SPDSS Memorandum - Final

To: Ray Alvarado, Ray Bennett
From: Riverside Technology, inc., Nils Babel, Jason Polly, and Timothy Martin
Subject: SPDSS, Spatial System Integration Component Task 104, 105, – Mapping Historic Land Use for 1997
Date: September 27, 2010

1. Introduction

Under phase 5 of the Spatial Systems Integration component of the South Platte Decision Support System (SPDSS) Riverside Technology, inc. (Riverside) is mapping and classifying 1997 irrigated lands and irrigation service areas for both ground and surface water. This memorandum provides details on the methods used to conduct a number of activities conducted under Phase 5, including:

- Task 104: Mapping of SPDSS Irrigated Lands in 1997
  - 104.01 **Collect and process reference data**
  - 104.02 **Develop irrigated vs. non-irrigated lands**
  - 104.03 **Develop irrigated parcel boundaries**
  - 104.04 **Identify crop types in each polygon**
  - 104.05 **Attribute ditch service areas and water sources**
  - 104.06 **Review, revision, and final classification of 1997 results**
  - 104.07 **Accuracy evaluation**
- Task 105: 1997 SPDSS Landsat Imagery Acquisition and Processing
  - 105.01 **Imagery selection and acquisition**
  - 105.02 **Landsat image processing.**
  - 105.03 **Report on Landsat image processing procedures**

The objective of Phase 5 is as follows:

Land use mapping for 1997 - including irrigated areas, water supply, and major crop types of the South Platte Study Area - will be mapped using satellite imagery, aerial photography, and applicable GIS data and agricultural statistics.

1.1 Overview

Procedures for mapping historic land use conducted under SPDSS – including data processing, reference data collection and processing, enhancements, interpretation, classification, water sourcing, and evaluation with their corresponding project subtasks are shown in ***Figure 1***. The SPDSS Study Area consists of the South Platte and Laramie River Basins in Division 1, and in Division 6 the North Platte (District 47). The procedure for mapping 1997 irrigated lands was similar to the procedure used to map historic irrigated lands (1956, 1976, and 1987), as well as mapping 2005 irrigated lands. As with 2001, these procedures followed a hierarchical approach starting with the classification of irrigated lands and continuing with the classification of irrigated crops. Historic water source assignments were performed last before overall evaluation and final quality assurance and quality control (QA/QC).

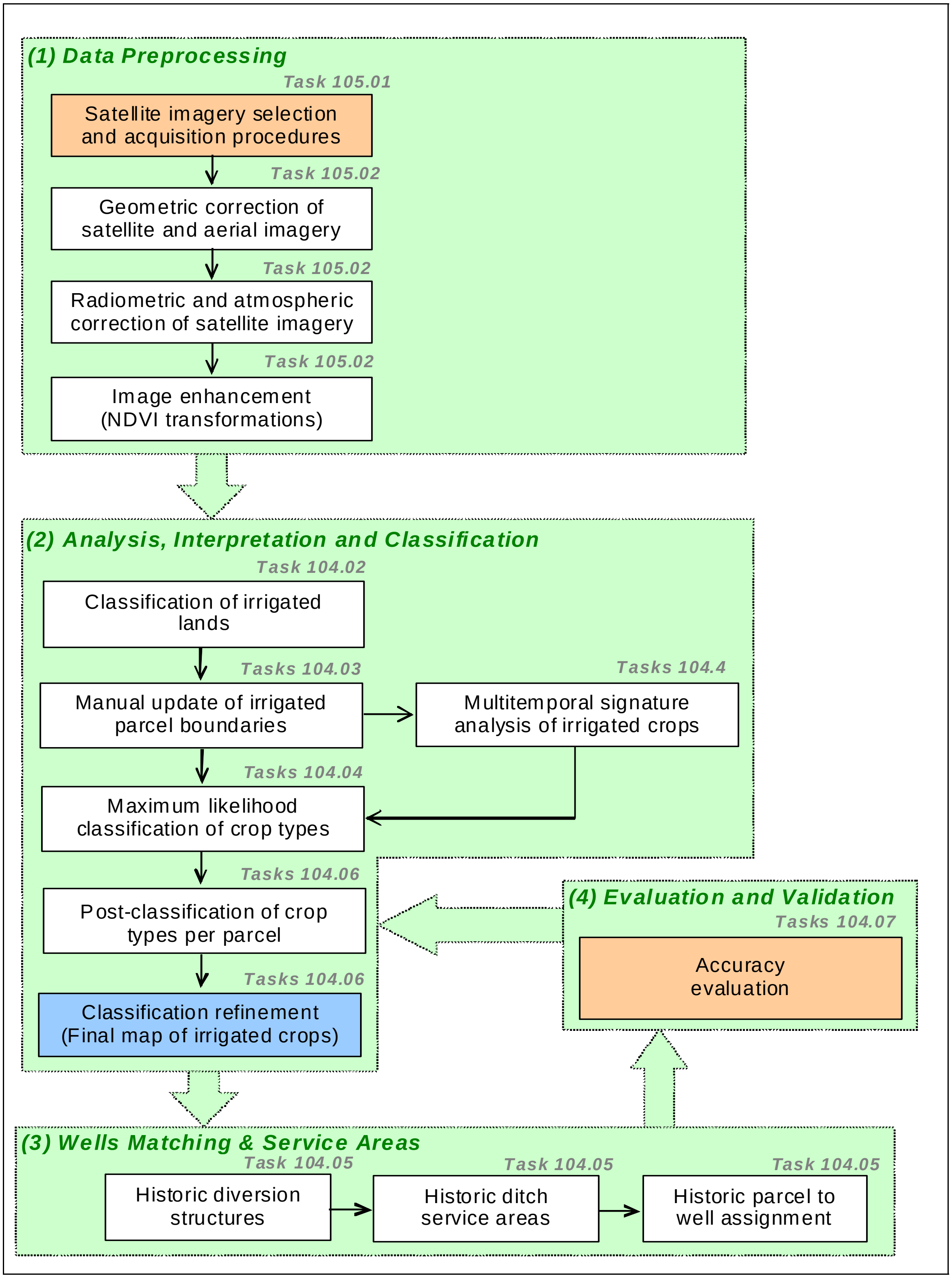

Figure 1. Flowchart of the SPDSS 1997 land use mapping procedures.

2. Data Pre-Processing

In December of 2008, USGS announced the availability of archived Landsat data at no cost. Unfortunately, the data is made available in a format that is not optimal for SPDSS classification (i.e. cubic convolution resampling). This format is inconsistent with past SPDSS processing and not ideal for irrigated lands classification. 1997 Landsat imagery was therefore collected in the nearest neighbor format. A total of 29 Landsat images were selected. Coordination with NCWCD provided seven of the identified 1997 Landsat images selected. ***Table 1*** lists identified imagery by source of collection.

Table 1. 1997 Landsat Image Inventory

Frame	No.	Date	Image ID	Source
34032	1	6/1	LT50340321997152AAA02	USGS
	2	7/3	LT50340321997184XXX02	USGS
	3	**8/20**	**LT50340321997232XXX02**	**NCWCD**
	4	9/5	LT50340321997248XXX02	USGS
34033	1	7/3	LT50340331997184XXX02	USGS
	2	**8/20**	**LT50340331997232XXX02**	**NCWCD**
33032	1	4/23	LT50330321997113XXX01	USGS
	2	**5/9**	**LT50330321997129AAA03**	**NCWCD**
	3	6/26	LT50330321997177AAA02	USGS
	4	7/12	LT50330321997193XXX02	USGS
	5	8/13	LT50330321997225AAA02	USGS
	6	**8/29**	**LT50330321997241XXX02**	**NCWCD**
	7	9/14	LT50330321997257XXX02	USGS
	8	9/30	LT50330321997273XXX02	USGS
	9	10/16	LT50330321997289AAA02	USGS
33033	1	5/9	LT50330331997129AAA03	USGS
	2	6/26	LT50330331997177AAA02	USGS
	3	7/12	LT50330331997193XXX02	USGS
	4	**8/13**	**LT50330331997225AAA02**	**NCWCD**
	5	9/14	LT50330331997257XXX02	USGS
	6	9/30	LT50330331997273XXX02	USGS
	7	10/16	LT50330331997289AAA02	USGS
32032	1	3/31	LT50320321997090AAA02	USGS
	2	**5/18**	**LT50320321997138XXX02**	**NCWCD**
	3	7/5	LT50320321997186XXX02	USGS
	4	7/21	LT50320321997202AAA01	USGS
	5	**8/22**	**LT50320321997234XXX02**	**NCWCD**
	6	9/7	LT50320321997250XXX02	USGS
	7	10/9	LT50320321997282XXX02	USGS

Landsat 5 Thematic Mapper (TM) data sets were acquired from the United States Geological Survey (USGS) and imported in ERDAS Imagine file format from the National Land Archive Production System (NLAPS) file format.

2.1 Geometric Correction

The geometric correction followed the processes documented in SPDSS Technical Memorandum 89.2, Section 2.2.2. Riverside conducted geometric correction for all Landsat TM frames. A minimum of 30 ground control points were collected for each image. The Digital Orthophoto Quarter Quadrangle was used as the ground control. Landsat TM geometric correction root mean squared (RMS) errors were less than one pixel (30 meters).

The imagery obtained from NCWCD was already georeferenced. Riverside reviewed the imagery to ensure the georeferencing was acceptable. Riverside digitized 23 ground control points on the separate Landsat frames. The points were digitized on the DOQQs and then the corresponding location was digitized on the Landsat images. The difference between the points was calculated in an attempt to determine the relative RMS error for the NCWCD Landsat images. The average difference among all of the points across all the images was approximately 15 meters. This is less than one pixel and acceptable for SPDSS standards.

2.2 Radiometric Correction

Pixel values in commercially available satellites are calibrated to fit a certain range of radiance values of the earth surface in the form of Digital Numbers (DN). Since each sensor has its own calibration parameters used in recording the DN values, the same DN values in two images taken by two different sensors may represent two different radiance values. Radiometric correction of Landsat TM imagery followed procedures described in SPDSS Technical Memorandum 89.2.

2.3 Cloud Removal

Clouds and cloud shadows can significantly alter classification results for multi-date satellite imagery. The 1997 imagery was considerably cloudy and a significant time was spent closely digitizing clouds and cloud shadows. After the clouds and shadows were digitized they were removed from the image using an ESRI Geoprocessing model to ”fill” the cloud or cloud shadow affected area with a value of zero. The cloud “holes” were then filled with imagery from another date or frame when possible. This is possible because the satellite frames have considerable sidelap (overlap on the side of the images) and some images in the same frame are only 16 days apart. For example, the July 12 image in frame 3332 contains some cloud cover on the western edge. The July 3 image in frame 3432 contains cloud free imagery in the cloud affected areas of the frame 3332 image. As a result, the July 3 image of frame 3432 was used to fill these holes. Another example is the August 13 and 29 images. A combined image was created that used imagery from both dates as well as imagery from August 20 in frame 3432. ***Table 2*** shows a list of the combined images that were created due to the cloud cover problems. The first column in the table lists the image composite name. The next column identifies the frame from which the source image is. The third column displays the date of the source image. The last column lists the priority or order that the image had when merging the multiple images together. Priority 1 means that image was essentially on top and other images were used to fill in holes or edges. ***Appendix D*** displays maps of the cloud affected areas. The darker red areas represent cloud cover on multiple dates.

Table 2. Cloud Affected Combined Images

Image Composite	Frame	Image Source	Priority
3332 April-May	3332	23-Apr	1
	3332	9-May	2
3332 July	3332	12-Jul	1
	3432	3-Jul	2
3332 August	3432	20-Aug	1
	3332	29-Aug	2
	3332	13-Aug	3
3332 Sept	3332	3-Sep	1
	3332	30-Sep	2
3232 July	3232	5-Jul	1
	3232	21-Jul	2
3232 May	3332	9-May	1
	3232	18-May	2
3232 October	3332	16-Oct	1
	3232	9-Oct	2

2.4 Image Enhancements: NDVI

As described in SPDSS Technical Memorandum 89.2, multi-temporal NDVI images produced by layer stack of individual NDVI rasters for each Landsat frame were used along with the DOQs in manual photo interpretation of irrigated parcel boundaries, as well as in subsequent processing for crop classification.

NDVI was derived from the difference between the near-infrared (NIR) bands and the visible red bands region (e.g. Landsat TM Band 3) with the following equation:

$$\mathrm{NDVI} = \frac{\mathrm{NIR}_{\mathrm{Band}} - \mathrm{Red}_{\mathrm{Band}}}{\mathrm{NIR}_{\mathrm{Band}} + \mathrm{Red}_{\mathrm{Band}}} \text{ Where,}$$

NIR band = Near infrared band (TM = band 4)
Red band = Red band (TM = band 3)

NDVI rasters for Landsat TM were rescaled from floating point to 8-bit unsigned rasters as described in SPDSS Technical Memorandum 89.2, Section 2.3.1.

