433	12798	13232

Note: Phase 5 Timeline from rg2007.ipy (11/2/2007)
**Phase 5 GIS estimated from older Phase 5 IPY step files (9/27/2007); some uncertainty in Total and Rio Grande Canal*

As expected, sprinkler parcel areas were slightly less in the Phase 6 GIS than in the Phase 5 GIS. Re-delineation with higher resolution aerial photography tends to result in slightly smaller parcels compared to those drawn conservatively around "fuzzy" edges in satellite imagery; but also the fallow sprinkler parcels that had been added to the Phase 5 modified GIS were removed in Phase 6.

However, the Table indicates that the Phase 5 sprinkler timeline total acreage for 1998 was over 31,000 acres less than the total acreage in the Phase 5 GIS. In Phase 5, the sprinkler acreage timeline and acreage development process was not dynamically related to the irrigated parcel datasets, and the sprinkler acreage timeline acreage overwrote GIS acreages even for years with irrigated parcel datasets.

As can also be noted in Table 1, Phase 5 sprinkler acres were often not allocated between areas with and without access to groundwater similarly to the distribution that was identified on a parcel scale in the irrigated parcel datasets. For instance, in the Rio Grande and Monte Vista Canal areas no sprinkler acres were distributed to surface water only acreage although some surface water only parcels had been identified in the irrigated parcel dataset; while in the Farmers Union Canal more acres were distributed to surface water only acreage than in the irrigated parcel dataset. This issue resulted from the issue noted above and because the Phase 5 sprinkler acreage timeline did not include any groundwater information.

Finally, a large amount of satellite imagery was available and processed in Phase 6 for years 1985 through 2010. An initial comparison of this satellite imagery to RGWCD sprinkler mapping in this time period indicated that the RGWCD often did not match the year that a sprinkler change could be observed in the satellite imagery and the tracking of sprinkler changes was poorer outside the main area of the RGWCD crop investigations (in the central San Luis Valley). Therefore, it was also identified that the original timeline based on RGWCD mapping could be improved through use of available satellite imagery.

3.2. Refinements to Sprinkler Acreage Timeline through Model Version 6P35

The majority of RGDSS Phase 6 enhancements to the sprinkler acreage timeline were integrated into model version 6P35. As mentioned earlier, refinements to the sprinkler acreage timeline integrated into model version 6P35 are described in detail in the November 2011 memorandum from Agro Engineering (Agro Engineering, K. Thompson 2011 attached).

3.3. Refinements to Sprinkler Acreage Timeline through Model Version 6P98

Subsequent to RGDSS model version 6P35, the groundwater structure information included with the irrigated parcel datasets was attached to parcels included in the sprinkler acreage timeline to record if parcels had access to groundwater (i.e. had a well listed as a water source). Also, additional satellite imagery was used to refine the year that individual sprinkler systems were installed, dismantled, or changed. In Phase 6, a total of 411 Landsat images were collected and processed for all years between 1985 and 2010; 179 of these images were collected and processed for years 1985 to 1997. This imagery was used primarily to refine the sprinkler parcel change for years in the 1985 to 1997 time period. After model version 6P35, a few additional modifications to the sprinkler acreage timeline were based on changes to the groundwater only areas that some parcels are associated with due to revisions in response area boundaries. Due to these changes, the GIS-based sprinkler acreage timeline database developed prior to model version 6P35 that documented sprinkler parcel installation year, annual percent fallow, annual irrigated acreage, and parcel access to groundwater was also revised accordingly.

A computer script was developed in prior to version 6P35 to process the sprinkler parcel information on a structure basis. Subsequent to 6P35, this script was developed further to ensure that the sprinkler acreage timeline was dynamically related to sprinkler acreages with and without groundwater in the irrigated parcel datasets. The script (“sprinkleripy.m”) was developed in Matlab (Mathworks, Inc) and the script can be run in the Matlab environment or an executable file that was compiled from the script can be run on any computer with the free Matlab Compiler Runtime (MCR) version R2014a installed.

The first step in the process to develop structure acreages is to run StateDMI to develop an initial IPY file without the sprinkler acreage timeline information. In the StateDMI process, total structure acreages for intervening years are determined by acreages in the irrigated parcel datasets. In Phase 6, years between the 1936 and 1998 and between 2005 and 2009 are determined from linear interpolation, while years between 1998 and 2002 and between 2002 and 2005 are determined from the 1998 and 2005 acreages, respectively. Prior to 2002, the structure acreage with access to groundwater is assumed to be the 1998 groundwater acreage unless limited by the total acreage or parcel well rights.

The script compiles parcel sprinkler areas from the sprinkler acreage timeline database into structure sprinkler acreages (with and without groundwater) and also reads the total structure acreages from the initial IPY file. For a particular year, the script then determines annual structure sprinkler acreages as follows. Therefore, the Phase 6 sprinkler acreage from the sprinkler acreage timelines are capped by the total acreages estimated by the StateDMI process similarly to what was done in Phase 5 although Phase 6 explicitly considers acreages with and without access to groundwater.

a) GWsprinkler = minimum (GWsprinkler acres, GWtotal); b) GWflood = GWtotal - SWsprinkler acres
c) SWsprinkler = minimum (SWsprinkler acres, SWtotal); d) SWflood = SWtotal - SWsprinkler acres

The script produces a ".sprink" file that summarizes annual structure sprinkler acreages with and without groundwater that have been "capped" by the original IPY file acreage for years without irrigated parcel datasets. The last step is to run StateDMI to build the final IPY files for StateCU using the acreages in the ".sprink" file for all years without irrigated parcel datasets. The sprinkler acreages for years with irrigated parcel datasets are not affected and are determined explicitly by the irrigated parcel datasets.

The integration of the initial IPY acreages with the sprinkler timeline acreages to produce the sprinkler acreages for the final IPY is highlighted in Figures 1 through 4 for structures with the largest sprinkler areas. In most cases, the sprinkler timeline acreage is not limited by the initial IPY acreage so that Sprinkler and Final IPY line plot together although this limitation did affect the structure in Figure 3. Flood irrigated acreages in the final IPY file with and without groundwater are equivalent to the area between the Final IPY GW and Total lines and the Initial IPY GW and Total lines, respectively.

3.4. Summary of Phase 6 Enhancements to Sprinkler Acreage Timeline

The following list summarizes specific enhancements that were incorporated into the sprinkler acreage timeline and the process by which structure acreages are compiled in Phase 6 with an indication if the enhancement was integrated into model version 6P35 or only 6P98.

- The sprinkler acreage timeline was extended to include years 1999 through 2008. (6P35)
- The sprinkler acreage timeline was re-developed using sprinkler parcels from the irrigated parcel datasets that were delineated with 1-meter resolution aerial photography in Phase 6. Sprinkler acreages for years 1970 through 2001 were based on 1998 parcel areas, 2002 acreages were based on 2002 parcels, and 2003 through 2008 acreages were based on 2005 parcels. (6P35)
- The RGWCD sprinkler mapping used in Phase 5 was used in the redevelopment of the sprinkler acreage timeline to initially identify when sprinklers were installed or removed beginning in 1975. As in Phase 5, sprinkler systems present in 1975 were interpolated to zero in 1970 (6P35)
- Additional satellite imagery that was processed in Phase 6 was used to refine the timeline of when sprinklers were installed, modified, or removed in the 1985 to 2008 period. (6P98)
- Individual sprinkler systems identified separately in the 1998, 2002, 2005, and 2009 irrigated parcel datasets were linked by a common identifier in a GIS-based timeline database. (6P35)
- A "percent irrigated" value was used in the timeline database to record partial or full fallowing of sprinklers indicated in irrigated parcel datasets. To acknowledge that some parcels are fallowed in every year, "percent irrigated" values were linearly interpolated through the timeline from the year of the irrigated parcel dataset to a value of one at the year of sprinkler installation. (6P35)
- Parcel access to groundwater (if a well was indicated as a parcel water source) was recorded in the sprinkler acreage timeline to calculate structure sprinkler areas with and with access to groundwater through the timeline. (6P98)
- A script was developed to easily and reproducibly sum the parcel based sprinkler acreages by structure with and without access to groundwater and dynamically generate structure acreages given acreages defined by the irrigated parcel datasets. (6P35 and 6P98)
- The StateCU process to generate the StateCU IPY file was modified to first produce an initial IPY file without sprinkler timeline information and then produce final IPY files using a file of structure acreages produced by the script. For years with irrigated parcel datasets, final IPY acreages are derived from the irrigated parcel datasets rather than from the script acreages. (6P98)

