Using Satellite Imagery to Estimate Irrigated Land: A Case Study in Scotts Bluff and Kearney Counties, Summer 2002

Final Report
March 2003

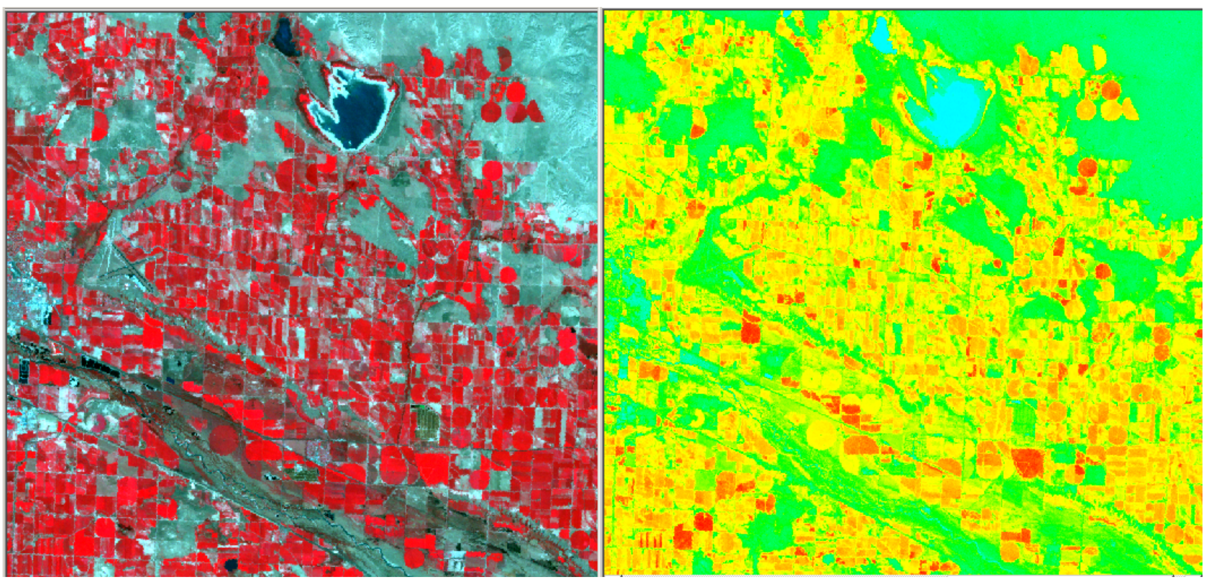

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The year 2002 was the third driest for Nebraska in more than a century that records have been kept. Moderate to extreme drought conditions also reached across the High Plains and much of the West. At the height of the drought last summer, more than half of the country was affected. According to UNL climate impact specialist Mike Hayes, only the Dust Bowl years of 1934 and 1936 were drier in Nebraska than what was experienced in 2002 (Institute of Agriculture and Natural Resources, 2003).

The lack of moisture significantly affected agricultural production. The drought wiped out many dry land crops and forced growers to irrigate more than normal, which sent irrigation costs skyrocketing according to Tina Barrett, interim director of the Nebraska Farm Business Association at UNL (Institute of Agriculture and Natural Resources, 2002). It was estimated that Nebraska's agricultural losses from the 2002 drought was close to $1.2 billion (Institute of Agriculture and Natural Resources, 2003)

The objective of this study is to test the accuracy of using satellite remote sensing techniques to estimate irrigated lands in Scotts Bluff and Kearney Counties during the summer of 2002. These results will supplement the research of the Cooperative Hydrology Study in the Central Platte River Basin (COHYST). COHYST is a multi-agency project intended to improve understanding of the hydrological conditions in the Central Platte River. COHYST is involved in the assemblage and creation of numerous geospatial data layers to be used in modeling and development of a water resources decision support system (DSS). Knowing the location and amount of irrigated lands is an important component of their modeling efforts.

Vegetation indices derived from satellite imagery provide an estimate of the health and vigor of agricultural crops. One of the most widely used vegetation indices, the Normalized Difference Vegetation Index (NDVI), was calculated to measure crop conditions during the summer of 2002. To aid in the classification, field data were collected in the fall of 2002 for Scotts Bluff and Kearney counties using Global Positioning System (GPS) to record the exact location of each field. Other information gathered at each location indicated the type of crop or land cover and if the field was or was not irrigated.