3. Reference Data

For the 1997 irrigated lands mapping, traditional reference data was not available. At the time of scoping for this project, it was believed that NCWCD possessed crop type reference data for a selection of irrigated lands in the South Platte. However, after contacting them it was discovered that the data was not available. The scope of work states that Riverside will attempt to obtain reference data where available and that a crop type classification similar to the historic crop type classifications in phase 4 will be performed. In the absence of reference data from NCWCD Riverside created reference parcels in accordance with the procedures performed in the historic crop type classification.

A random selection of irrigated parcels was made for Landsat frames 3332, 3232, and 3333. The parcels that were selected were similar in location to reference parcels created and used in 2001 irrigated parcel mapping. A negative 30-meter buffer was applied to the selection to create a subset of irrigated parcels used as reference data. These parcels were used with the multi-band zonal stats tool that is part of the Irrigated Lands/Crop Type Monitoring tools created jointly by Riverside, NCWCD, and CWCB. This tool returns the mean NDVI for each irrigated parcel on each image date. This data was imported into Excel and graphed. The graph represented the NDVI curve or crop signature for a single reference parcel. For each reference parcel, the graphs were inspected and the crop type was interpreted from the curve. The inspection and interpretation was based on our experience with the 2001 irrigated lands mapping and the historic mapping. Representative crop type curves are included in Appendix 3 of Memo 89.2 of the SPDSS documentation. ***Figure 2*** displays several crop type curves for small grains along with other curves that are not small grains.

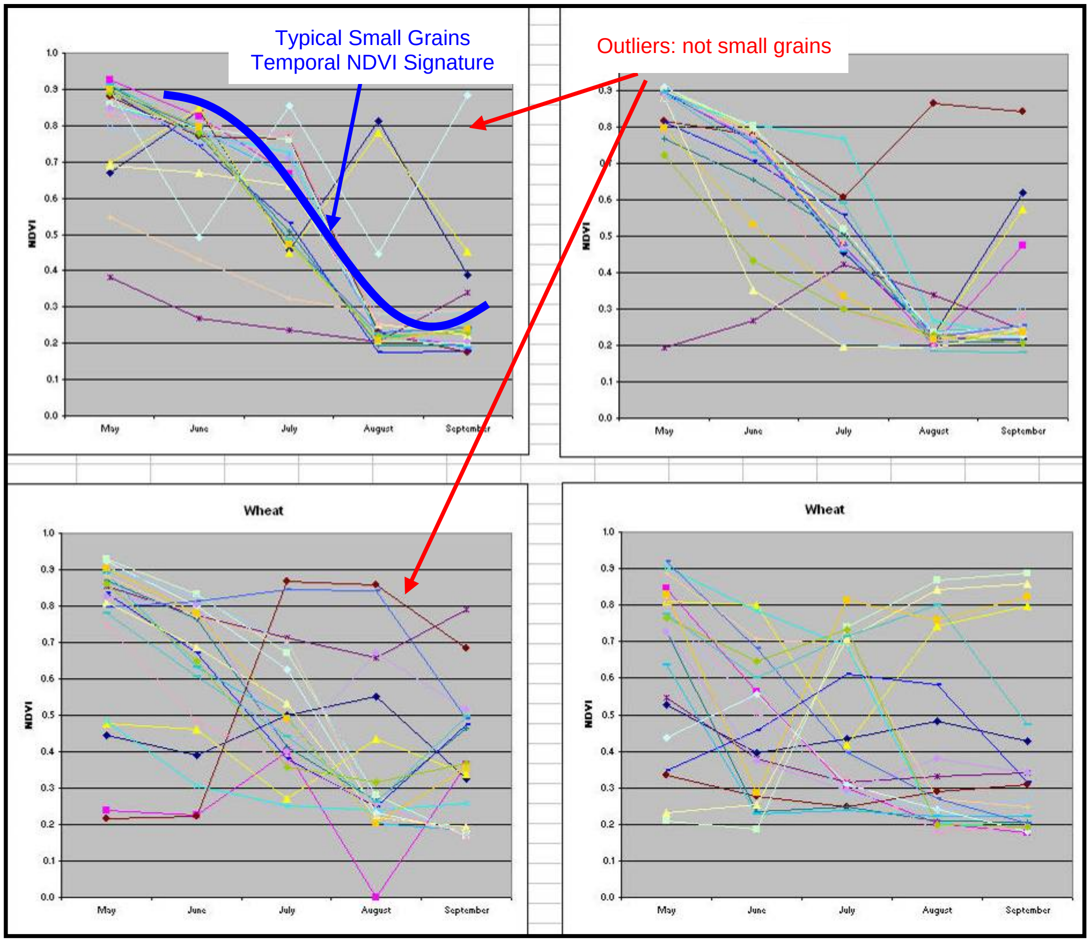

Figure 2. Example of multi-temporal signature analysis

Table 3 shows the number of reference parcels used for classification training data in each satellite frame.

Table 3. 1997 Reference Parcels

Landsat Frame	3332	3232	3333
No. of Reference Parcels	479	76	55

Another source of reference data is the USDA's National Agricultural Statistics Service (NASS), and the Colorado Agricultural Statistics Service (CASS) both report annual agricultural statistics for all reported irrigated crops by county dating historically to 1909. Data from HydroBase was summarized by the Consumptive Use (CU) contractor and provided to Riverside for each crop type within all SPDSS counties. For counties lying partially within the SPDSS study area (Sedgwick, Logan, Washington, Logan, Elbert, El Paso, Teller, and Park), the percentage of irrigated agriculture in the SPDSS area was estimated and used to prorate the agricultural statistic totals within these partial counties. ***Figure 3*** shows the decadal trends of the agricultural statistics reported acreage within SPDSS counties for the years 1950 thru 2001.

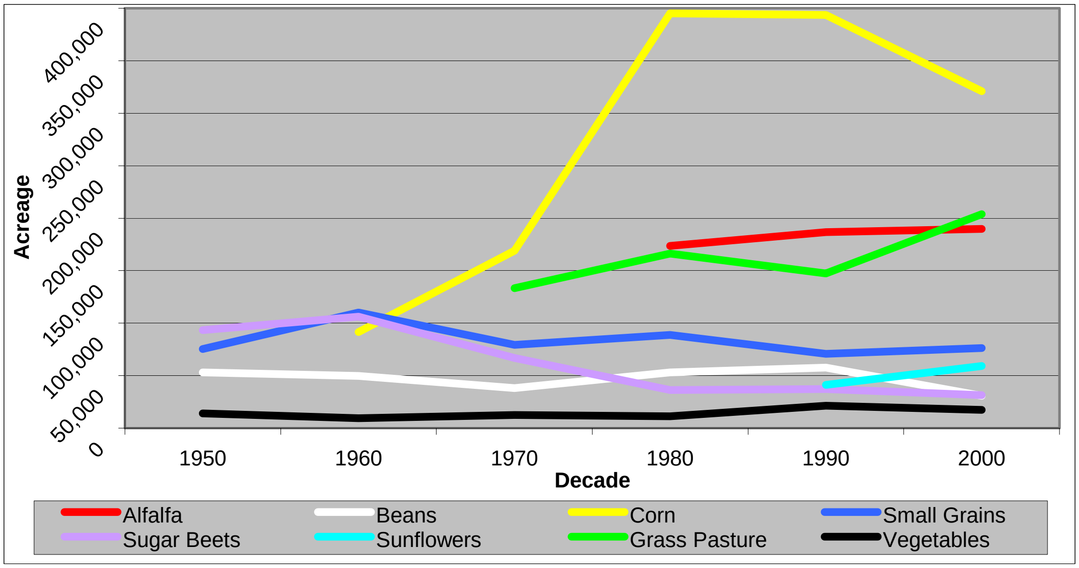

Figure 3. Agricultural statistics decadal total acreage per crop type within SPDSS, 1950 - 2001 as compiled from NASS and CASS data by the SPDSS CU contractor.

The agricultural statistics are a useful indicator of crop production within a county for a given time period. Although agricultural statistics are reported annually, there are errors in the data set. Prior to 1987, irrigated acreage of alfalfa was not fully reported each year. Likewise, prior to 1986, grass pasture also was not fully reported each year. ***Figure 3*** highlights the absence of full reporting for all crops in 1976 and 1956. In addition to missing data, some acreage reported within the agricultural statistics appears to be erroneous. For example, every five years grass pasture acreage increased by an average of 200 percent, followed by an average 200 percent decrease the following year. The grass pasture acreage fluxuations likely were due to combining CASS: “hay other” category with irrigated grass pasture NASS crop type on a five-year basis. These factors were taken into consideration when this information was compared to irrigated acreage classification results. Due to a lack of true reference data the agricultural statistics, along with other years of SPDSS irrigated lands mapping, were used as test data to compare the results of the 1997 crop type classification.

4. Classifications

Classification procedures used in the 1997 mapping were adapted from 2001 classification methods described in SPDSS Technical Memoranda 89.2, Section 2.5. The hierarchical classification procedure began with the discrimination of irrigated lands from non-irrigated lands through interpretation and analysis of multi-temporal NDVI data derived from Landsat imagery for 1997. Next, using GIS the irrigated lands classification was combined with DOQs to “back-date” 2001 irrigated parcel boundaries to represent 1997 parcel boundaries. Parcel back-dating consisted of adding parcels, modifying existing parcel shapes to represent 1997 parcels apparent in satellite imagery, and removing existing parcels that were not present during 1997. Backdating of parcels was used to modify 2001 parcels to 1997.

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Once the parcels were delineated, irrigated lands for 1997 were classified into major crop types using the ERDAS Imagine Maximum Likelihood Classifier (MLC[1]). The MLC is a commonly used method of classification in remote sensing, in which a pixel with the maximum likelihood is classified into the corresponding class (e.g. Jensen, 1996, Lillesand and Kiefer, 2000).

4.1 Update Irrigated vs. Non-irrigated Lands

As in previous SPDSS phases, the classification of 1997 irrigated lands consisted of analysis of temporal signatures of irrigated and non-irrigated cover types. This analysis consisted of creating a multi-temporal NDVI composite image. ***Figure 4*** displays an example of the NDVI composite image with the SPDSS image base map. The figure shows irrigated areas in red, yellow, green, and blue. Shades of gray and brown are not irrigated. The NDVI composite image allows very quick review and interpretation of each image date. The composite can be displayed with any NDVI date as the red, green, or blue color band. Early dates are typically displayed with blue, middle dates are displayed with green, and late dates are displayed with red. With this color combination, blue areas represent vegetation that is at its peak early in the season. Yellow and red areas represent vegetation that is at its peak later in the season.

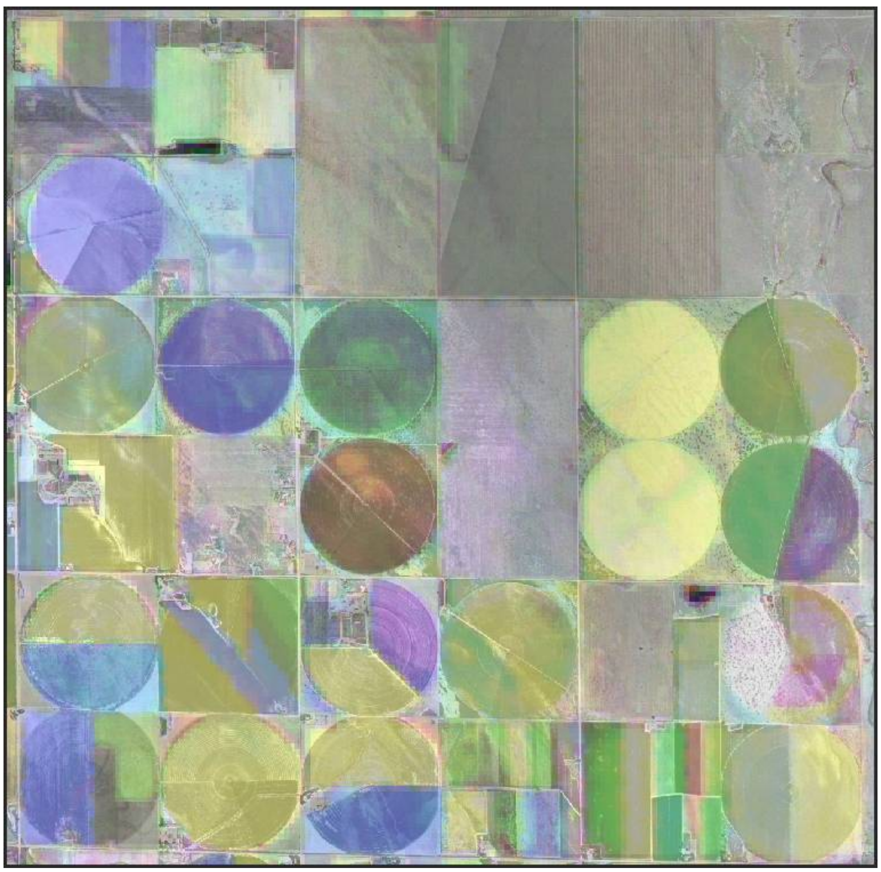

Figure 4. Example of NDVI composite and SPDSS ortho image base map

[1] The Maximum Likelihood Classifier MLC is based on the probability that a pixel belongs to a particular class. The basic equation assumes that these probabilities are equal for all classes, and that the input bands have normal distribution. The maximum likelihood classifier uses the Gaussian threshold stored in each class signature to determine if a given pixel falls within the class or not. The threshold is the radius (in standard deviation units) of a hyperellipse surrounding the mean of the class in feature space. If the pixel falls inside the hyperellipse, it is assigned to the class. The class bias (BIAS) is used to resolve overlap between classes, and weights one class in favor of another.