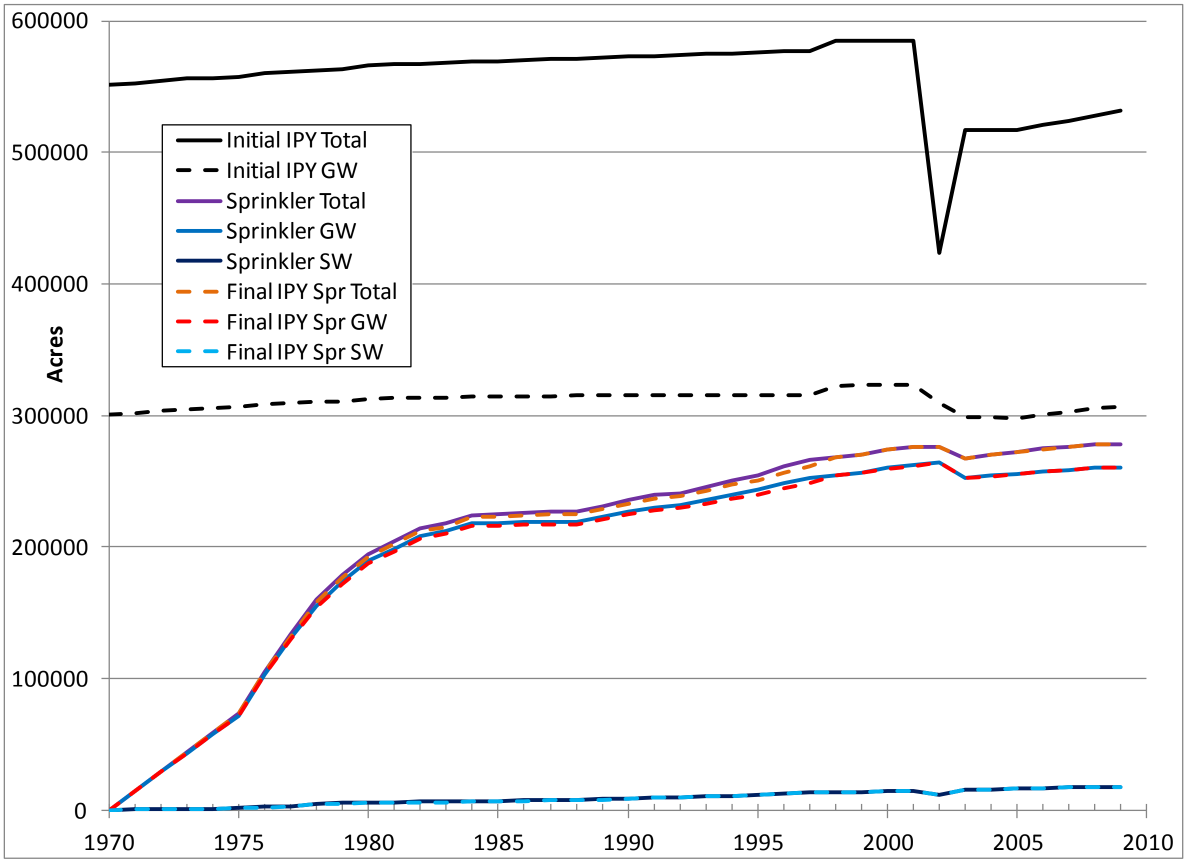


Figure 1. Total Basin - Sprinkler Timeline and IPY File Acreages

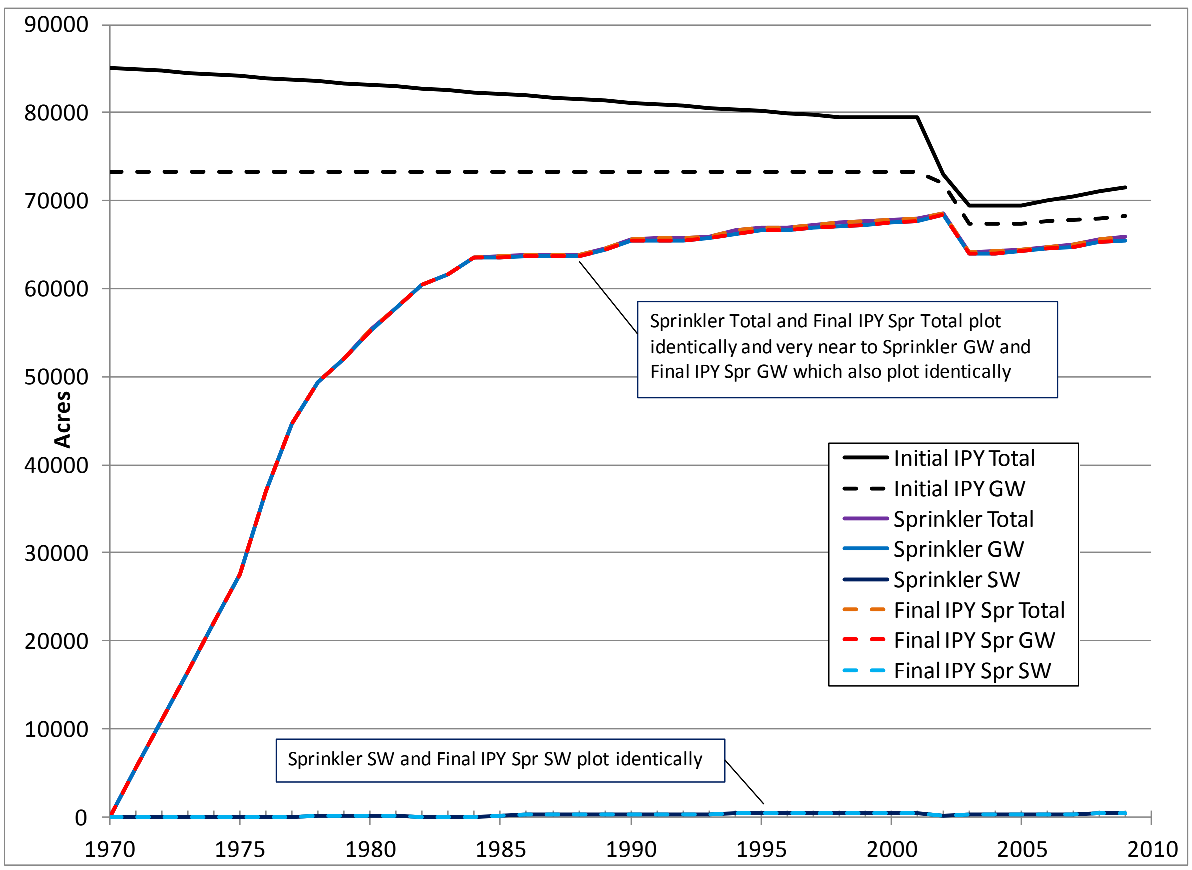


Figure 2. Rio Grande Canal - Sprinkler Timeline and IPY File Acreages

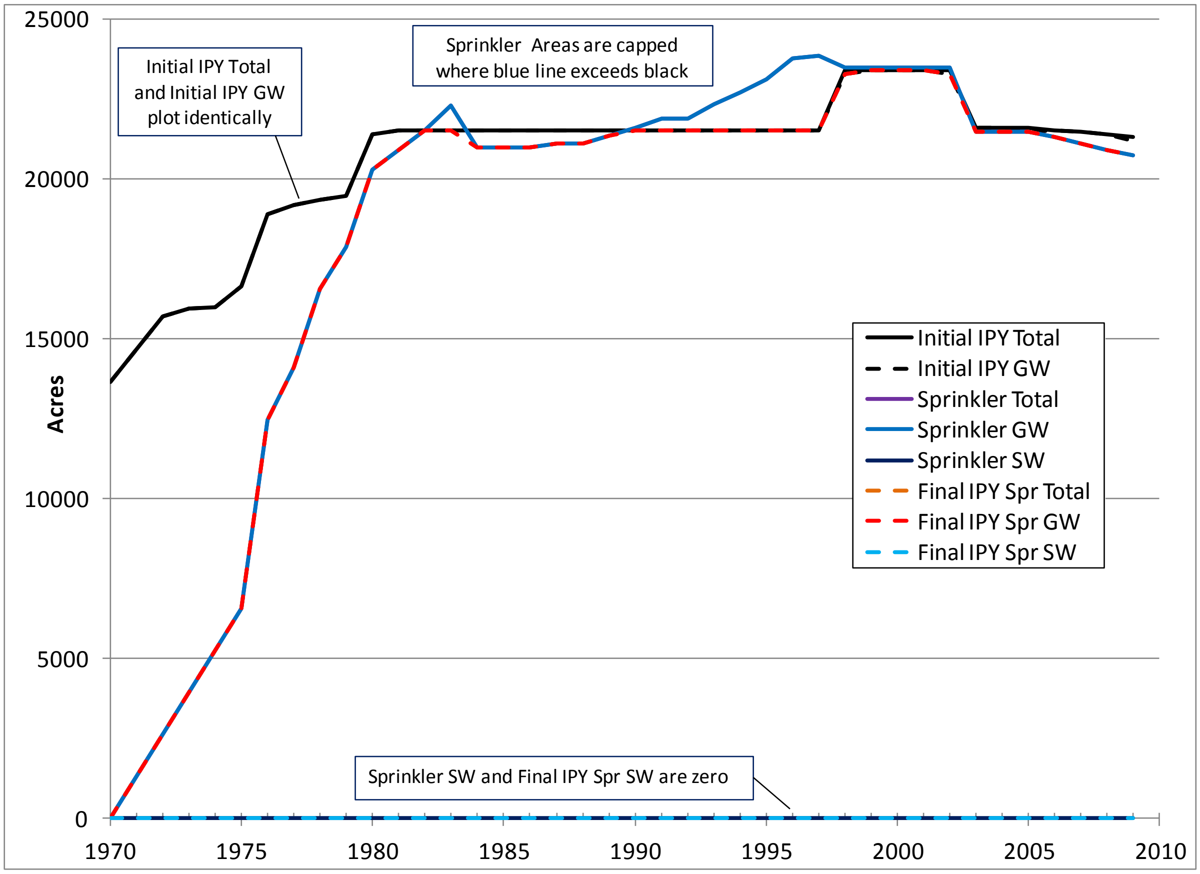


Figure 3. SubDistrict 1 Response Area GW-Only Area - Sprinkler Timeline and IPY File Acreages

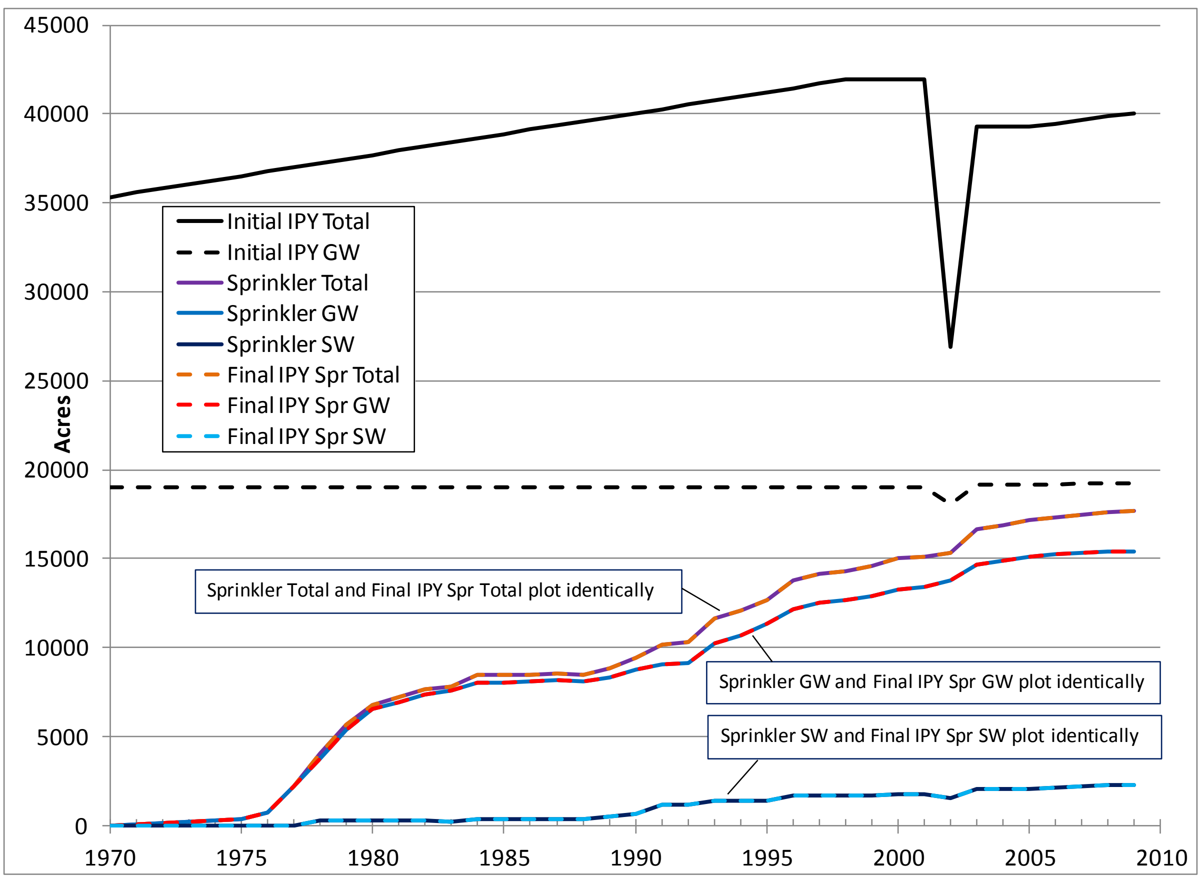


Figure 4. Empire Canal System - Sprinkler Timeline and IPY File Acreages

4. Results

Total annual sprinkler acreages as used in the RGDSS Phase 5 and Phase 6 models are presented in Figure 5 and Table 2. These sprinkler acreages are from the Phase 5 and Phase 6 StateCU IPY files that incorporate the sprinkler acreage timelines.

In Phase 6, annual changes in sprinkler areas have more detail than in Phase 5 due to use of satellite imagery for all years after 1985 and tracking of fallow areas; and modeled sprinkler areas both match irrigated parcel datasets in the years they are available and are dynamically related to the datasets in intervening years. Acreages for sprinklers using only surface water was higher in Phase 6 than Phase 5 due to the tracking of groundwater access in the Phase 6 sprinkler acreage timeline. The comparison of Phase 5 and Phase 6 total sprinkler acreages and sprinklers with access to groundwater is complicated by the Phase 5 total acreage issue discussed earlier.