THE STUDY AREA

Scotts Bluff and Kearney Counties were selected to represent different environments of the Cooperative Hydrology Study in the Central Platte River Basin (COHYST) study area (Figure 1). These counties have significant contrasts in topography, climate patterns and differences in the types of crops produced.

The 1997 COHYST land cover classification identified variations in land cover (Dappen & Tooze, 2001). In 1997 over 59% of Kearney County was irrigated cropland, the majority of which was irrigated corn. In comparison, only 34% of Scotts Bluff County was irrigated cropland (Table 1). These percentages, derived from an analysis of Landsat satellite imagery, compare with published figures from the 1997 Agricultural Census, which reported that 57% of Kearney County was irrigated cropland while 36% of Scotts Bluff County was irrigated cropland (USDA, 1999).

Both counties were strongly affected by the drought of 2002. The summer of 2002 had unusually high temperatures and record low precipitation totals.

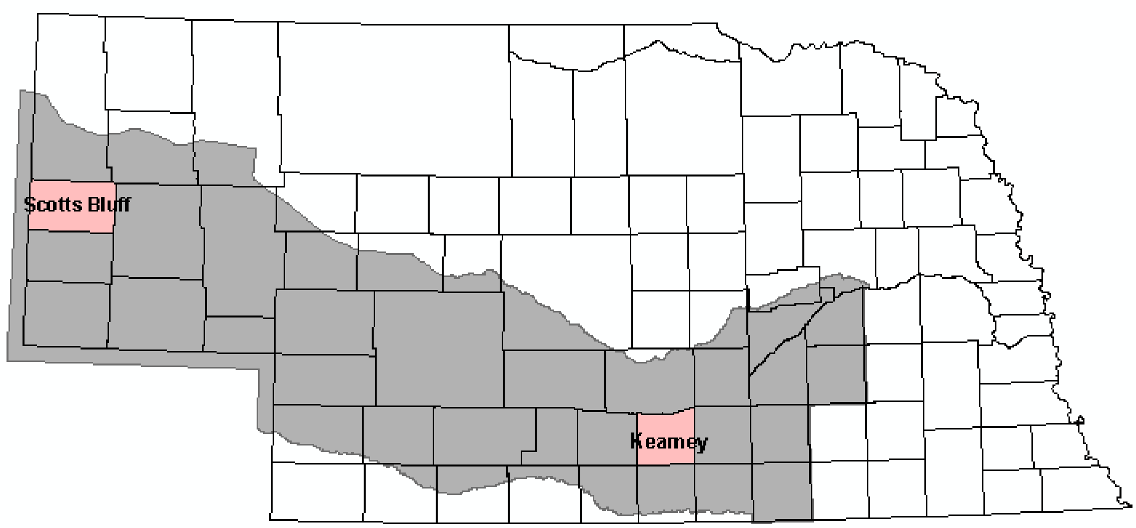

Figure 1. The Study Area

Table 1. Percent of Total Land Cover For Selected Crops within Kearney and Scotts Bluff County (Dappen & Tooze, 2001)

1997 Land Cover	Kearney	Scotts Bluff
Irrigated Corn	50.33%	13.89%
Irrigated Sugar Beets	0.00%	3.85%
Irrigated Soybeans	6.08%	2.35%
Irrigated Sorghum	1.15%	0.00%
Irrigated Potatoes	0.18%	0.00%
Irrigated Dry Edible Beans	0.00%	6.72%
Irrigated Alfalfa	1.23%	5.57%
Irrigated Small Grains	0.49%	2.05%
Range/Pasture/Grass	12.23%	41.34%
Irrigated Sunflower	0.00%	0.46%
Summer Fallow	1.85%	2.52%
Dryland Corn	7.72%	1.17%
Dryland Soybeans	3.74%	0.23%
Dryland Dry Edible Beans	0.00%	0.42%
Dryland Alfalfa	2.17%	1.61%
Dryland Small Grains	3.16%	3.40%
Dryland Sunflower	0.00%	0.07%

The 2002 monthly temperature and precipitation values for Kearney and Scotts Bluff Counties are listed in Appendix A and B. As a whole, the entire state of Nebraska was affected by record low precipitation levels (Figure2).