This image was analyzed with 2001 irrigated parcel boundaries, SPDSS ortho image base, and 1997 IRS imagery. 2001 parcels were marked as non-irrigated if the NDVI indicated they were not irrigated. Likewise, irrigated parcels were added if the NDVI indicated that they were irrigated. However, previous experience with irrigated parcels in the basin was accounted for in this step. For example, dryland parcels and certain drainages were not mapped if they were not mapped in 2001 or they do not have access to a water source. This guarantees that we do not add parcels that were fully evaluated and determined not to be irrigated in 2001. All of the parcels were reviewed and edited, and then reviewed by a second analyst for quality assurance. This redundancy ensures that we achieve the best possible irrigated vs. non-irrigated segregation.

4.2 Irrigated Parcel Boundary Update

SPDSS 1997 irrigated parcel boundaries were created from the SPDSS 2001 irrigated parcel boundaries. The following procedures describe the editing that was performed on the SPDSS 1997 irrigated parcels in order to make them consistent with 1997 satellite imagery and the 1997 irrigation season.

The first step in editing and reviewing the irrigated parcels was to determine which parcels needed to be split due to multiple crop types spanning a single parcel. To identify these parcels Riverside developed a semi-automated parcel change detection procedure. The parcel change detection consisted of an analysis of the NDVI multi-temporal composites. The objective of this analysis was to select parcels that are homogeneous and bimodal or multimodal, and therefore contain more than one crop type. This indicates there may be a change needed in the boundary of that particular parcel. The following steps outline the process for identifying parcels that may need to be edited:

In the first step, a simple unsupervised classification was produced from the NDVI multi-temporal composites. The purpose of this classification was to cluster temporal differences between cover types in the NDVI composite into distinctive groups (***Figure 5***).

In the second step, a neighborhood statistics analysis was conducted on the unsupervised classification. The analysis was performed using a density function with a 3 by 3 window. As a result, each pixel was assigned a value ranging from 1 to 9. A pixel with a value of 1 does not match any of the 8 surrounding pixels, and therefore belongs to a heterogeneous area; conversely, a pixel with a value of 9 belongs to the same class as the 8 surrounding pixels, indicating that it belongs to a homogeneous area (***Figure 6***).

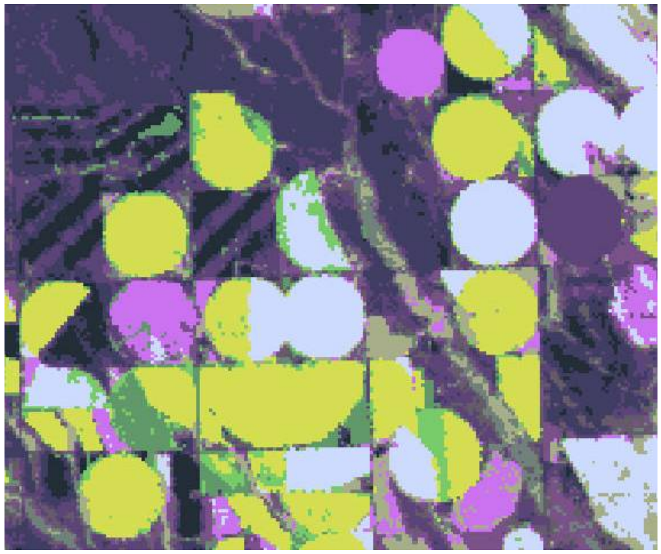

Figure 5. Unsupervised classification of multi-temporal NDVI composite showing temporal differences of irrigated crops

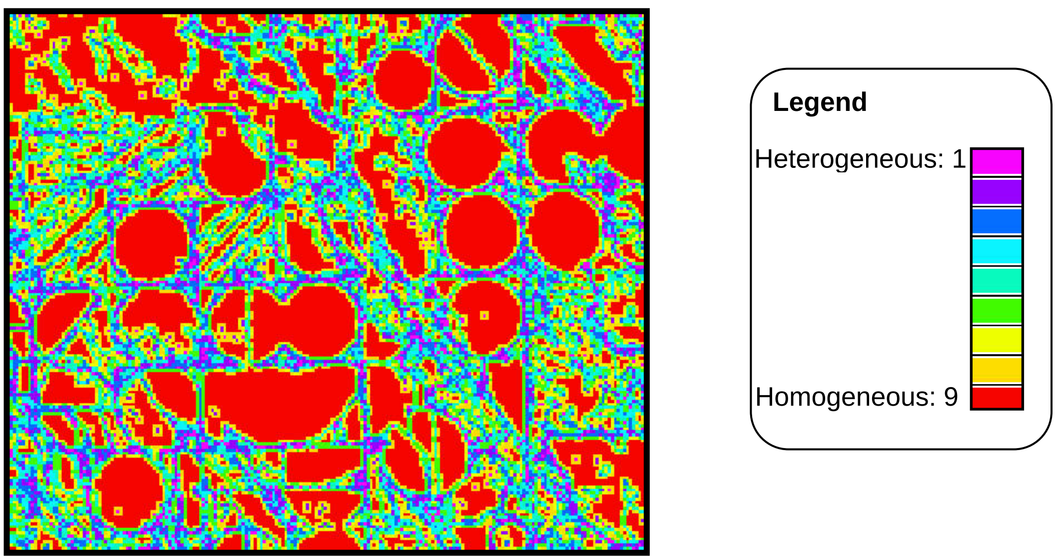

Figure 6. Density raster obtained from unsupervised classification of NDVI imagery.

In the third step, a zonal statistics analysis was performed using the SPDSS 1997 irrigated parcel data as the zone layer, and the unsupervised NDVI classification as the value raster using the majority fraction function. The irrigated parcel data and the density raster were used to obtain the mean density value for each parcel. This resulted in majority fraction and density field attributes, indicating the predominance of a particular temporal class and its corresponding density value (***Figure 7***).

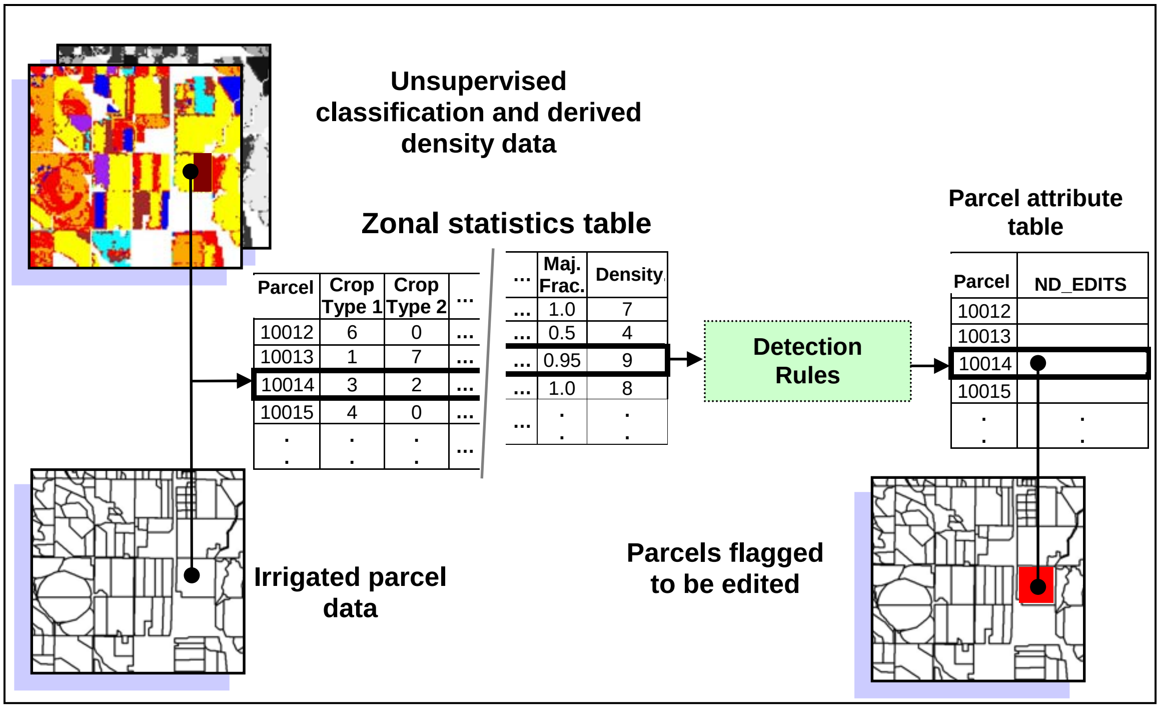

Figure 7. 2005 Parcel Change Detection Procedure

In the fourth step, a query was conducted using the recently computed majority fraction and density attributes in the irrigated parcel layer. The objective of the query was to flag parcels that met certain majority fraction and density criteria[2] (***Figure 7***), that is, parcels that might need to be edited for consistency with 2005 crop type formations.

Although the semi-automated parcel change detection procedure provides a reliable and significantly more efficient way of detecting and editing irrigated parcels, the procedure is not perfect. The selection algorithm missed some parcels in need of editing, and selected some parcels that did not need editing. Therefore, once the parcels were flagged, Riverside analysts conducted a detailed evaluation to determine if boundary edits were required. The flagged parcels were reviewed in ArcMap by overlaying them with the SPDSS ortho image base map and 1997 IRS imagery. Parcel updates included splitting parcel into two or more crops, editing the boundaries of flood-irrigated parcels into center pivots or vice versa, and editing parcel boundaries to match the enhanced resolution of the orthoimagery. ***Figure 8*** shows an example of the parcel editing. The red parcel boundaries represent the 2001 irrigated parcels and the green boundaries represent the 1997 boundaries.

[2] These values were determined empirically and may vary depending on the characteristics of the classification. In general, values above 0.68 for the majority fraction and below 6.5 for the density image identify parcels that need to be edited.

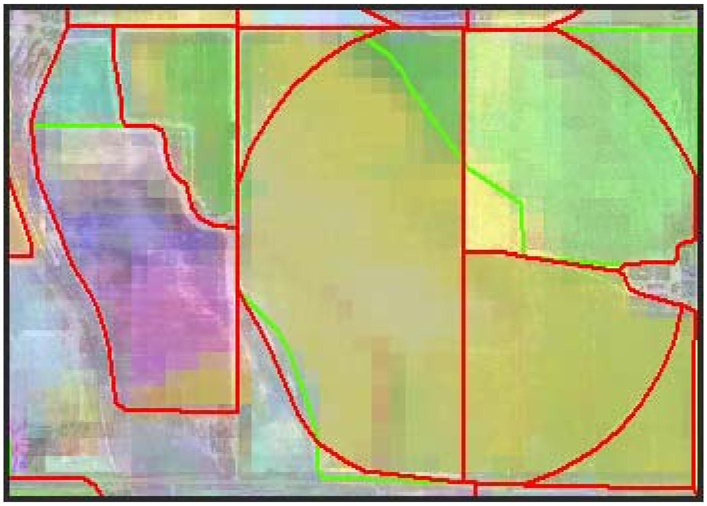

Figure 8. Example of parcel edits conducted during the SPDSS 1997 irrigated lands mapping

After updating the flagged parcels, the remaining areas of SPDSS were systematically inspected to identify additional parcel updates that might have been missed by the semi-automated selection procedure. During this process, the NDVI composite was used in combination with the orthoimagery and IRS imagery to identify new irrigated parcels in previously unmapped irrigated areas as well as to identify parcels not irrigated in 1997. In addition to this, adjacent parcels containing the same crop type were merged into a single parcel to reduce the number of parcels and the size of the parcel database. This process was conducted by systematic image interpretation of the orthoimagery and NDVI multi-temporal composite. Photo interpretation was greatly improved by combining the orthoimagery with the multi-spectral information of the Landsat imagery. Analysts could quickly confirm a parcel's irrigated or non-irrigated status.

4.3 Crop Type Classification

The crop type classification for 1997 used unsupervised classifications, multi-temporal NDVI signature analysis and spectral signature analysis, GIS data (i.e. parcel data), as well as other ancillary data in a combined MLC classification procedure. In addition, ancillary data was used to refine the classification of questionable crop signatures. The irrigated crop type classification for 1997 consisted of three steps: (1) irrigated lands masking, (2) NDVI spectral signature analysis and maximum likelihood classification, and (3) post-classification refinement (***Figure 9***).

As in SPDSS Technical Memorandum 89.2, Section 2.5.2.1, a list of crop types to be classified for all time periods was determined by (1) availability of 2001 crop types for comparison, (2) crops and acreage reported by the CASS, (3) spectral characteristics of the crops, and (4) input from the CU contractor on categories of crops with similar water requirements. Based on this information, the following crops or crop groups were classified: Small Grains, Dry Beans, Corn and Sorghum, Sugar Beets, Alfalfa, and Grass for Pasture and Hay. The crop types of corn and sorghum were combined due to similar spectral signatures and relatively low proportion of sorghum within the SPDSS study area (less than one percent).