Total sprinkler acreage in the San Luis Valley rose rapidly in the 1970s and early 1980s. After leveling off somewhat in the late 1980s, sprinkler acreage rose steadily in the 1990s. The highest acreage of sprinklers with access to groundwater occurred in the drought of 2002 but dropped off in 2003 primarily due to voluntary removal of end guns from sprinkler systems. Use of sprinklers using surface water dropped in 2002 dropped but has been rising since that time. Use of sprinklers with groundwater also rose in recent years, such that the highest total sprinkler acreage (through 2010) was observed in 2009 at over 282,000 acres.

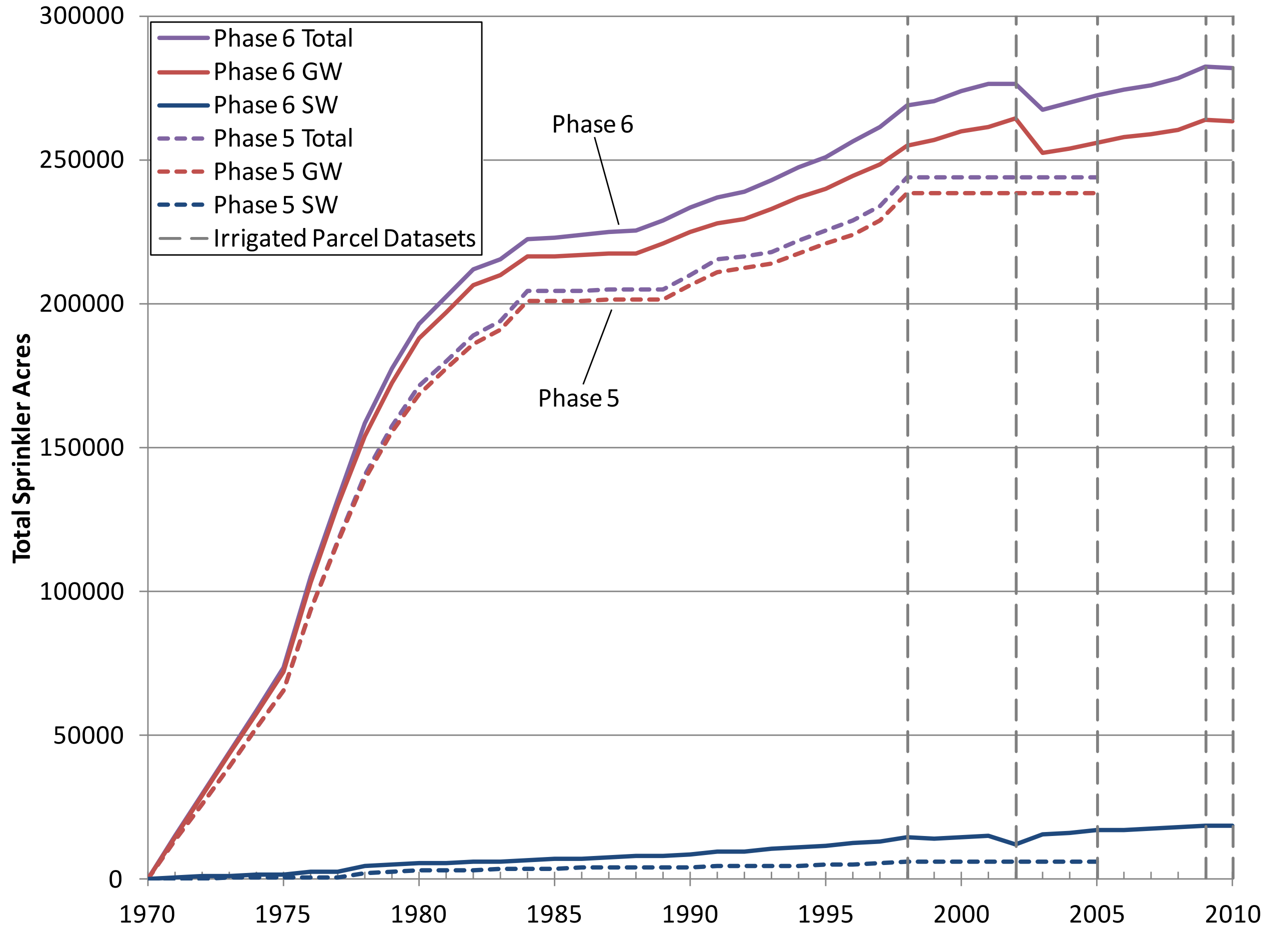


Figure 5. Total Annual RGDSS Phase 5 and Phase 6 Sprinkler Acreages

Table 2. Total Annual RGDSS Phase 5 and Phase 6 Sprinkler Acreages

	Phase 5 Sprinkler Acres			Phase 6 Sprinkler Acres		
Year	SW	GW	Total	SW	GW	Total
1970	0	0	0	0	0	0
1971	0	13043	13043	275	14357	14631
1972	1	25966	25967	550	28712	29262
1973	17	38888	38905	824	43069	43893
1974	34	52206	52240	1064	57425	58489
1975	52	65216	65268	1247	71783	73030
1976	57	93180	93237	2106	102675	104782
1977	381	116765	117146	2237	129623	131860
1978	1759	138561	140320	4369	154006	158375
1979	2213	155050	157263	4847	172234	177081
1980	2716	168378	171094	5221	187611	192832
1981	2807	177037	179844	5378	196867	202244
1982	2959	185759	188718	5535	206363	211898
1983	3105	190746	193851	5540	209871	215411
1984	3384	200969	204353	6305	216171	222476
1985	3467	200969	204436	6733	216119	222852
1986	3550	200969	204519	6986	216987	223973
1987	3553	201050	204603	7259	217299	224559
1988	3638	201050	204688	7654	217509	225163
1989	3584	201188	204772	7935	220834	228769
1990	3832	206096	209928	8264	224988	233252
1991	4040	210992	215032	9203	227697	236900
1992	4101	212414	216515	9382	229522	238904
1993	4160	213834	217994	10028	232670	242697
1994	4304	217281	221585	10623	236848	247471
1995	4541	220611	225152	11145	239833	250977
1996	4749	223826	228575	12181	244318	256498
1997	5142	228805	233947	12946	248450	261397
1998	5724	238301	244025	14049	254571	268620
1999	5724	238301	244025	13789	256609	270399
2000	5724	238301	244025	14094	259811	273905
2001	5724	238301	244025	14534	261513	276047
2002	5724	238301	244025	11788	264261	276049
2003	5724	238301	244025	15131	252307	267438
2004	5724	238301	244025	15835	253916	269751
2005	5724	238301	244025	16761	255559	272320
2006	0	0	0	16679	257707	274386
2007	0	0	0	17054	258589	275643
2008	0	0	0	17633	260407	278040
2009	0	0	0	18373	264001	282374
2010	0	0	0	18269	263413	281682

Note: Phase 5 acreages from rg2007.ipy (11/2/2007), Phase 6 from rg2012.ipy (3/6/2014)
Phase 5 sprinkler acres from 1998 irrigated parcel dataset was 272,896 acres

5. Comments and Concerns

5.1. Electronic File Descriptions

The following files were produced or are used for the Phase 6 processing of the sprinkler acreage timeline. Assemblies of GIS shapefiles are noted as .shp.