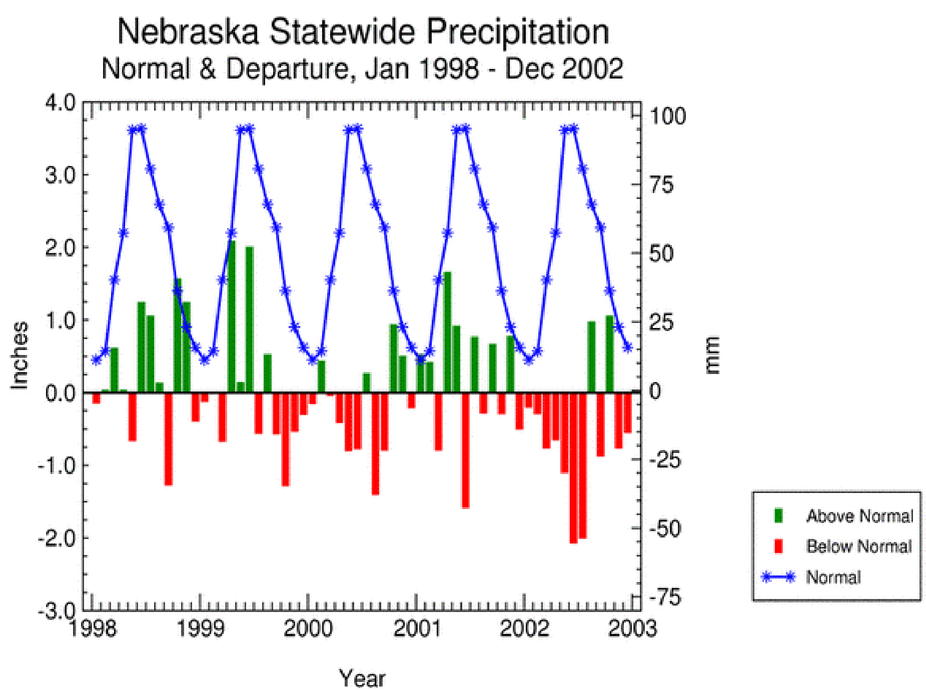

Figure 2. Nebraska Statewide Precipitation January 1998-December 2002
(National Climatic Data Center/NESDIS/NOAA)

BACKGROUND

The use of satellite-derived vegetation indices for crop monitoring and assessment is well established. (Benedetti & Rossini, 1993; Moulin *et al.*, 1998, Meyer-Roux & King, 1992). Vegetation indices are quantitative measures based on mathematical combinations of spectral reflectance data that estimate such things as vegetation biomass and vigor. Most vegetation indices are based on the inherent characteristics of actively photosynthesizing vegetation. Chlorophyll in healthy plants absorbs red and blue energy for photosynthesis. Vegetation reflects highest in the near infrared due to the internal cell structure of plants (mesophyll cells). In healthy plants, mesophyll cells reflect 40 to 50 percent of the infrared radiation incident upon the leaf (Lillesand & Kiefer, 1994).

NDVI

One of the first successful vegetation indices, the Normalized Difference Vegetation Index (NDVI), was developed by Rouse *et al* (1974). NDVI uses band ratioing of the visible red and near infrared bands of the electromagnetic spectrum. Band ratioing, also known as spectral ratioing, is an enhancement resulting from the division of digital number values in one spectral band by the corresponding values in another band (Lillesand and Keifer, 1994). One advantage of band ratioing is that it conveys the spectral or color characteristics of image features regardless of variations caused by topographic slope and aspect, shadows, or seasonal changes in illumination conditions.

NDVI is calculated as:

$$NDVI = \frac{\text{Near Infrared Radiance} - \text{Visible Red Radiance}}{\text{Near Infrared Radiance} + \text{Visible Red Radiance}}$$

The nature of NDVI is such that the greater the amount of photosynthesizing vegetation present, the larger the digital number value for each pixel. Vegetation will generally yield high NDVI values, water will yield negative values, and bare soil will yield values near zero based on the reflectance characteristics of these surface materials (Sabins, 1987).