4.3.1 Irrigated Lands Masking

In the first step, non-irrigated areas were eliminated from the Landsat imagery by applying the irrigated lands mask described in ***Section 4.1*** of this memo. This procedure eliminated areas associated with other land-cover types (e.g., dry-land crops, riparian vegetation, urban areas, etc.). The result is a single multi-band satellite image that includes all bands from all the dates in the frame.

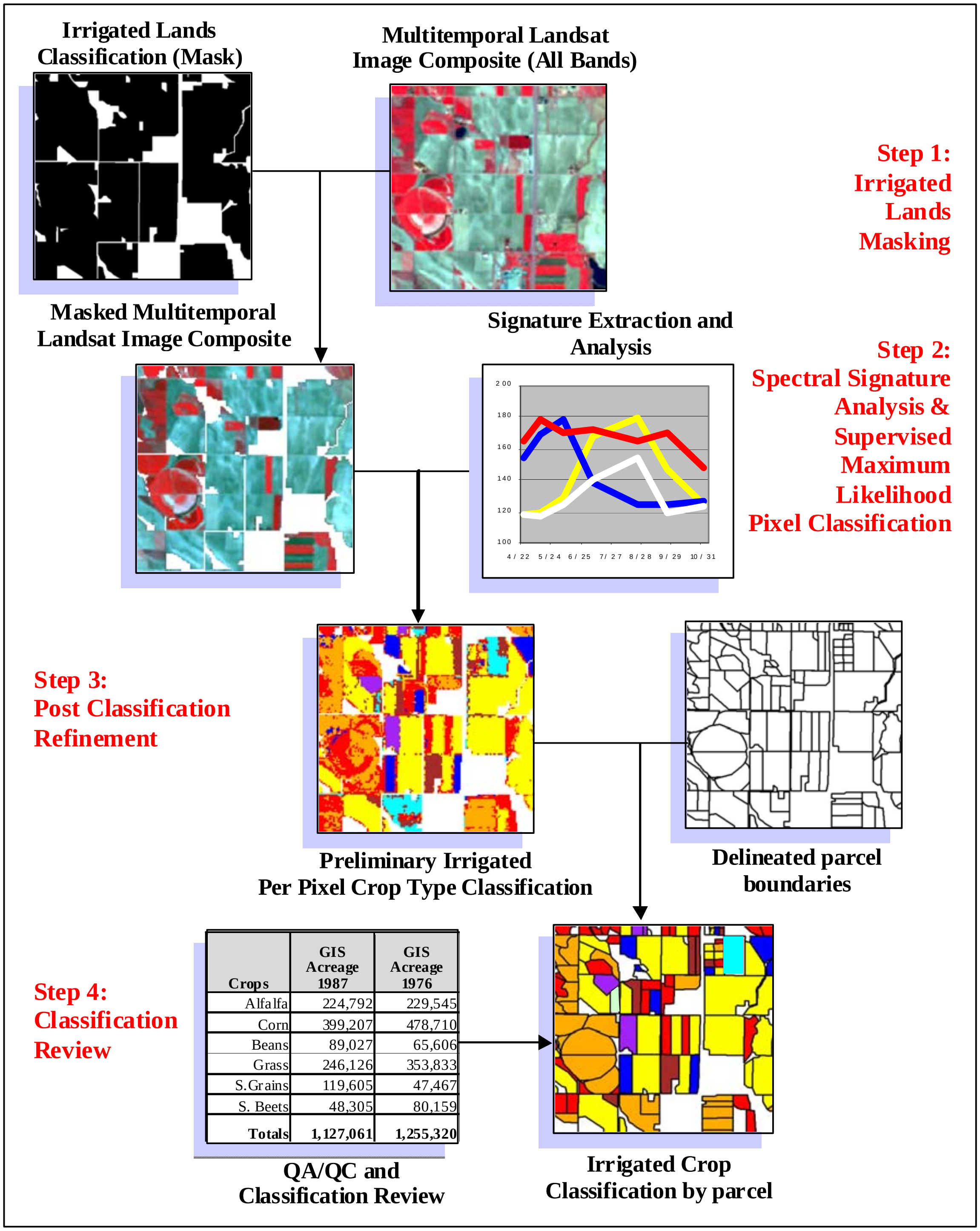

Figure 9. Historical irrigated crops classification procedure.

4.3.2 Spectral Signature Analysis and MLC Classification

The second step began with creating a signature file from the reference training data. As described in ***Section 3***, the training data includes the crop types from interpreting the NDVI signatures. The training data was used to extract spectral signatures from the masked multi-band Landsat image. The signature file was then used in a supervised classification. This procedure was performed for each satellite frame.

4.3.3 Post Classification Refinement and Review

In the third step, the classification for each satellite frame was reviewed and changes made. In frame 3332, it was determined that the classification was still affected by cloud cover for a portion of the frame. This was apparent because the classification was almost entirely small grains in this section. ***Figure 10*** displays this area.

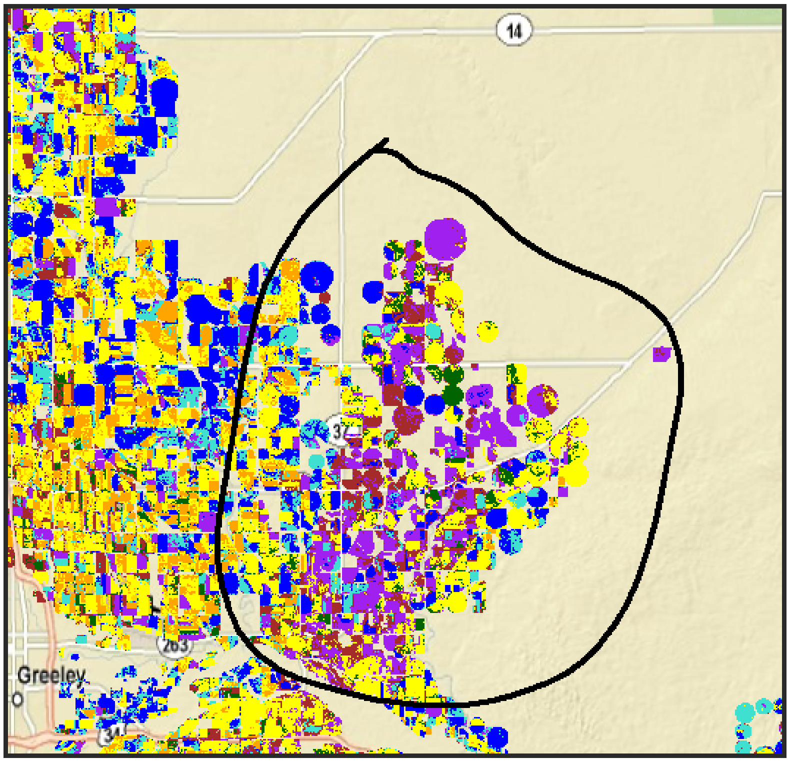

Figure 10. Cloud Affected Classification, Frame 3332

To achieve a better classification in this region a new Landsat composite image was created that did not include the August images, which contained the cloud cover. A new signature file was created with the training data and the new Landsat composite and then used in a supervised classification. This produced a result more consistent with the surrounding classification. The new classification was used to replace the cloud-affected area in the original classification. ***Figure 11*** displays the result.

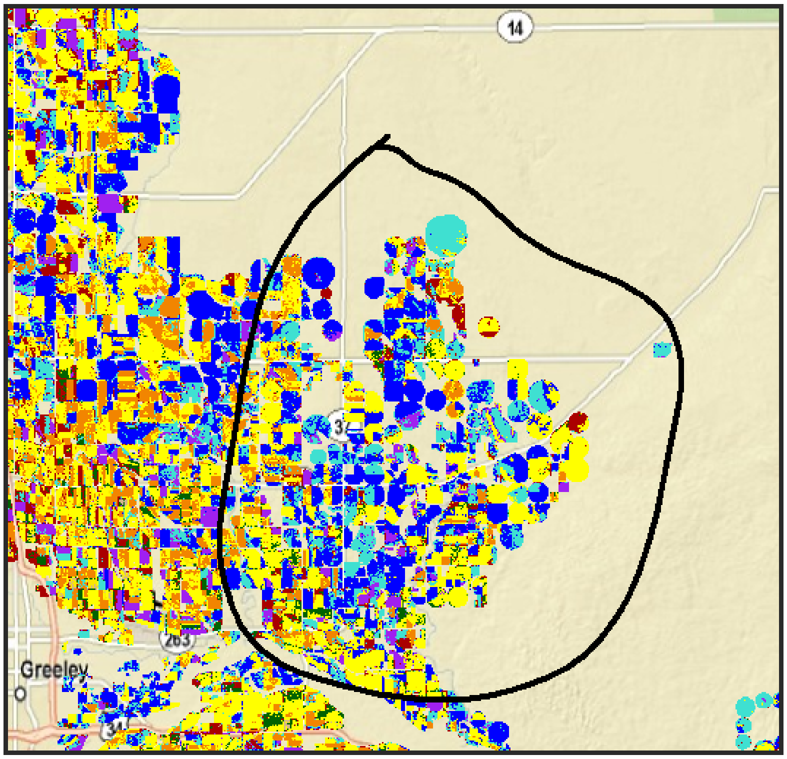

Figure 11. Final classification of Frame 3332

The crop type classification in frame 3232 was also reviewed. Frame 3232 was severely affected by cloud cover, containing essentially no useful imagery until August. This resulted in a classification of almost entirely corn. After discussion with the State on this issue, a routine was designed to compare the NDVI values of the parcels in the cloud-affected frame with the NDVI values for 2001. This routine calculated the crop type for the parcels by either copying the 2001 crop type or manually interpreting the crop type using the NDVI signature. ***Figure 12*** displays a flow chart of the routine used.

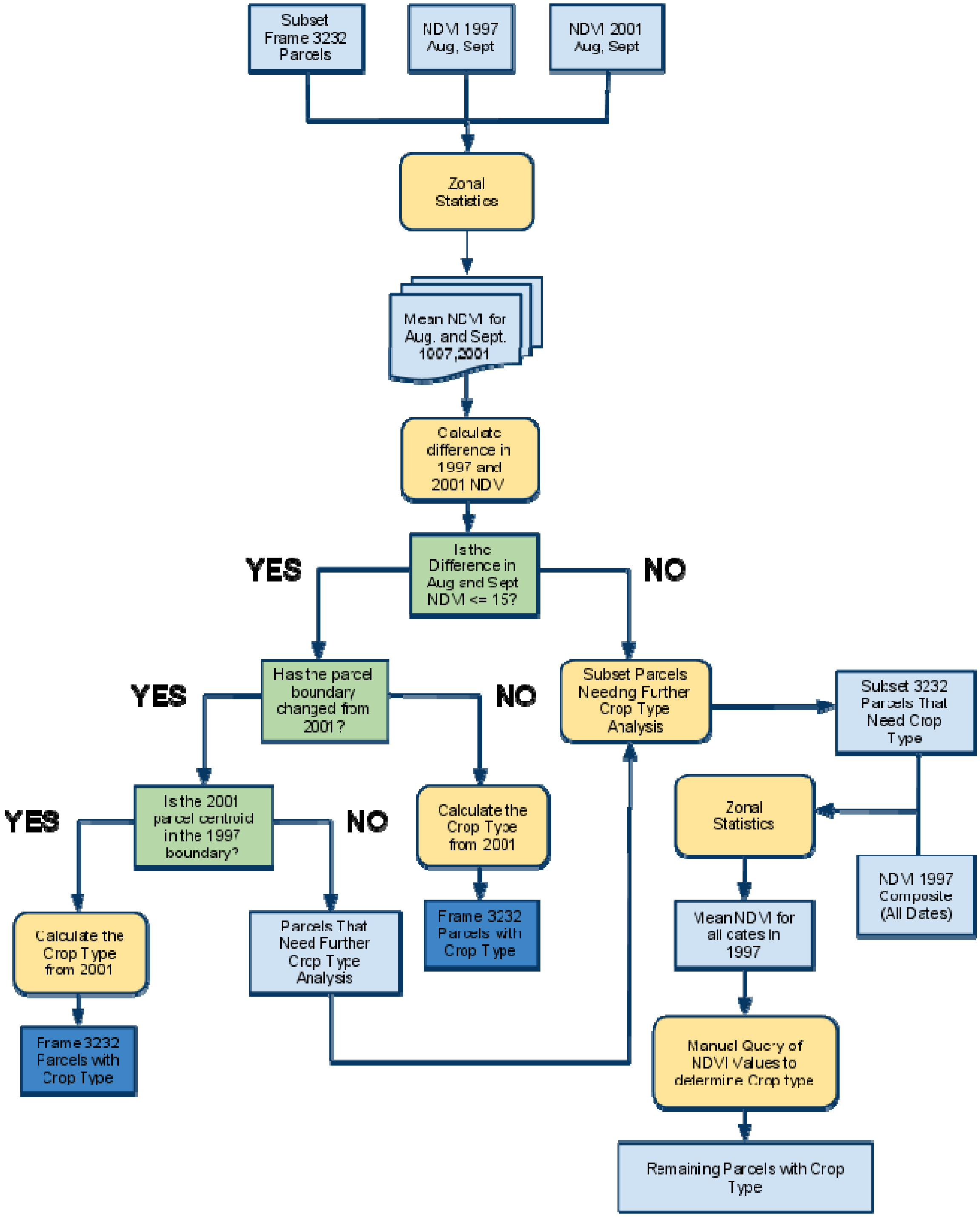

Figure 12. Flowchart of frame 3232 crop type assignment routine

While this routine is not perfect, Riverside and the client feel that it is the best possible outcome given the limited satellite data.