- *div3_sprinklers_agromaster.shp* – GIS-based sprinkler acreage timeline database. Sprinklers are shown spatially with 1998 parcel delineations (or newer if installed after 1998). The shapefile DBF file is the "sprinkler timeline database" and includes a linkage between irrigated parcel datasets, an annual timeline of parcel percent irrigated, an annual timeline of parcel irrigated acreage, and a "GW" field indicating if the parcel has access to groundwater.
- *sprinkleripy.m* – This script written in the Matlab language compiles sprinkler acreage timeline information, calculates structure acreages given an initial StateCU IPY file, and outputs a ".sprink" file with structure acreages (SWflood, SWSprinkler, GWflood, and GWsprinkler) for years without irrigated parcel datasets. This script was used for the RGDSS rules dataset.
- *sprinkleripy_new.m* – This script operates identically to the above but options were added to facilitate use in future model versions. Hardwired filenames were removed and options were added to browse for files, to avoid overwriting files, and to choose plotting options.
- *sprinkleripy_new32bit.exe/sprinkleripy_new64bit.exe* – These executables were compiled from the above script and can be run from any computer with the free Matlab MCR R2014a installed which can be downloaded from http://www.mathworks.com/products/compiler/mcr/index.html.
- *sprinksummary.txt* – A tab delimited text file that is output by the Matlab script for informational purposes. The file summarizes all structure acreages from the initial IPY file, structure acreages compiled from the sprinkler acreage timeline, and resulting structure acres for the final IPY file. The file can be opened directly into MS Excel.
- *spinkleryears.csv* – This file is used by the script for the timeline of parcel sprinkler acreages. The comma delimited file lists sprinkler parcel ID (based on original 1998 irrigated lands dataset) and annual sprinkler parcel irrigated acres for years 1970 through 2009. This file can be regenerated by saving the *div3_sprinklers_agromaster.dbf* file with only the INC and ACxx fields as a comma delimited file.
- *spinklerditch.csv* – This file is used by the script to associate sprinkler parcels with one or more ditches and define if parcels have access to groundwater. The comma delimited file lists sprinkler parcel ID, the identifier for the ditch structure, multi-structure, or groundwater water only area, and a field with a one indicating that the parcel has access to groundwater. The process to recreate this file can be found in comments in the above Matlab scripts.
- *rg2012_Pre_Sprink_IPY.StateDMI* – A StateDMI command file that creates the initial IPY file without consideration of the sprinkler acreage timeline.
- *rg2012_pre_sprink.ipy* – The initial IPY file created by the above command file that is used by the Matlab script to calculate final structure acreages.
- *rg2012_IPY.StateDMI* – A StateDMI command file that incorporates the sprinkler acreage timeline information (".sprink" file) to create the final IPY files.
- *rg2012.ipy* – The final IPY file created by above StateDMI command file for use in the StateCU historical runs.
- *rg2012_NoQ.ipy* – The final IPY file created by above StateDMI command file for use in the StateCU no pumping run.

5.2. Recommendations

In RGDSS Phase 7, allowing sprinkler acreages to exceed overall structure acreages for years without irrigated parcel datasets in construction of the StateCU input files could be evaluated. For several structures for some years, sprinkler acreages in the sprinkler acreage timeline exceed overall acreages (with and without groundwater) that are estimated (often using linear interpolation) by the StateDMI process and the structure sprinkler acres are then capped. Sprinkler timeline acreage can exceed overall structure acreages when the rates of sprinkler installation between years with irrigated parcel datasets were not linear or when groundwater acreages were reduced given well installation dates estimated from decrees or permits below timeline acreages. This reduction in groundwater area and capping can be noted in Figure 3. Additional investigation on a structure basis would be needed to clarify why structure acreages are higher in the sprinkler acreage timeline and ensure that the timeline acreage would indeed be more appropriate for the particular structure or if other issues may need to be addressed.

To implement this change in structure acreages, the ".sprink" file (or a similar file with just total acreage) would also have to be imported and utilized in the StateCU crop pattern file (CDS) file prior to creation of the final IPY file. Overall structure acreages are determined first by StateDMI for the CDS file, and these acreages are then imported into the IPY file. A mismatch in total acreage in the IPY and CDS files causes StateCU to issue a warning although StateCU uses the IPY acreages if different. In order to remain dynamic to changes in the irrigated parcel datasets, the script may also need to compare structure acreages in the irrigated parcel datasets to acreages in the sprinkler acreage timeline and adjust acreages for intervening years accordingly using the comparison percentage.

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 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.

LRE; Erin M. Wilson. June 2004. *Historic Crop Consumptive Use Analysis, Rio Grande Decision Support System*. Leonard Rice Consulting Water Engineers, Inc. Available from the CWCB CDSS website (http://cdss.state.co.us/DSSDocuments/Pages/TaskMemorandums.aspx)

LRE; Erin M. Wilson. June 1 2004. *Rio Grande Historic Consumptive Use – Annual Irrigation Parameter Time Series.* Leonard Rice Consulting Water Engineers, Inc. RGDSS Memorandum to Ray Bennett, Ray Alvarado, and Andy Moore; Colorado Division of Water Resources and Colorado Water Conservation Board. Included as Appendix A to the Historic Crop Consumptive Use Analysis Report.

RGDSS; Kelley Thompson. December 2015. *Phase 6 - Enhancement of Irrigated Parcel Datasets*. Colorado Division of Water Resources. RGDSS Final Memorandum to File.

Attachments

LRE June 1 2004 memorandum including description of Phase 5 development of sprinkler acreage timeline

Agro Engineering November 7, 2011 memorandum including description of Phase 6P35 enhancements to sprinkler acreage timeline

Attachment 1

LRE June 1 2004 memorandum including description of Phase 5 development of sprinkler acreage timeline

Appendix A
RGDSS Memorandum
Final

To: Ray Bennett, Ray Alvarado, and Andy Moore

From: LRCWE, Erin Wilson

Subject: Rio Grande Historic Consumptive Use - Annual Irrigation Parameter Time Series

Date: June 1, 2004

Introduction

This memorandum describes the approach and results obtained under Contingency #3, Annual Time Series Parameter Generation. It has been updated from the June 2002 version to reflect the extension of the previous analysis period through 2002 and peer review refinements to irrigated acreage and well assignments. This task includes generating the following information on an annual basis for the Rio Grande Basin historic consumptive use analysis (1950 through 2002):

1. Irrigated acreage, by crop, for key, aggregated, and ground water only diversion structures, representing 100 percent of the irrigated acreage in the Rio Grande Basin.
2. Acreage irrigated by sprinklers for key, aggregated, and ground water only diversion structures.
3. Acreage with available ground water supply and associated permitted or decreed monthly pumping volume for key, aggregated, and ground water only diversion structures.

Data generated under this subtask are incorporated into the StateCU Crop Distribution input file (**rg2004.cds**) and the Annual Irrigation Parameter input file (**rg2004.ipy**), described in the StateCU Documentation, for use in the Rio Grande Basin historic consumptive use analysis. The Annual Irrigation Parameter input file also includes maximum conveyance, flood irrigation, and sprinkler irrigation efficiencies for modeled structures. These parameters are described in the memorandum Rio Grande Historic Crop Consumptive Use - Ditch System Efficiencies.

In addition, the file includes an annual flag to consider whether a structure will be treated as a "mutual ditch" system or the analysis will "maximize supply". When the "mutual ditch" option is chosen, surface water is distributed evenly to all acreage in the ditch service area. Acreage with ground water supply then meets remaining irrigation water requirement with ground water, up to the maximum permitted pumping volume. The "maximize supply" option first applies surface water to lands under the ditch without access to ground water, then to flood irrigated lands that have ground water supply.

Ground water is used to meet the entire irrigation water requirement on lands with ground water supply that use sprinklers, and to meet any remaining requirement on lands that flood irrigate and also have ground water supply. For the Rio Grande Basin historic consumptive use analysis, the "maximize supply" option was chosen for all structures.

Two BASIC language pre-processor programs, developed under this subtask, were used to create the Crop Distribution and Annual Time Series input files (**sprink.bas** and **wellproc.bas**). The data management interface **StateDMI** will be used to create future input files for the Rio Grande Basin historic consumptive use analysis scenario.