NDVI indices provide valuable information on the temporal variation and characteristics of vegetation communities (Schwartz, 1994, Goetz, 1997). The use of remote sensing methods to measure vegetation characteristics is unique because the measurement of the reflected energy from vegetation is directly correlated to its biological functioning (Tucker, 1979).

NDVI and Drought Monitoring

There are varied definitions of drought, but in general terms drought is considered a given period of reduced plant growth due to a lack of precipitation (Peters et al., 2002). Satellite remote sensing platforms provide a timely means of monitoring the condition of vegetation over large areas (Moulin *et al*., 1998). Using satellite imagery, one can quickly assess the effects of drought on vegetation over large areas.

By measuring the health and vigor of vegetation, NDVI provides an indicator of the severity of drought conditions. NDVI is directly related to the amount of photosynthetically active radiation that a plant may absorb. The less sunlight a plant absorbs, the less it is photosynthesizing and the lower its productivity. If plants do not have enough water, the cells of the leaves get smaller and the cell structure changes, causing less reflection in the near infrared. Unhealthy or stressed vegetation produces less chlorophyll resulting in less absorption of visible red light. (Lillesand and Keifer, 1994).

Evidence of such drought effects was observed in fields monitored by CALMIT during the summer of 2002. Part of CALMIT research facilities include the Field Research Facility (CFRF), located at the University of Nebraska Agricultural Research and Development Center-Ithaca (ARDC), about 35 miles north and slightly east of Lincoln, near Mead, Nebraska. At this center an impressive array of facilities and equipment combine to provide faculty, staff, students, and visiting scientists with an unusual opportunity to conduct field-oriented investigations. The emphasis of the field activities is on close-range remote sensing, but data collected by means of many other related technologies can be linked to spectral data.

During the summer of 2002, field plots were evaluated using an Ocean Optics USB 2000 spectroradiometer. A spectroradiometer is hand held device that measures spectral reflectance data in real time. Figures 3 and 4 show the results from 12 field plots on August 19th, 2002 near Mead, NE. 36 readings were taken in each field to produce these spectral signatures of irrigated and non-irrigated soybean fields. Upon review of these graphs, the non-irrigated soybean fields had significantly less reflection in the near-infrared and less absorption in the visible red than the irrigated fields. The irrigated soybean fields have a spectral curve indicative of healthy vegetation. These field results indicate that the irrigated soybean fields would have a higher NDVI value than the non-irrigated fields.

These types of results are what we expect to find in the Landsat satellite imagery for Kearney and Scotts Bluff counties. Similar spectral differences may allow us to discriminate between irrigated and non-irrigated fields.