In the final step of classification, the crop type acreage was summarized and compared with other SPDSS crop type mapping and agriculture statistics. These results are described in ***Section 5***.

5. Results: Irrigated Lands and Crop Type Classifications

The result of the 1997 irrigated acreage shows 920,114 irrigated acres in the South Platte Basin and 106,299 irrigated acres in the North Platte Basin. The total irrigated acreage for the SPDSS in 1997 is 1,026,413 acres. This is very similar to the 910,517 acres for the South Platte Basin in 2001 and 1,016,483 acres for the South and North Platte Basins in 2001. ***Table 4*** summarizes the irrigated acreage by crop type and water district. ***Table 5*** summarizes the irrigated acreage by water source and water district.

Table 4. 1997 Irrigated Crop Acreage Summarized by Water District

District	Alfalfa	Corn	Dry Beans	Grass/ Pasture	Orchards	Small Grains	Sod Farm	Sugar Beets	Vegetables	District Total
1	69,923.9	135,903.2	3,159.9	35,084.7	-	27,658.1	726.6	48,535.9	-	**320,992**
2	39,275.3	40,109.6	2,020.8	29,842.4	-	10,650.4	-	11,060.6	-	**132,959**
3	29,223.1	55,177.3	2,720.1	34,508.7	-	6,836.3	-	18,535.5	-	**147,001**
4	12,504.6	21,832.4	390.6	15,642.7	-	5,570.9	-	8,949.3	-	**64,890**
5	12,872.8	15,248.5	205.4	20,682.9	-	7,313.5	-	5,357.7	-	**61,681**
6	5,262.9	3,463.3	19.84	13,690.0	-	2,280.8	-	1,700.8	-	**26,418**
7	188.0	41.67	0.00	1,448.3	-	43.00	-	0.00	-	**1,721**
8	8.5	243.1	103.3	3,064.5	-	0.00	-	0.00	-	**3,419**
9	-	47.8	-	1,349.1	-	0.00	-	0.00	-	**1,397**
23	-	123.1	-	7,882.8	-	0.00	-	0.00	-	**8,006**
48	-	-	-	3,708.4	-	0.00	-	0.00	-	**3,708**
64	41,446.2	79,656.8	907.1	14,283.8	-	7,095.4	-	3,920.7	-	**147,310**
80	-	-	-	611.2	-	0.00	-	0.00	-	**611**
South Platte Total	**210,705**	**351,847**	**9,527**	**181,799**	-	**67,448**	**727**	**98,060**	-	**920,114**
47	-	-	-	106,299	-	-	-	-	-	**106,299**
SPDSS Total	**210,705**	**351,847**	**9,527**	**288,098**	-	**67,448**	**727**	**98,060**	-	**1,026,413**

Table 5. 1997 Irrigated Acreage Summarized by Water Source and Water District

District	Ground Water Only	Ground and Surface Water	Surface Water Only	Other*	District Total
1	109,484	101,286	110,222	0	**320,992**
2	14,251	47,561	71,147	0	**132,959**
3	3,960	31,038	110,787	1,216	**147,001**
4	294	2,594	62,003	0	**64,890**
5	256	1,631	59,794	0	**61,681**
6	82	275	26,061	0	**26,418**
7	123	89	1,509	0	**1,721**
8	1,086	729	1,604	0	**3,419**
9	0	0	1,397	0	**1,397**
23	0	0	8,006	0	**8,006**
48	0	0	3,708	0	**3,708**
64	39,639	42,027	65,644	0	**147,310**
80	0	0	611	0	**611**
South Platte Total	**169,174**	**227,230**	**522,494**	**1,216**	**920,114**
47	0	684	105,615	0	**106,299**
SPDSS Total	**169,174**	**227,914**	**628,109**	**1,216**	**1,026,413**

Results from the irrigated lands classification and crop type classification were also summarized and compared to agricultural statistics. ***Table 6*** reports irrigated lands acreage totals and crop type specific acreage totals as compared to agricultural statistic estimated acreages for Division 1 and District 47. The table includes 1956, 1976, 1987, 1997, and 2001 GIS acreage and agricultural statistics for relative comparisons.

Figure 13 displays summaries from ***Table 6*** in graphical format against per year agricultural statistics from 1950 through 2004 for Adams, Arapahoe, Boulder, Larimer, Morgan, and Weld Counties. These six counties are completely within the SPDSS study area and contain a large percentage of agriculture within the SPDSS. ***Figure 14*** compares mapped GIS irrigated acreage by crop type to agricultural statistics for 1950, 1976, 1987, and 2001 for the South Platte Basin. These different tables and graphs show that the irrigated acreage and crop type distribution follows the general trend for agriculture in the South Platte Basin. Irrigated acreage reaches its peak in the 70s and 80s and then continues to decline.

Table 6. SPDSS acreage by crop type for years 1956, 1976, 1987, and 2001 compared to estimated agricultural statistics totals for Division 1 and District 47

Crop Type	GIS Acreage 1956	Ag Stats Estimated 1956 [2]	GIS Acreage 1976	Ag Stats Estimated 1976 [2]	GIS Acreage 1987	Ag Stats Estimated 1987	GIS Acreage 1997	Ag Stats Estimated 1997	GIS Acreage 2001	Ag Stats Estimated 2001
Division 1										
Alfalfa	196,734	0	206,362	0	217,892	189,820	210,705	195,780	310,521	218,230
Corn	394,342	0	423,683	227,130	387,976	403,896	351,847	425,989	333,943	424,104
Dry Beans	52,542	54,444	58,523	43,688	86,966	73,385	9,527	41,600	29,401	30,845
Grass Pasture	232,633	0	217,660	782	131,095	124,337	181,799	133,190	120,073	116,065
Orchard w/o	0	0	0	0	0	0	0	0	2,239	0
Small Grains	37,402	149,495	40,192	76,708	116,448	102,012	67,448	80,964	65,849	86,785
Sod Farm	0	0	0	0	0	0	0	0	5,246	0
Sugar Beets	68,691	105,501	69,826	73,315	46,763	36,948	98,060	54,343	26,904	29,428
Vegetables	0	0	0	0	0	13,580	0	22,281	16,343	0
Sunflowers	0	0	0	0	0	0	0	0	0	33,130
Division 1 Totals	982,345	309,440	1,016,246	421,623	987,139	942,977	920,114	954,147	910,518	938,587
District 47										
Alfalfa	0	0	0	0	0	2,000	0	0	0	0
Grass Pasture	117,403	0	113,007	0	110,154	102,809	106,299	75,000	105,966	59,000
District 47 Totals	117,403	0	113,007	0	110,154	104,809	106,299	75,000	105,966	59,000
SPDSS Totals	**1,099,748**	**309,440**	**1,129,253**	**421,623**	**1,097,293**	**1,047,786**	**1,026,413**	**1,029,147**	**1,016,484**	**997,587**

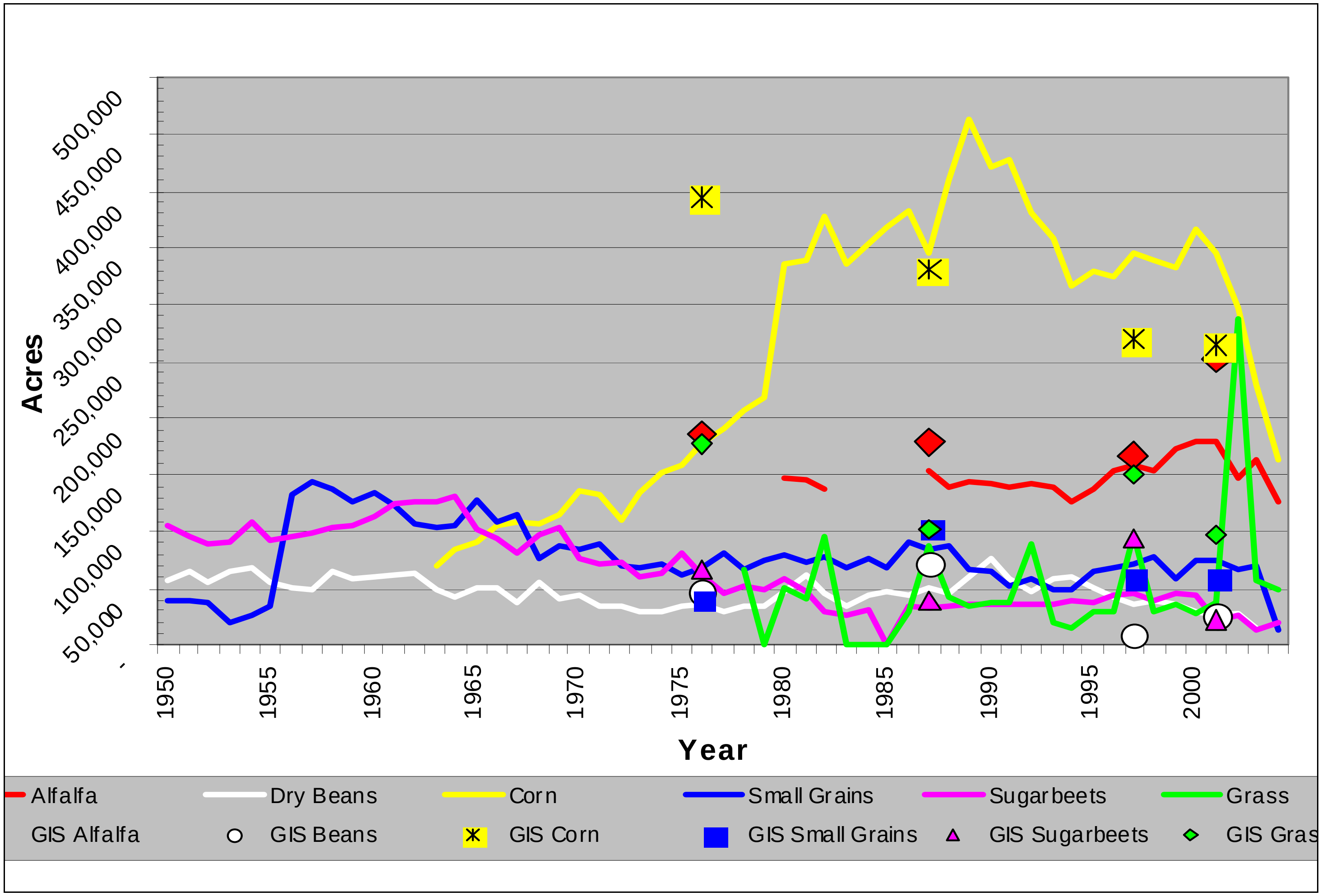

Figure 13. Agricultural statistics vs. SPDSS-derived acreage in 1976, 1987, and 2001 for Adams, Arapahoe, Boulder, Larimer, Morgan, and Weld counties.