Approach and Results

Generate Irrigated Acreage Time Series

The crop distribution file (**rg2004.cds**) contains acreage and associated crop percentages for each key, aggregated, and ground water only structures for every year in the analysis period (1950 through 2002). The 1998 acreage and crop types were determined during the Irrigated Acreage Assessment performed by Agro Engineering, Inc. as part of the Consumptive Use and Water Budget component of RGDSS. Irrigated acreage was assigned to a ditch system structure identifier based on service area locations, as described in the 1998 Irrigated Lands Assessment Using Satellite Imagery in the Rio Grande Basin of Colorado, Agro Engineering Inc., July 2000. Parcels without a surface water source were assigned to ground water only aggregates, as described in the Task 8.1 Review Wells and Lands Served by Ground Water Only memorandum, developed by the Surface Water Contractor. Acreage for aggregated diversion structures was determined by adding the acreage of the individual structures making up the aggregate, as described in the Task 7.1 Aggregated Water Rights/Irrigated Lands Not Explicitly Modeled memorandum, developed by the Surface Water Contractor.

The 1998 irrigated acreage assessment focused on defining acreage in the floor of the San Luis Valley. Acreage outside the valley floor was defined where possible, but in some areas it was difficult to distinguish irrigated acreage from forested areas, or acreage could not be defined due to cloud cover. There are 108 structures with current diversions for irrigation where acreage could not be defined, 14 of these structures have been defined as "key" and the remaining are included in aggregates. For these structures, user-defined acreage reported in the diversion record database for 1998 was used. **Table 1** summarizes the 1998 acreage used as a basis for historic consumptive use estimates by source. **Table 2** summarizes the 1998 acreage by crop type.

Table 1
1998 Irrigated Acreage by Source

Acreage Source	Acreage	% of Total
1998 Irrigated Acreage Assessment	615,092	99 %
1998 User Defined	7,776	1 %
Total Basin	622,868	100 %

Table 2
1998 Irrigated Acreage by Crop Type

Irrigated Crop Type	Acreage	% of Total
Irrigated Meadow	278,760	45 %
Alfalfa	141,265	23 %
Small Grains	114,841	18 %
Potatoes	80,507	13 %
Vegetables	7,495	1 %
Total Basin	622,868	100 %

Colorado Agricultural Statistics (CAS) are county-based, and not provided on a ditch or well basis. However, to determine supply-limited consumptive use, it is necessary to associate acreage with surface water and/or ground water sources. The 1998 acreage estimates were assigned to surface and ground water sources, and therefore were used in conjunction with the CAS estimates to determine historic (1950 through 2002) acreage by structure. **Table 3** shows a comparison of 1998 irrigated acreage from the RGDSS effort and 1998 CAS data.

Table 3
Comparison of 1998 RGDSS Irrigated Estimates to 1998 Colorado Agricultural Statistics (acres)

Crop Type	Irrigated Acreage Assessment	CO Agricultural Statistics	Difference	Percent Difference
Irrigated Meadow	278,760	87,000	191,760	69 %
Alfalfa	141,265	135,000	6,265	4 %
Small Grains *	114,841	105,000	9,841	9 %
Potatoes	80,507	76,900	3,607	4 %
Vegetables	7,495	N/A	N/A	N/A
Total	622,868	402,391	211,473	34 %
* Small Grains include Barley, Oats, and Wheat				

There are several reasons for the discrepancies between the irrigated acreage assessment and the amount reported by the Colorado Agricultural Statistics including:

- The CAS estimates are obtained by a random survey of a sample of growers and are subject to the errors associated with this approach.
- The CAS estimates reflect the acres of harvested crop, not the acres of planted crop defined in the irrigated acreage assessment.
- The irrigated meadow category of the CAS estimates reflect only the acreage that was hayed (had a harvested crop removed from it) and does not include the acreage that was pastured or grazed.

Colorado Agricultural Statistics (CAS) for potatoes, small grains, and alfalfa were determined to be an appropriate basis for estimating historic acreage and crop types. On-the-other hand the CAS data were determined to be a poor indicator of historic irrigated meadow in the basin. This is because the amount of harvested irrigated meadow may vary greatly from year to year, while the amount of irrigated meadow generally does not. Therefore the amount of irrigated meadow each year is estimated to be constant. Note that in water short years, less water is likely applied to irrigated meadow than cash crops grown under the same ditch. CAS estimates were not available for the small percentage of vegetables grown in the San Luis Valley; therefore the amount of vegetables each year of the analysis was estimated to be constant.

The following example illustrates the process used to estimate the irrigated acreage time series for a sample structure (Ditch "X") in 1992. **Table 4** shows example CAS crop acreage for county "A" for two years, 1992 and 1998. Also shown is the 1998 acreage for the sample structure (Ditch "X") from the irrigated acreage assessment (IAA). In this example, all the acreage served by Ditch "X" is in County "A". Small grains, potatoes, and alfalfa are referred to as "Time-varying Crops" in this example.

Table 4
Example Acreage Estimates

	County "A"		Ditch "X"
Crop Category	1992 CAS	1998 CAS	1998 IAA
Small Grains (Barley, Oats, and Wheat)	12,000	12,500	2,000
Potatoes	6,000	7,500	500
Alfalfa	12,000	11,000	800
Sub Total	**30,000**	**31,000**	**3,300**
Irrigated Meadow	N/A	N/A	2,000
Vegetables	N/A	N/A	20
Total	**N/A**	**N/A**	**5,320**

1. Determine Total Acreage of Time-varying Crops. Colorado Agricultural Statistics acreage for crop types barley, oats, wheat, alfalfa, and potatoes were combined for 1998 and 1992. The acreage assigned to small grains, potatoes, and alfalfa for the sample structure during the 1998 Irrigated Acreage Assessment were combined.

   1998 County "A" CAS Subtotal = 12,500 + 7,500 + 11,000 = 31,000 acres
   1992 County "A" CAS Subtotal = 12,000 + 6,000 + 12,000 = 30,000 acres
   1998 Ditch "X" Subtotal = 2,000 + 500 + 800 = 3,300 acres

2. Determine Total 1992 Sample Structure Acreage for Time-varying Crops. The estimated sample structure acreage for time-varying crops in 1992 is the 1998 structure acreage from the irrigated acreage assessment (3,300) prorated by the ratio of total county acreage in 1992 (30,000) to the total county acreage in 1998 (31,000).

   1992 Subtotal for Sample Structure = 3,300 x (30,000 / 31,000) = 3,194 acres

3. Determine 1992 Sample Structure Crop Mix. The sample structure crop mix for time varying crops in 1992 is determined by weighing the 1998 IAA crop acreage for Ditch "X" by the ratio of crop acreage for County "A" in 1992 to crop acreage for County "A" in 1998. Irrigated meadow and vegetable acreage are estimated to be the same as 1998 acreage in each year of the analysis.

   Weighted Ditch "X" Small Grains = 2,000 x (12,000/12,500) = 1,920 acres
   Weighted Ditch "X" Potatoes = 500 x (6,000/7,500) = 400 acres
   Weighted Ditch "X" Alfalfa = 800 x (12,000/11,000) = 873 acres

   Percent Ditch "X" Small Grains = 1,920 / (1,920 + 400 + 873) = 60 %
   Percent Ditch "X" Potatoes = 400 / (1,920 + 400 + 873) = 13 %
   Percent Ditch "X" Alfalfa = 873 / (1,920 + 400 + 873) = 27 %

   1992 Ditch "X" Small Grains = 3,194 x 60% = 1,918 acres
   1992 Ditch "X" Potatoes = 3,194 x 13% = 415 acres
   1992 Ditch "X" Alfalfa = 3,194 x 27% = 862 acres