Non-Irrigated Soybeans

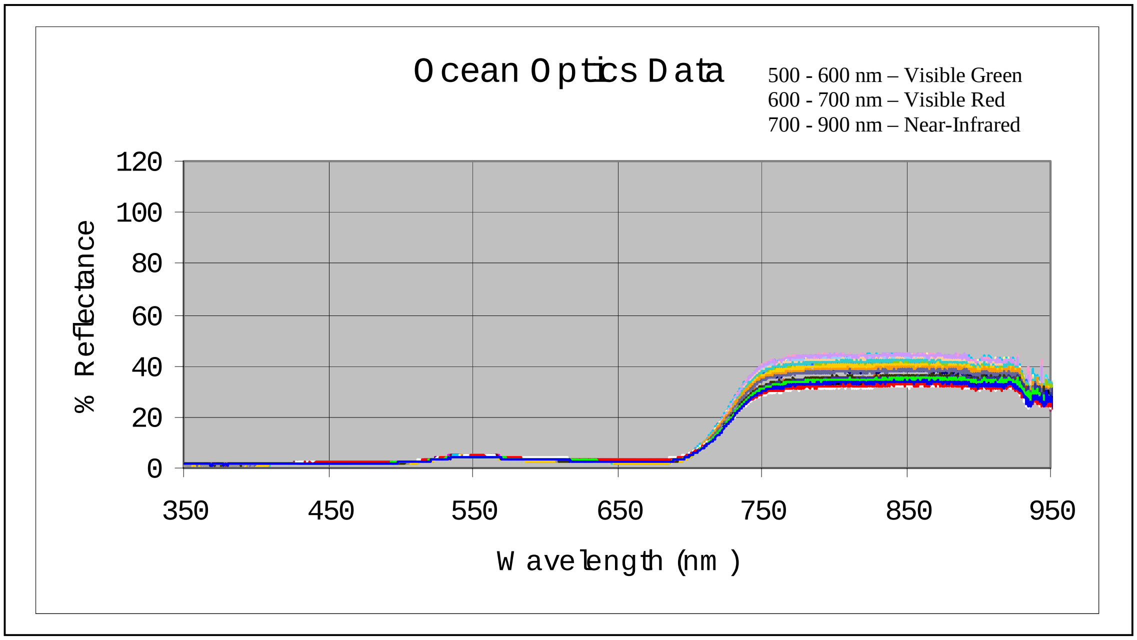

Figure 3. Non-Irrigated Soybean Field Samples Mead, NE. 8-19-02

Irrigated Soybeans

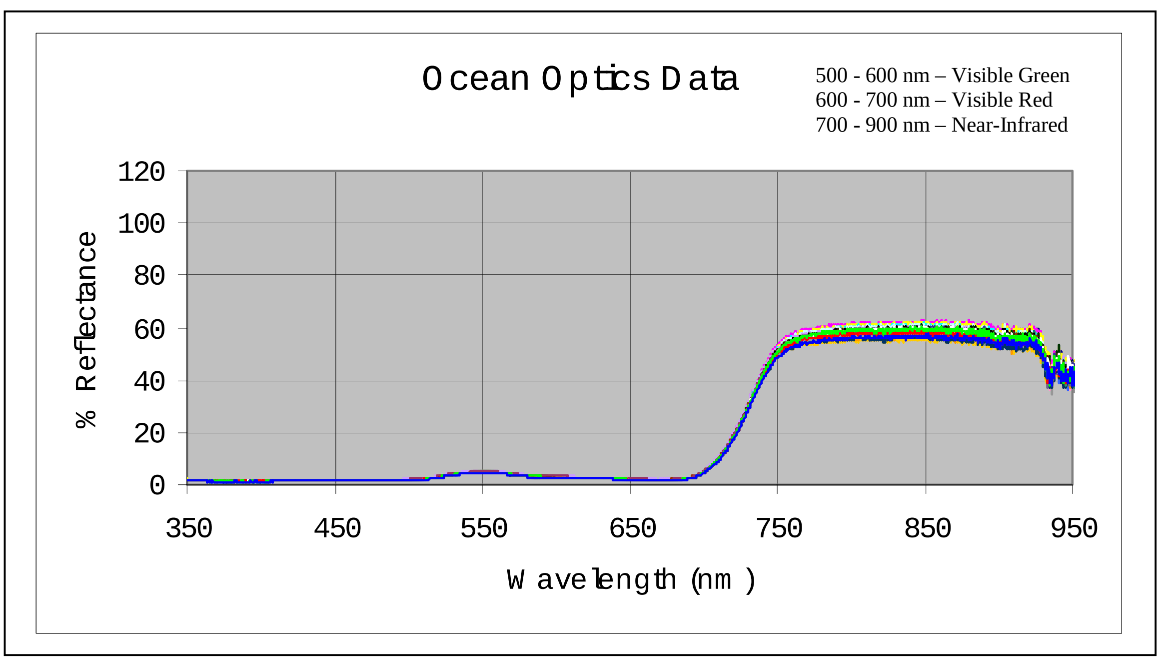

Figure 4. Irrigated Soybean Field Samples Mead, NE. 8-19-02

METHODS

Satellite Data Acquisition and Image Processing

To find the best date for acquiring satellite imagery we contacted a crop specialist, Roger Elmore, at the University of Nebraska's South Central Research and Extension Center. He concluded that the last half of July to the first week in August would be the best time to compare irrigated and non-irrigated fields. He noted that during this time the very high temperatures and lack of precipitation significantly stressed the crops so that irrigated vs. non-irrigated fields should be easily identified. Initially, one Landsat 7 Enhanced Thematic Mapper (ETM) satellite image was ordered for Scotts Bluff County for July 18, 2002. After a preliminary assessment it was decided that a later date would capture more crops at fuller canopy. A second date, August 19th, 2002, was then selected. For Kearney County, August 14th, 2002 was selected as the single date of coverage (Table 2). A total of three cloud-free satellite images were ordered from the U.S. Geological Survey EROS Data center in a systematic and terrain-corrected format.