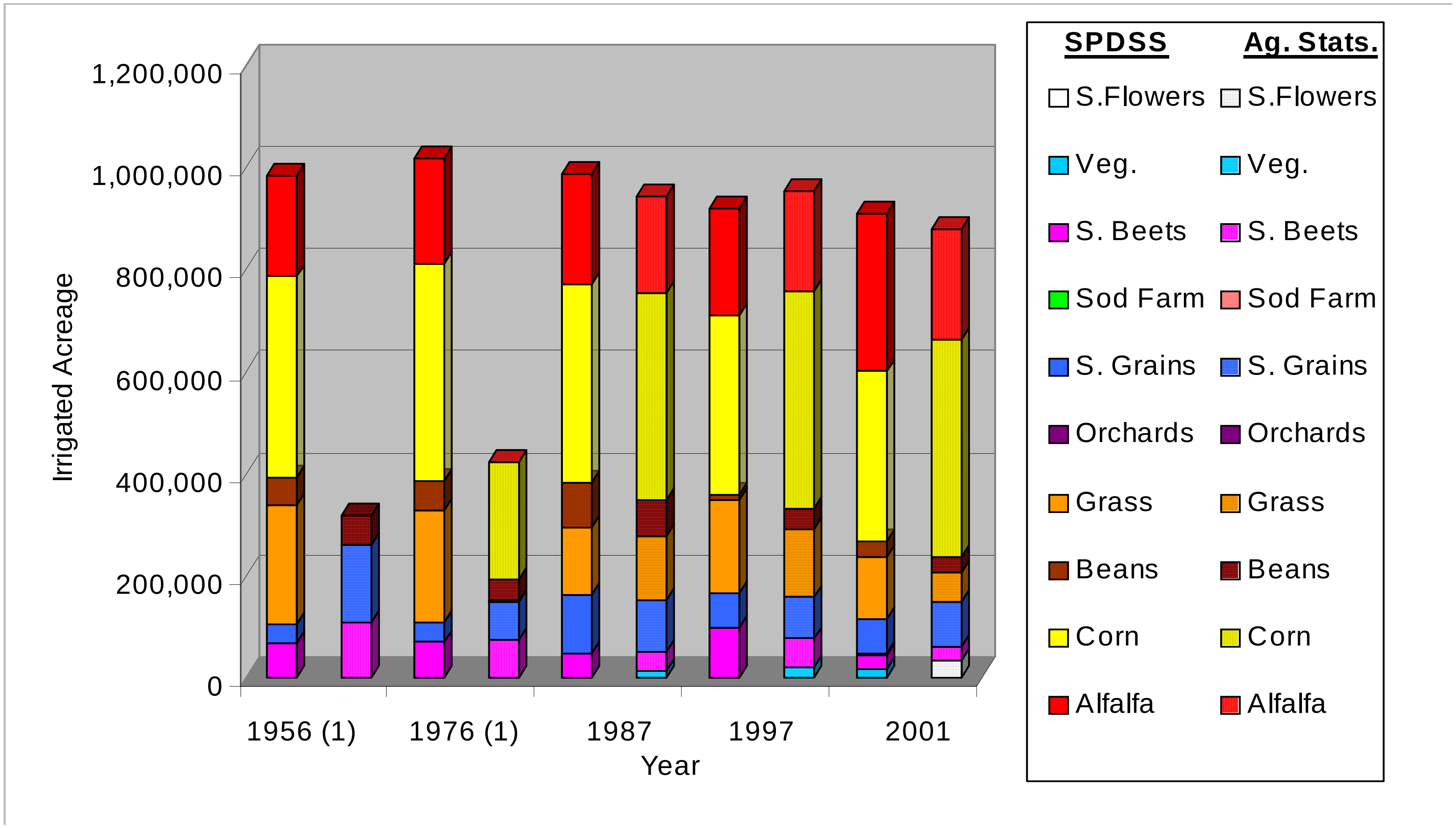

Figure 14. Division 1 irrigated acreage crop types: SPDSS vs. agricultural statistics[3].

[3] Agricultural statistics not fully reported for grass or alfalfa prior to 1986.

6. Historic Water Source Assignment

After the parcel boundary edits and preliminary irrigated land and crop type classifications were complete, water source was assigned to the SPDSS 1997 irrigated parcels. This included surface water sources from diversion structures and ground water sources from wells. The SPDSS 2001 irrigated parcels and irrigation service areas were used as a guide. The same procedure performed on the SPDSS historic parcels, outlined in Memo 93 were performed with the SPDSS 1997 parcels. The water source was assigned to the 1997 parcels from the 2001 parcels in the same way that the 1987 parcels were assigned water source from 2001. ***Figure 15*** shows a flow chart of the water source assignment process.

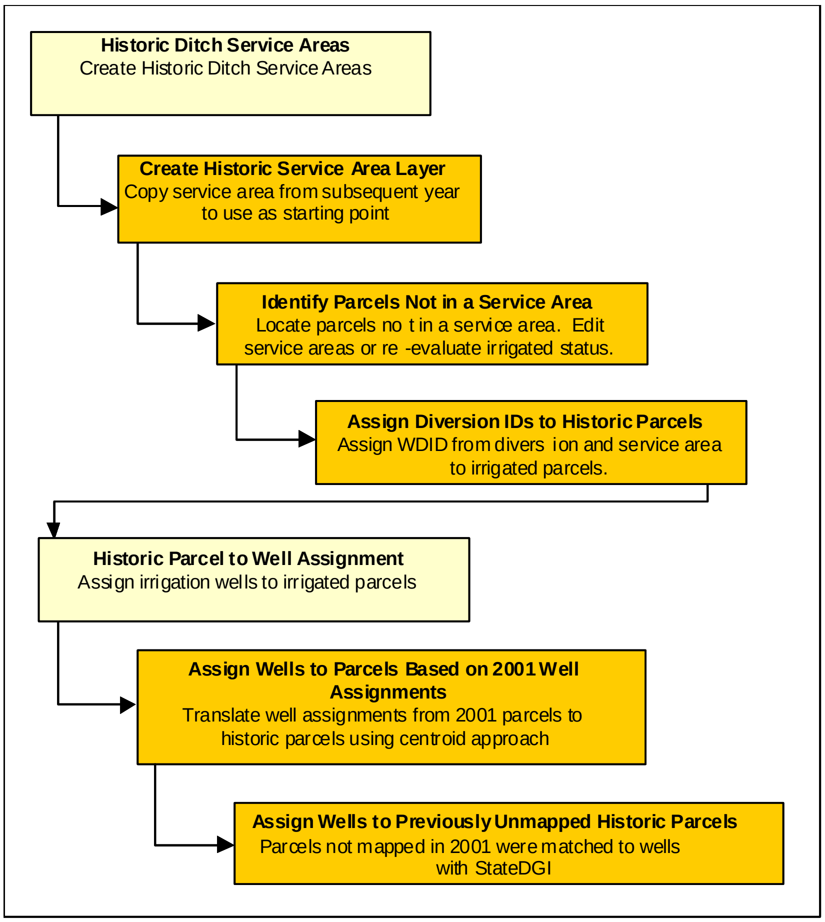

Figure 15. Overview of SPDSS irrigated parcel historic water source assignment.

6.1 Surface Water Diversion Irrigation Service Areas

SPDSS 2001 irrigation service areas were used as a base for assigning surface water sources to SPDSS 1997 irrigated parcels. First, the 2001 service areas were copied to create a 1997 service area layer. Then the service areas were intersected with the 1997 irrigated parcels to assign the diversion structure IDs to the individual parcels. For more detail on this procedure, see **Section 6.2** of **SPDSS Memo 93**.

6.2 Well Assignment

The 2001 well-to-parcel assignments were used for the 1997 irrigated parcels. This was accomplished using the same well translate methodology described in **Section 6.3** of **SPDSS Memo 93**. 2001 decreed wells and permitted wells were used for the well translate procedure.

6.3 Review and Revision

After assigning surface and ground water sources to the irrigated parcels, the entire dataset was again reviewed and quality controlled. This included a review by Riverside. It also included a final check on the irrigated parcel dataset for CDSS and HydroBase consistency.

Internal review by Riverside analysts was conducted to ensure all parcels had a proper water source. If a new parcel was identified as being irrigated but there was no reasonable water source nearby, Landsat Imagery and NDVI composites were consulted again. If the parcel appeared marginally irrigated or questionable, it was attributed as non-irrigated. The review also ensured each parcel had the correct irrigation type and a proper irrigation service area polygon.

The final review involved summarizing the irrigated acreage by water source and comparing the acreage to 2001 and other years mapped in the SPDSS. This review shows that the 1997 irrigated acreage follows the general trend for surface water, ground water, and ground and surface water acreage among the different years. The proportions of each are very similar to 2001: 57%, 18%, 25%, respectively.

6.4 Results: Irrigated Acreage by Water Source

Table 7 and ***Figure 16*** show the irrigated acreage for Division 1 by water source. District 47 is irrigated almost entirely with surface water.

Table 7. Division 1 Historic Irrigated Acreage by Water Source

Water Source	1956	% of Total	1976	% of Total	1987	% of Total	1997	% of Total	2001	% of Total
Groundwater Only	111,674	11%	176,598	17%	179,383	18%	169,174	18%	165,737	18%
GW & SW	199,283	20%	235,319	23%	225,050	23%	227,230	25%	234,182	26%
Surface Water Only	671,399	68%	604,329	59%	581,881	59%	522,494	57%	509,089	56%
Budweiser (Anheiser-Busch) Multi-Use Water	0	0.0%	0	0.0%	827	0%	1,216	0%	1,510	0.2%
Total	982,345	100.0%	1,016,246	100.0%	987,139	100.0%	920,114	100.0%	910,518	100.0%

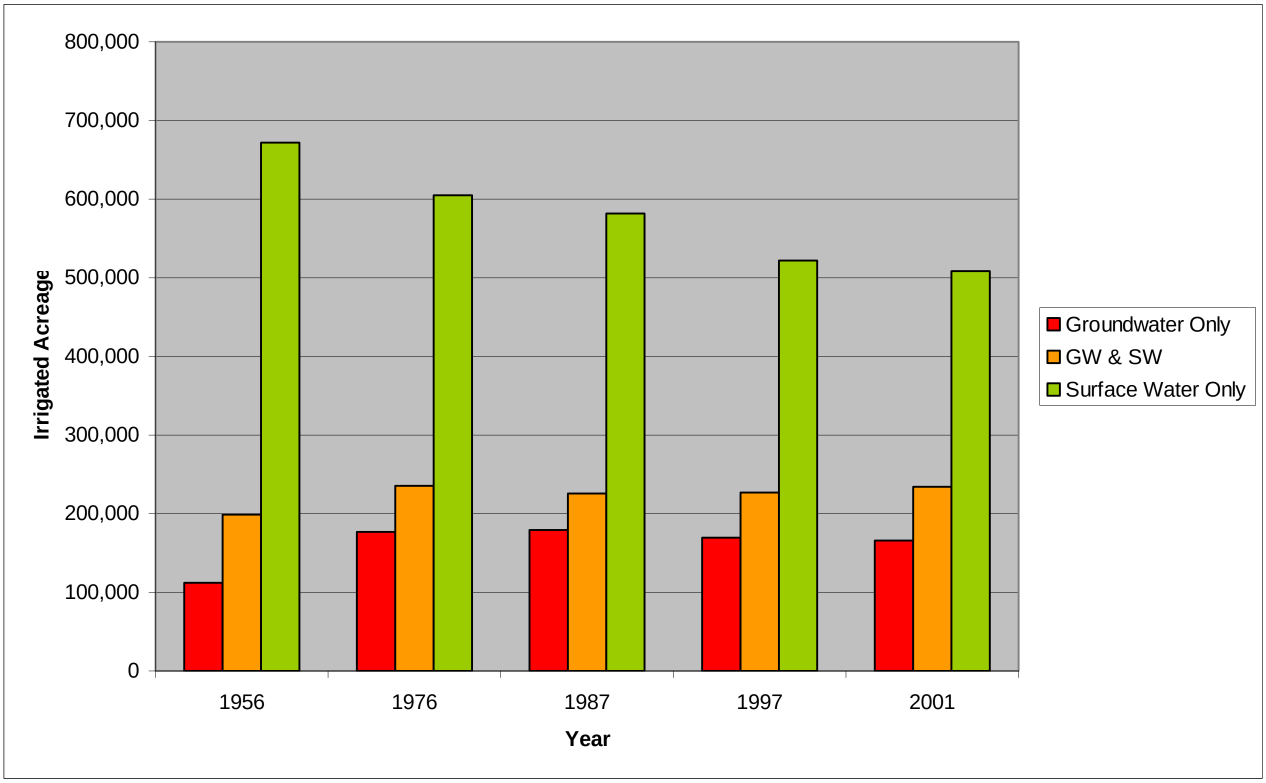

Figure 16. Division 1 historic irrigated acreage by water source.

Table 8 and ***Figure 17*** show the irrigated acreage for Division1 by irrigation type. District 47 is irrigated entirely by flood.

Table 8. Division 1 Historic Irrigated Acreage by Irrigation Type

Irrigation Type	1956	% of Total	1976	% of Total	1987	% of Total	1997	% of Total	2001	% of Total
Flood	982,345	100%	875,411	86%	771,871	78%	661,068	71%	615,522	67%
Sprinkler	0	0%	140,835	13%	215,268	21%	259,045	28%	294,996	32%
Total	982,345	100%	1,016,246	100%	987,139	100%	920,114	100%	910,518	100%

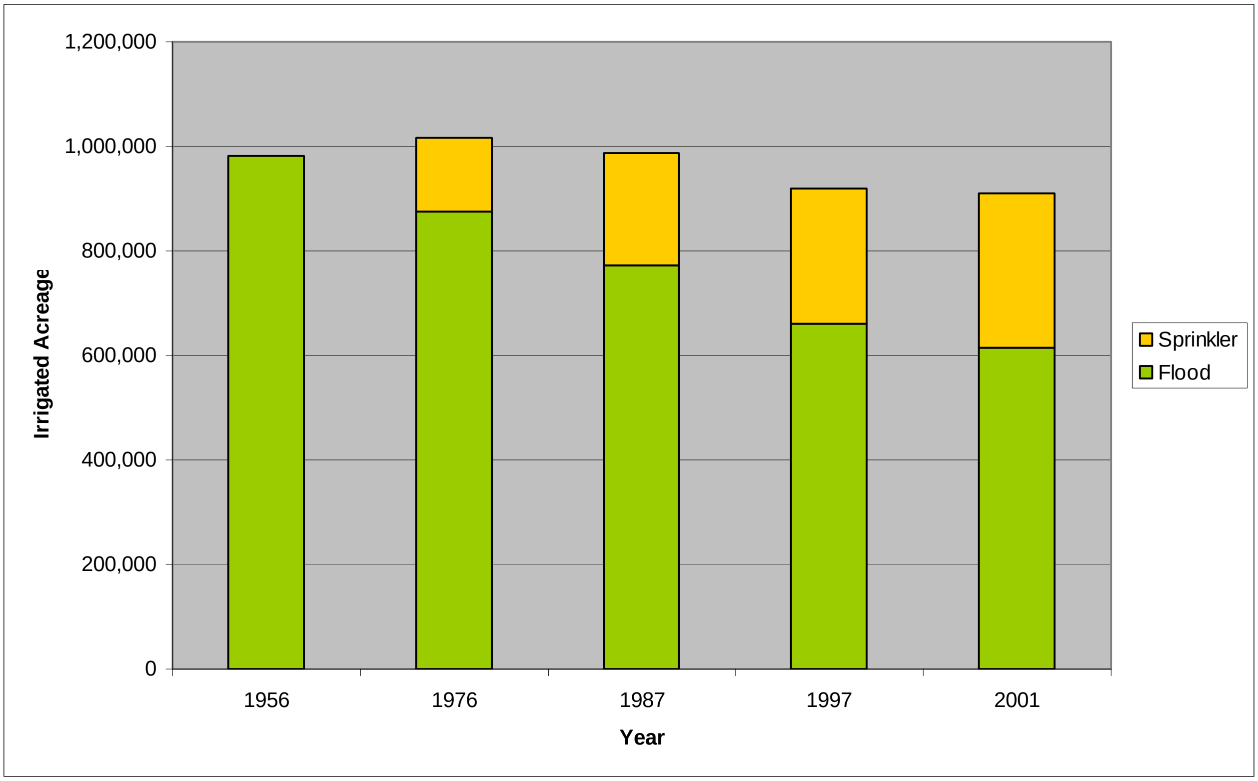

Figure 17. Division 1 historic irrigated acreage by irrigation type.