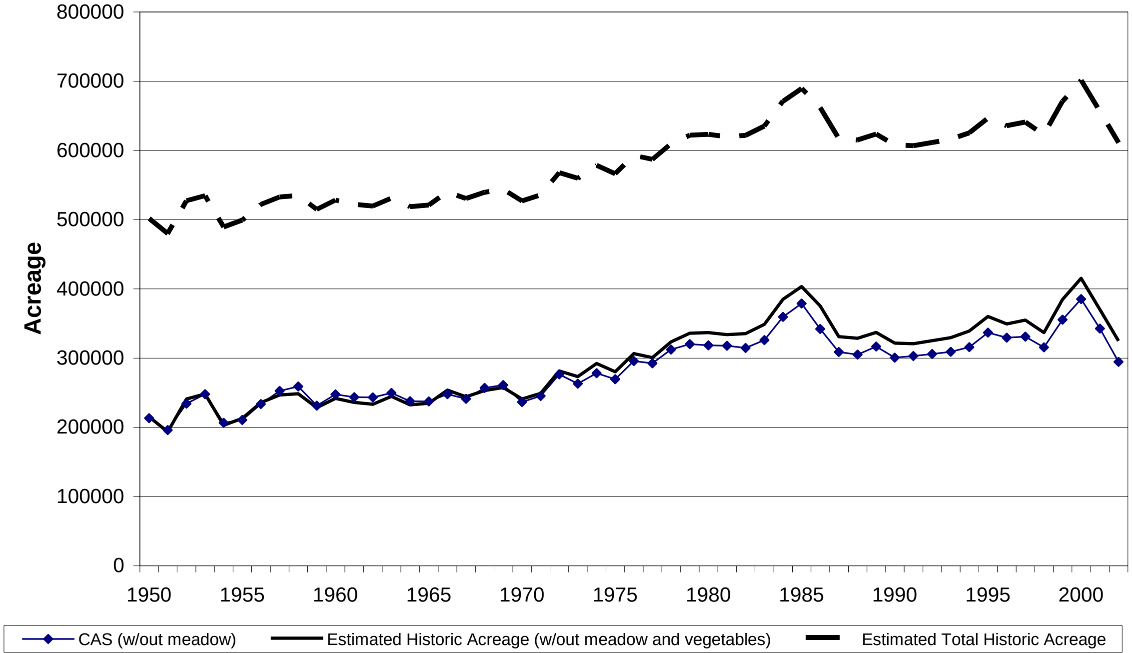
   1992 Ditch "X" Irrigated Meadow=1998 Ditch Irrigated Meadow=2,000 acres
   1992 Ditch "X" Vegetables = 1998 Ditch Vegetables = 20 acres

4. Determine Total 1992 Ditch "X" Acreage. Add the five crop types structure acreage for 1992 to determine the total structure acreage for 1992.

   Total Structure = 1,918 + 415 + 862 + 2,000 + 20 = 5,215 acres

The methodology outlined in the above example is applied to each structure in the analysis for the years in the study period. The total acreage and percentage of each crop type by year is written to the *.cds file for each structure in the analysis. **Figure 1** shows the total basin CAS acreage for time varying crops and the total basin acreage used in the historic consumptive use analysis for time varying crops developed using the methodology outlined in the above example. Also shown is the total basin acreage including irrigated meadow and vegetables.

Figure 1
Irrigated Acreage Estimate 1950 through 2002



Generate the Sprinkler Acreage Time Series

The annual irrigation parameter time series file (**rg2004.ipy**) contains the estimated acreage irrigated by sprinklers for key, aggregated, and ground water only structures for every year in the analysis period (1950 through 2004). The following steps were performed to generate this time series.

1. Sprinkler extent maps for 14 years (1975,76,77,78,79,80,82,83,84,89,91,93,96 and 1998) were obtained from Alan Davey of Davis Engineering in paper format. These maps, prepared for Rio Grande Water Conservancy District (RGWCD), were digitized to create 14 different ArcView coverages.

2. The ArcView 1998 irrigated parcel coverage, prepared by Agro Engineering for the Irrigated Acreage Assessment, had an irrigation methodology attribute assigned to each parcel. Parcels identified as having a "sprinkler" method were selected from this coverage using a query command in ArcView. The selected parcels were saved to a new coverage named **98sprink**.

3. Several parcels were identified by the 1998 RGWCD map, but not the 1998 Irrigated Acreage Assessment, as having sprinklers. These parcels may represent side roll or lateral sprinklers not easily identified from satellite imagery. These parcels were added to the **98sprink** coverage (and the 1998 Irrigated Acreage Assessment

coverage) using heads-up digitizing. The revised theme was then copied to a new coverage called **96sprink** for use in preparing the sprinkler extent coverage for the previous year of mapping (1996). The new coverage for 1996 was then compared to the RGWCD map of sprinkler extent for 1996 and sprinklers were added or subtracted to reflect the RGWCD map. The **96sprink** coverage was saved and used as the base for modifications for the previous year where sprinkler coverage was available (1993). This process continued until all 14 maps were represented by ArcView coverages.

4. An ArcView script (**modfind**) was developed that performs intersections between the irrigated parcel coverage and ditch service area coverage. The script assigns ditch systems, and the percent of the parcel covered by the ditch system, as attributes to the irrigated parcel coverage. The script was used during the irrigated acreage assessment, and is described in the <u>Irrigated Lands Assessment Report</u>, prepared by Agro Engineering. The **modfind** script was used to associate sprinkler irrigated acreage to ditch systems for each of the 14 years with ArcView sprinkler coverages.

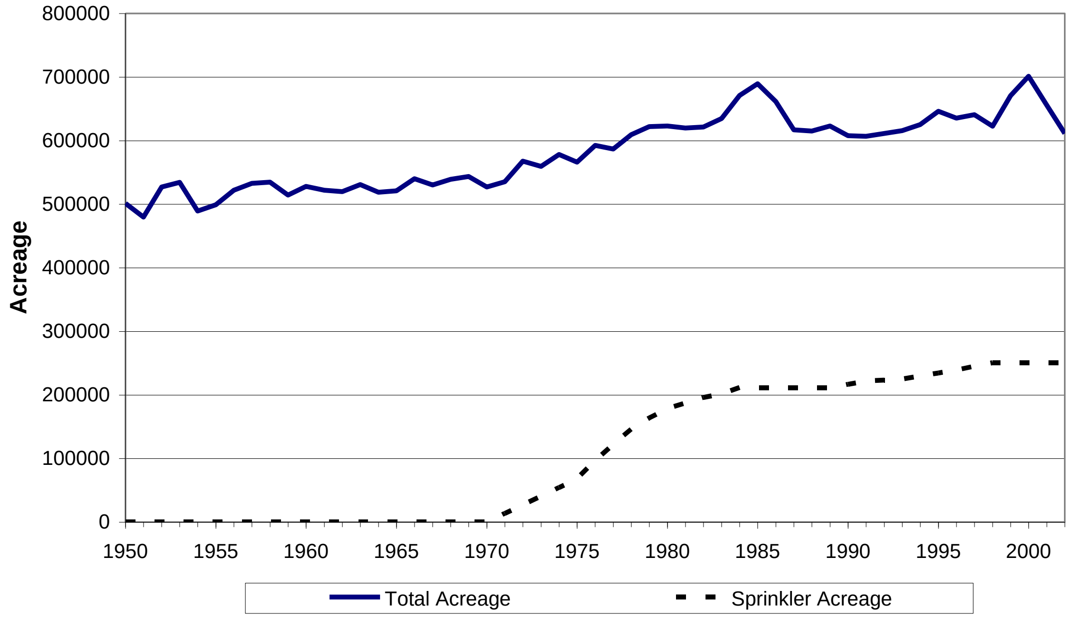
5. The resulting attribute table for each sprinkler coverage was exported from ArcView to a comma-separated file with the name of the sprinkler extent coverage and a .txt suffix (i.e. **sprink98.txt**).