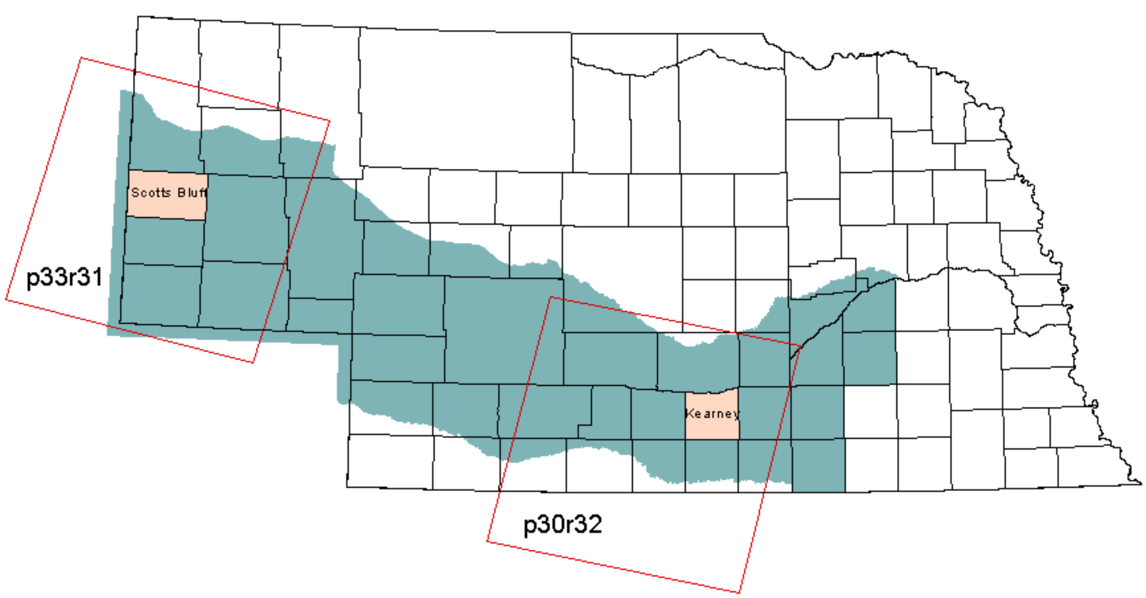

Figure 5. Landsat 7 ETM+ Satellite Coverage of the Study Area.

Additional geometric corrections were applied to these images to achieve a high level of spatial accuracy. All three images were re-projected from the original Universal Transverse Mercator (UTM) projection system to a State Plane projection system. After re-projecting the imagery, each county was subset from the imagery

Table 2. Landsat 7 ETM Data used in Analysis

No.	Path/Row	Date of Image Acquisition	Scene ID
1	33/30	7/18/2002	LE703303000219950
2	33/30	8/19/2002	LE703303000223150
3	30/32	8/14/2002	LE703003200022650

NDVI Calculation

Landsat 7 ETM band 3 (visible red) and band 4 (near infrared) were used to compute NDVI for each date of imagery (Table 3). NDVI output values range from +1.0 and –1.0, with vegetated areas generally yielding high NDVI values due to their high near-infrared reflectance and low visible red reflectance. Clouds and water have larger visible red reflectance than near infrared so these features yield negative index values. Rock and bare soil have similar reflectances in the visible red and near-infrared bands so these features have an NDVI value near zero (Lillesand and Keifer, 1994). An example of the NDVI calculation is found in Figure 6. The image on the left is the original Landsat 7 ETM while the image on the right is the calculated NDVI image. Higher NDVI values correspond with the yellow and red colors and the lower NDVI values correspond with blue and green colors.