7. Comments and Concerns

The accuracy of the SPDSS 1997 irrigated acreage estimates was affected by the cloud cover during the 1997 growing season and overall lack of ground data and water user inputs. Lack of clear satellite imagery on key dates during the growing season has a negative affect on the crop type classification. However, accurate irrigated parcel delineation can be accomplished with diminished satellite image availability. Consequently, Riverside feels that the 1997 irrigated acreage determination is very accurate while the crop type acreage is slightly less accurate. This is apparent when comparing the 1997 data with other years mapped in the SPDSS. The overall irrigated acreage is lower than the 1987 irrigated acreage and slightly higher than the 2001 irrigated acreage. This follows the trend of declining irrigated acreage from 1976.

The 2001 crop type classification procedure was adapted for the 1997 crop type classifications to overcome the absence of crop type reference data. Knowledge gained about crop phenology and spectral reflectance during the 2001 growing season was applied to the 1997 season. This experience enabled classification of crop types without parcel specific crop type reference data. The lack of quality satellite imagery in some portions of the basin on certain dates made interpreting the crop types for reference data challenging. Riverside spent additional time to prepare and process the satellite imagery in order to extract the maximum amount of useful information from the imagery. This allowed for a reasonable estimate of the crop types for 1997, with some uncertainty however. The comparison of 1997 crop types with other years mapped by SPDSS shows some differences in crop type trends. For instance, alfalfa is generally increasing over time; however, in 1997 alfalfa acreage is slightly below the 1987 acreage. In addition, the amount of dry beans appears to be low in 1997. Some of this acreage could be mistaken for sugar beets, which appears high in 1997. The lack of parcel specific crop type reference data also prohibited formal accuracy assessment of classification results.

Concerns and solutions were discussed with the State throughout the duration of the project. The implemented solutions effectively overcame many of the limitations and concerns with the data. The resulting irrigated parcel and irrigation service area dataset for 1997 is a high quality estimate of the irrigated lands in the South Platte and North Platte River Basins.

8. References

Anderson, J.R., Hardy, E.E., Roach, J.T., Witmer, R.E., 1976. A Land Use and Land Cover Classification System for Use With Remote Sensor Data. USGS Professional Paper 964.

Catts, G.P., Kohorram, S., 1985, Remote Sensing of tidal chlorophyll-a variations in estuaries. International Journal of Remote Sensing 6(11): 1685-1706.

Chavez, P.S. Jr., 1996, Image-based atmospheric corrections—revisited and revised. Photogrammetric Engineering and Remote Sensing 62(9): 1025-1036.

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Jensen, J.R. 1996. Introductory Digital Image Processing: A Remote Sensing Perspective. Second Edition. Prentice Hall Series in Geographic Information Science. Upper Saddle River, New Jersey. 318 p.

Appendix A: Estimated Agricultural Statistics Summary Tables

Table A- 1. Agricultural statistics adjusted for percentage of county agriculture within SPDSS area for year 1997.

County	Est. % of County Ag. in SPDSS	Small Grains	Dry Beans	Corn	Sugar Beets	Alfalfa	Grass	Vegetables	Total Estimated AgStats Acreage
Adams	100%	4,000	500	7,000	1,690	7,800	1,500	4,940	27,430
Arapahoe	100%	1,200	-	1,800	-	2,400	1,500	3	6,903
Boulder	100%	5,400	500	7,600	1,150	11,500	9,000	584	35,734
Clear Creek	100%	-	-	-	-	-	-	-	0
Denver	100%	-	-	-	-	-	-	-	0
Douglas	100%	200	N/A	-	-	-	2,000	3	2,203
El Paso	3%	54	-	24	-	180	90	-	348
Elbert	40%	400	-	-	-	2,600	800	-	3,800
Jackson	100%	-	-	-	-	-	75,000	-	75,000
Jefferson	100%	-	-	-	-	1,000	700	20	1,720
Larimer	100%	7,100	4,700	26,000	4,680	21,700	13,500	1,549	79,229
Logan	95%	11,210	2,850	56,715	7,391	29,450	3,800	380	111,796
Morgan	100%	15,100	5,000	87,900	11,270	26,000	1,800	1,320	148,390
Park	95%	-	-	-	-	-	8,550	-	8,550
Sedgwick	50%	2,900	2,100	19,400	1090	2,650	750	-	28,890
Teller	10%	-	-	-	-	-	200	-	200
Washington	25%	3,300	950	8,550	452	2,000	500	-	15,752
Weld	100%	30,100	25,000	211,000	26,620	88,500	13,500	13,482	408,202
Total		**80,964**	**41,600**	**425,989**	**54,343**	**195,780**	**133,190**	**22,281**	**954,147**

Appendix B - ArcGIS Models

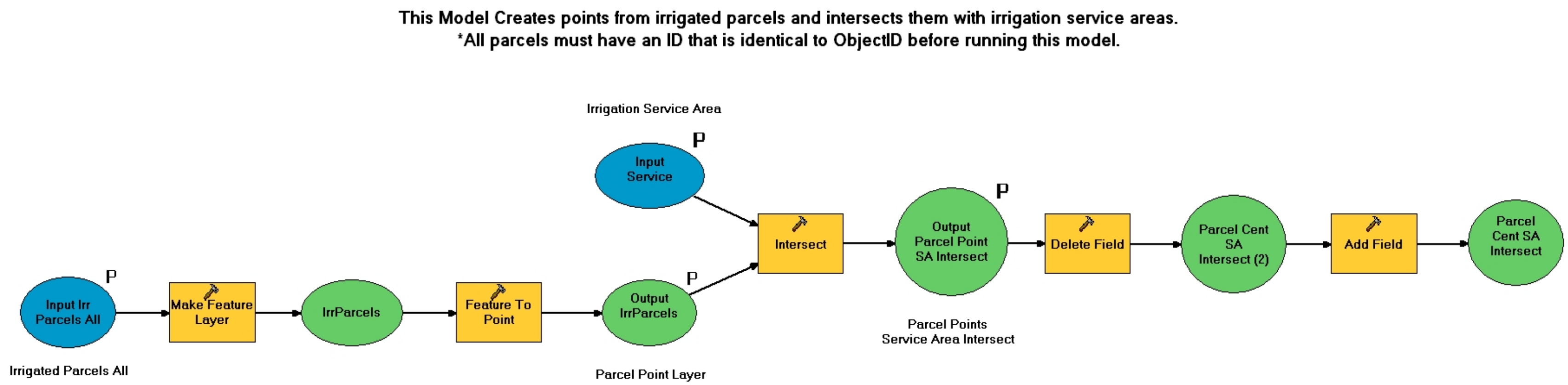


Figure B- 1. ArcGIS model used for intersecting parcels with service areas.

This model subsets the parcel point service area intersect layer by the number of service areas they intersect with.

*Must first calculate the MultiSA attribute in ArcMap with he following script:
T:\Tools\ArcGIS\calc_scripts\ec50\field\field_Mark_Duplicates_2.cal (use [ID])
before running this model.

Figure B- 2. ArcGIS model used for sub setting parcels by service area.

RIVERSIDE

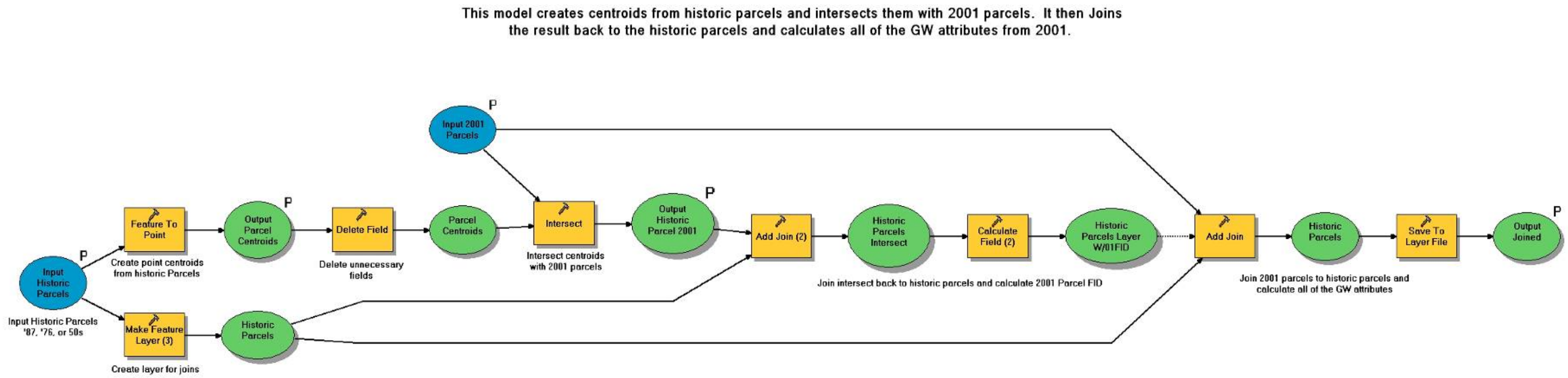


Figure B- 3. Well translate model.