6. A BASIC language program (**sprink.bas**) was developed that takes the sprinkler extent coverage tables (i.e. **sprink98.txt**) and summarizes, by ditch system (or parcel for ground water only lands), the acreage estimated to be covered by sprinklers in a year. For years during the 1950 through 1998 period where sprinkler extent maps were not available, linear interpolation was used between surrounding years of data. 1998 estimates of sprinkler acreage were used to represent 1999 through 2002 sprinkler acreage. Sprinkler installation generally started around 1970 in the San Luis Valley. Therefore, values for 1971 through 1974 were linearly interpolated from a zero value in 1969 and the sprinkler extent determined from the 1975 map.

7. The result of this program was a file (**sprinko.txt**) that contains values of estimated sprinkler extent acreage by ditch system (or parcel for ground water only lands) and by year. This file was then input into the well processing program (**wellproc.bas)** used to create the annual time series data input file.

As noted, sprinkler irrigation did not become a common practice in the San Luis Valley until the early 1970s. The installation of sprinklers rose sharply during the 1970s, and continued a steady incline through 1998. **Figure 2** shows the estimated acreage irrigated with sprinklers from 1950 through 2002. Also shown is the estimated total irrigated acreage for the time period.

Figure 2
Estimated Sprinkler Acreage and Total Acreage
1950 through 2002



<u>Generate the Ground Water Supply Acreage and Pumping Capacity Time Series</u>

Acreage with ground water supply and the corresponding well pumping volume are based on the well-matching routine developed for RGDSS and outlined in the memorandum <u>Task 3.1 - Data Centered Ground Water Model</u>, June 2002, developed by the RGDSS Spatial System Integration Contractor. The following steps were performed to generate the time series of acreage with ground water supply.

1. A comma-separated file (well2002.csv) was provided by the Spatial System Integration Contractor that identified each well assigned to a parcel, the well permitted capacity, the well permit date, and the well appropriation date.

2. This file was input into the well processing program (**wellproc.bas**) used to create the annual time series data input file. For each year in the analysis (1950 through 2002), the acreage and pumping capacities of parcels under a structure were accumulated if either the well permit or appropriation date was active for that year.

The amount of acreage with ground water supply and corresponding pumping capacity rose from 1950 through the mid 1970s, but has remained relatively constant since that time. **Figure 3** shows the estimated irrigated acreage with ground water supply from 1950 through 2002. Also shown is the estimated total irrigated acreage for the time period. **Figure 4** shows the estimated irrigated acreage with ground water supply (left axis) and the corresponding permitted pumping volume (right axis).

Figure 3
Estimated Ground Water Acreage And Total Acreage
1950 through 2002

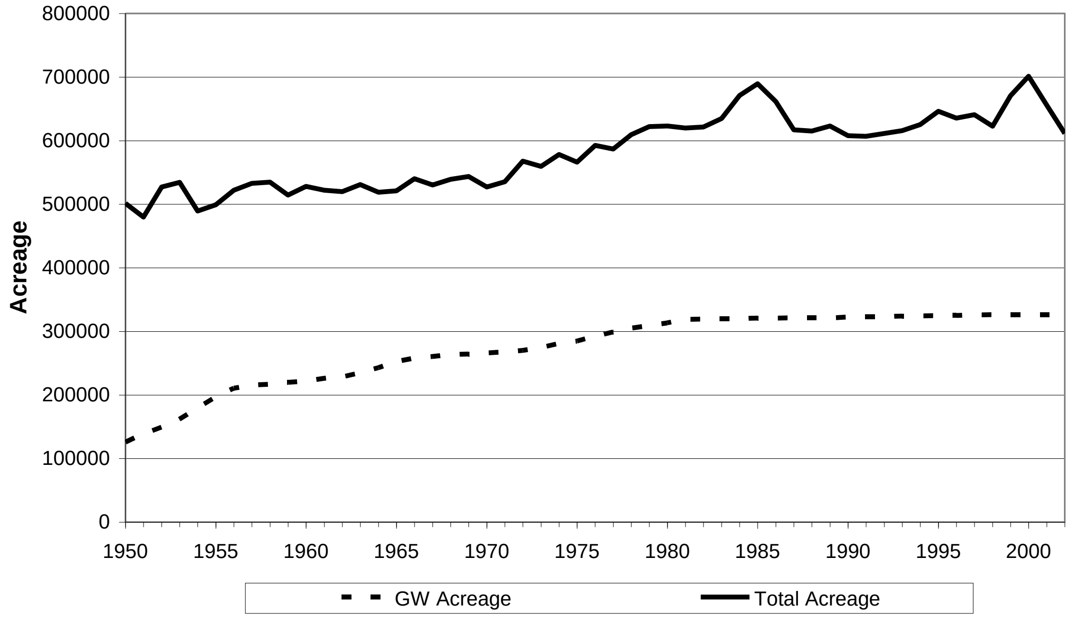
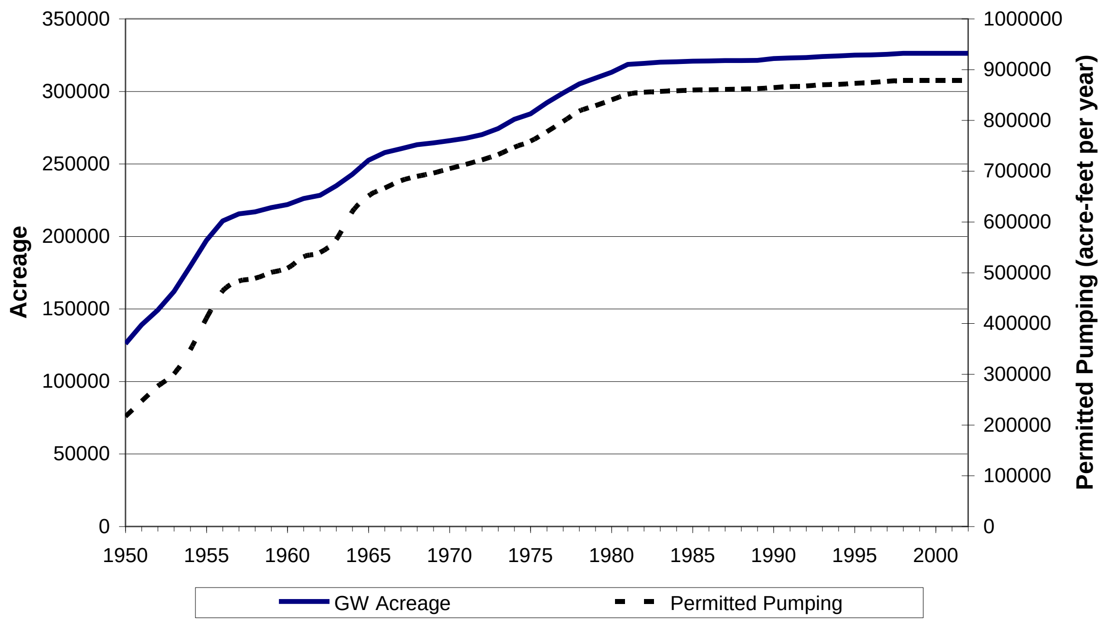


Figure 4
Estimated Ground Water Acreage and Permitted Pumping
Volume - 1950 through 2002



Comments and Concerns

The time series information developed for the RGDSS historic consumptive use analysis is considered appropriate to use for the RGDSS planning and administration efforts. Areas of potential improvement include:

- Irrigated Acreage Time Series. The 1998 irrigated acreage, which serves as the basis for estimating historic acreage, is considered very accurate. Acreage estimated based on aerial photography or satellite imagery for years prior to 1998 could provide a better estimate of historic acreage than the use of County Agricultural Statistics.
- Well Data. As noted in the memorandum Task 3.1 - Data Centered Ground Water Model, the well to irrigated acreage association task highlighted missing information in the State's well permit database. Updates or improvements made to the database should be incorporated into future estimates of historic consumptive use.

Attachment 2

Agro Engineering November 7, 2011 memorandum including description of Phase 6P35 enhancements to sprinkler acreage timeline

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.

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