RIVERSIDE

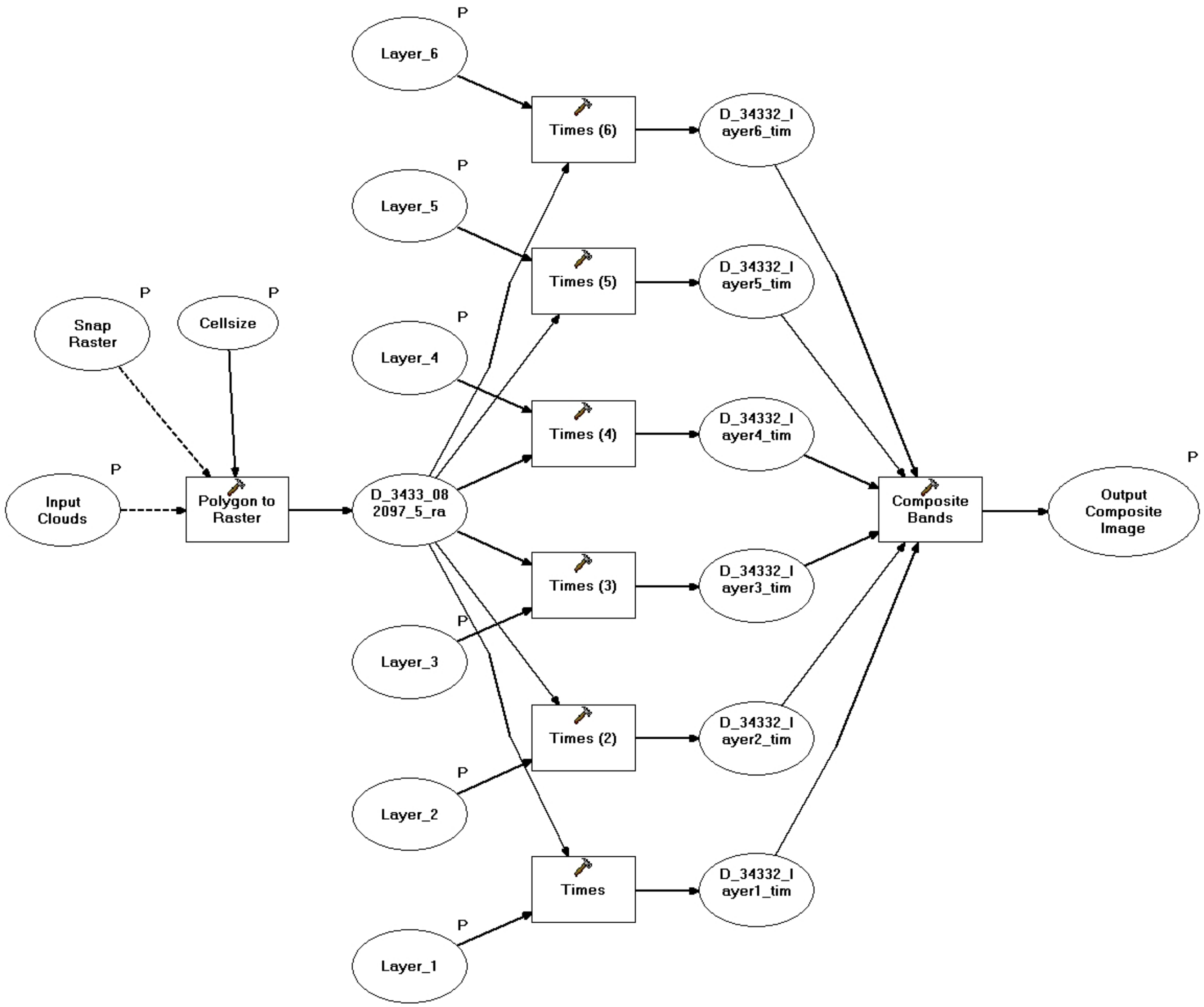


Figure B- 4. Cloud Fill ArcGIS Model

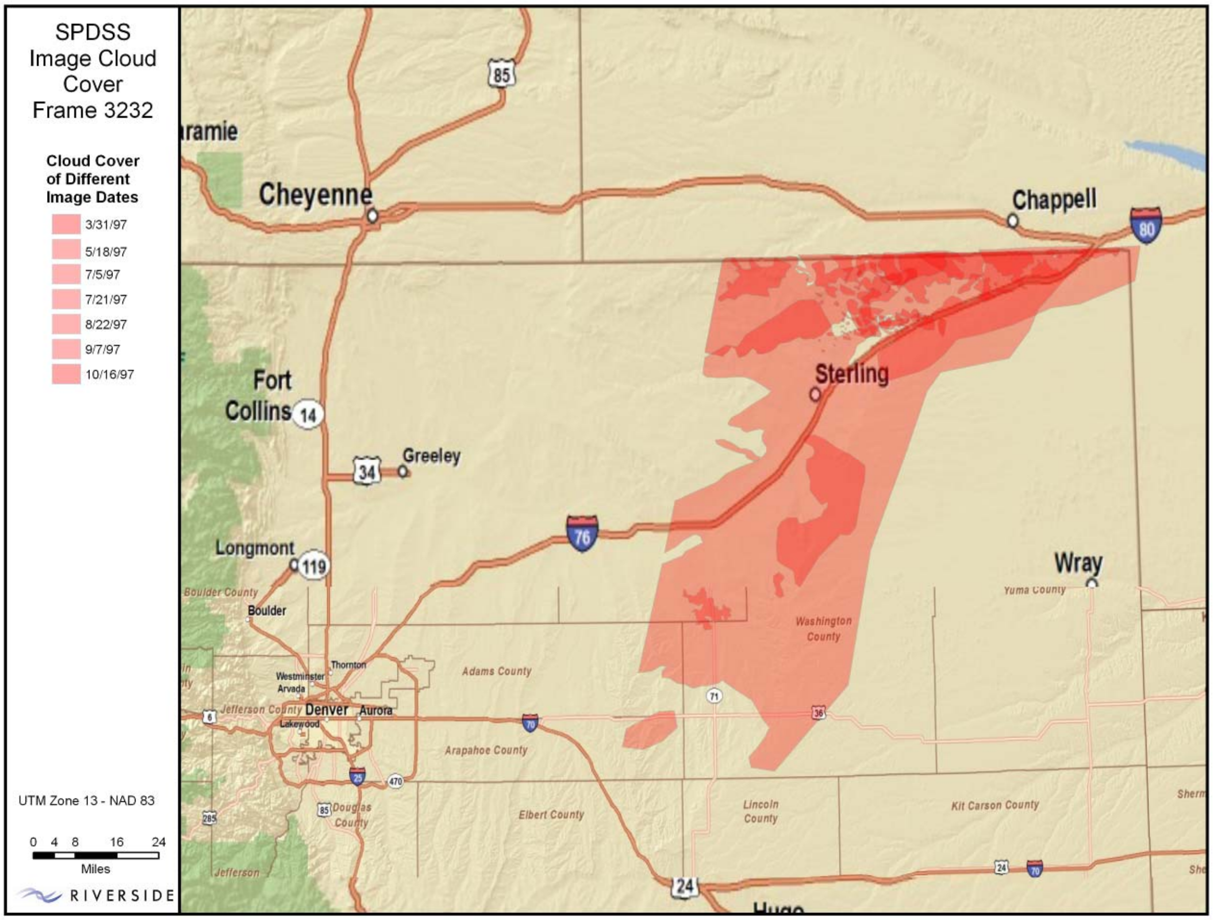
Appendix C

The following attribute checks were performed on the historic irrigated parcels:

- IRRIG_TYPE checked to ensure all records were either FLOOD or SPRINKLER.
- CROP_TYPE checked to ensure all records were capitalized and in the list of HydroBase crop types.
- SW_WDID checked to make sure they were populated correctly. SW_WDID2 cannot have a record if SW_WDID1 is blank. Corrections were made appropriately.

SW_COV was populated with the same method as the 2001 parcels. Since no information on how much of a ditch a particular parcel uses was obtained, each parcel is given an equal portion of the ditch it has access to. Parcels with only SW_WDID1 populated receive SW_COV1 = 100. Parcels with SW_WDID1 and SW_WDID2 populated receive SW_COV1 and SW_COV2 = 50. Parcels with SW_WDID1, SW_WDID2, and SW_WDID3 populated receive SW_COV1 = 33.3, SW_COV2 = 33.3, and SW_COV3 = 33.4. Parcels with additional entries in SW_WDID all receive an equal portion of the ditch in the SW_COV attributes.

Appendix D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Chappell
Fort
Collins
Greeley
Sterling
Longmont
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Arapahoe County
Elbert County
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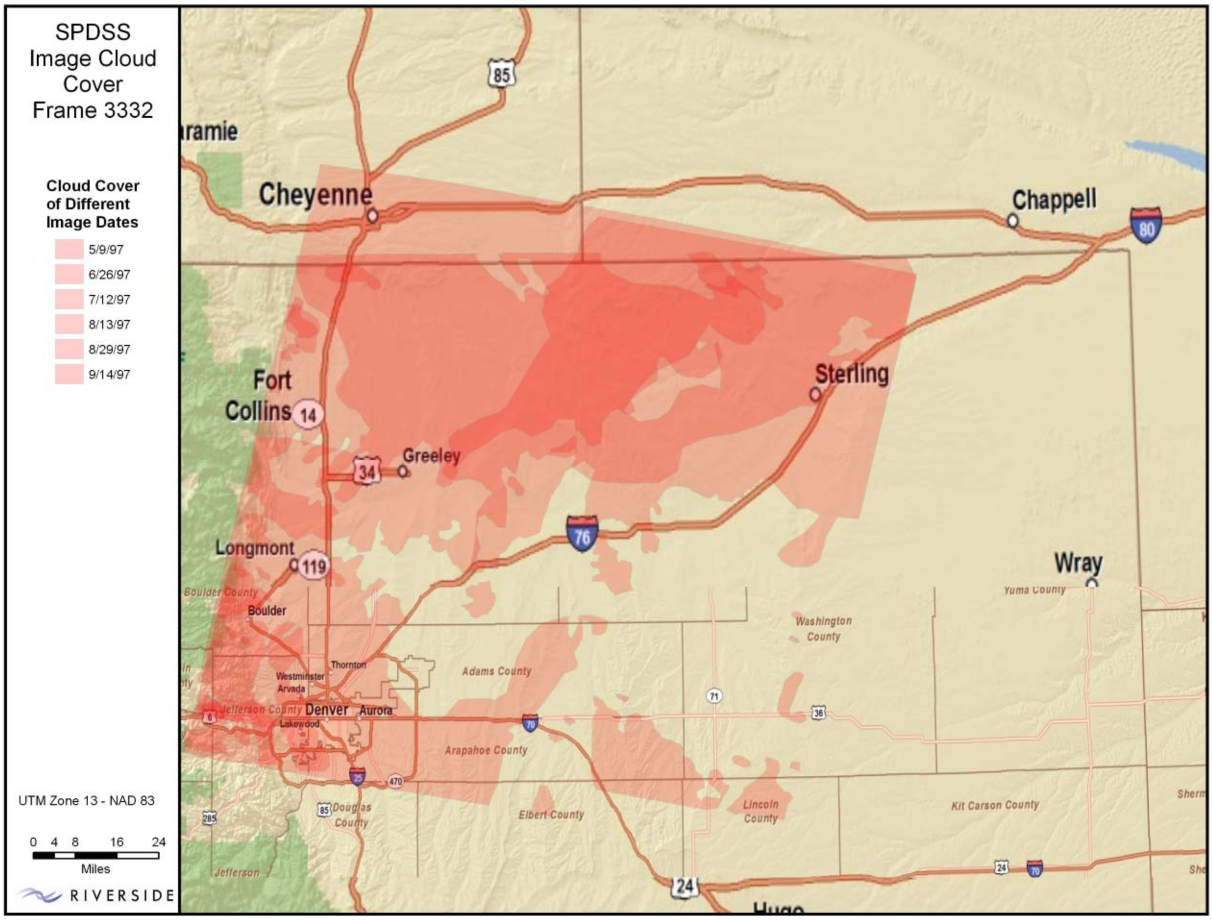
County
Kit Carson County
Yuma County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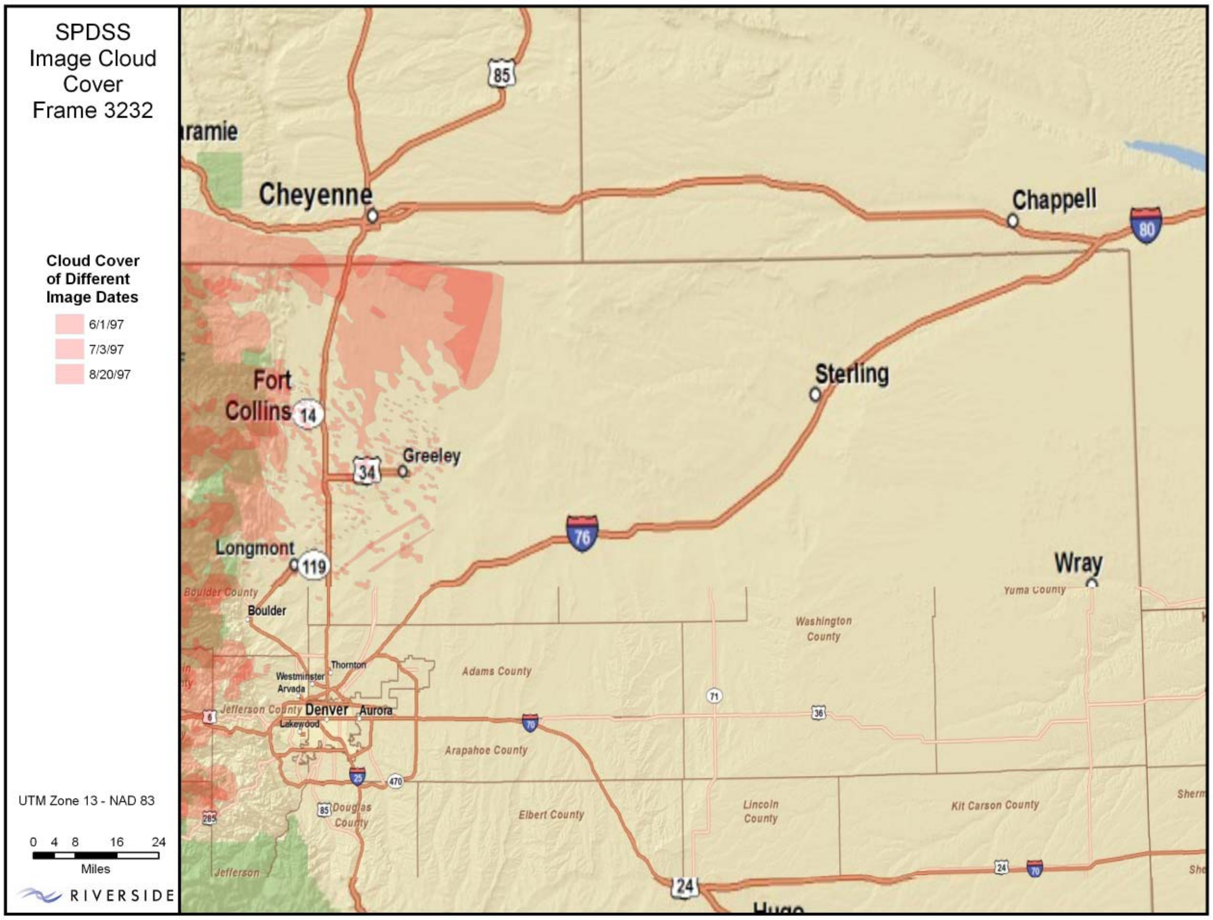
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