Table 3. Characteristics of Landsat 7 ETM

Spectral Band	Spectral Range (μm)	Nominal Spectral Location	Ground Resolution (m)
1	0.450 - 0.515	Visible Blue	30
2	0.525 – 0.605	Visible Green	30
3	0.630 – 0.690	Visible Red	30
4	0.750 – 0.900	Near infrared	30
5	1.55 – 1.75	Mid-infrared	30
6	10.40 – 12.5	Thermal infrared	60
7	2.09 – 2.35	Mid-infrared	30
8	0.522 – 0.900	Panchromatic	15

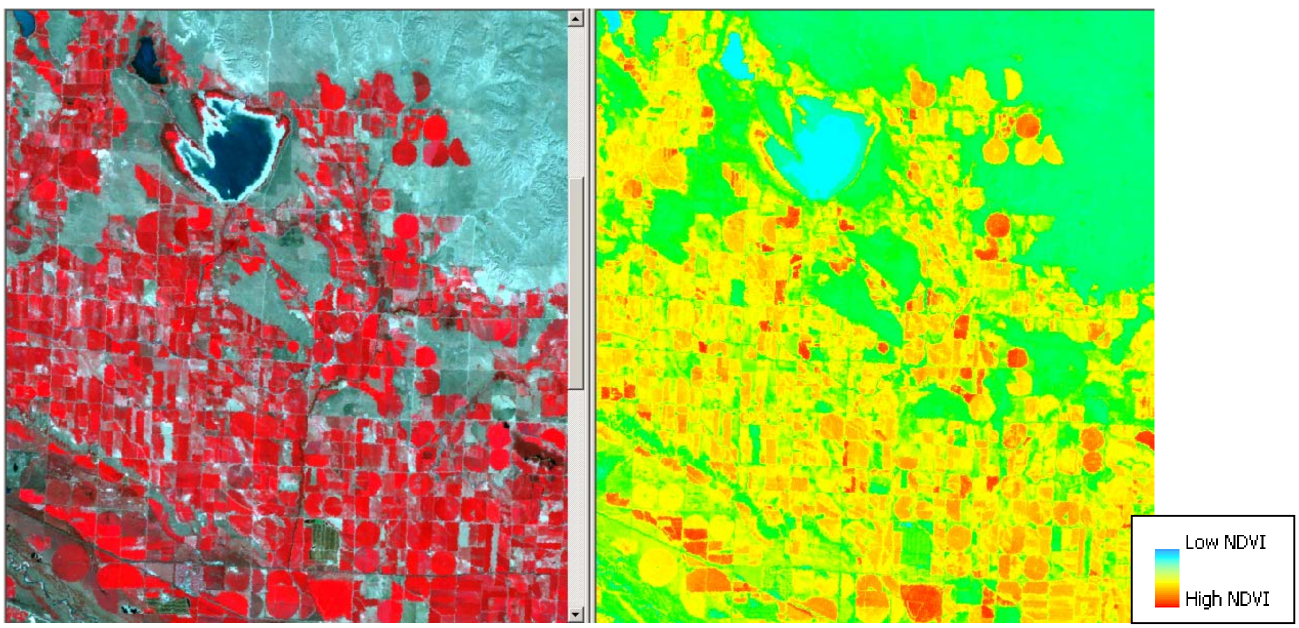

Figure 6. Example of NDVI Calculation for a Portion of Scotts Bluff County

To avoid using negative values in this study, the NDVI values were rescaled to values between 0-200. Adding a value of one before multiplying by 100 retained the negative index values in NDVI (Eve, 1995). For example, an original value of .320 would be converted to 132.0. This computation can be shown as:

$$NDVI = \{(NIR-RED)/ (NIR + RED) +1\} * 100$$

Field Work

Field data used to validate the study were collected in the fall of 2002 by members of the North Platte and the Tri-Basin NRDs. Sites were randomly selected and each location was identified using a handheld Global Positioning System (GPS). At each location information was gathered as to the type of crop or land cover, and whether the crop was irrigated or not irrigated. A digital photograph was taken at each location. Although some of the locations were examined after harvest, enough information was available to identify the crop. In many cases, irrigation equipment or a center pivot was still on the field to indicate if the crop was irrigated. For most locations the GPS data coordinates were acquired at least 50 meters inside of each field or land cover boundary. These GPS point locations were imported as an ESRI shapefile and then re-projected to the State Plane projection system.

Approximately 132 GPS point locations were collected in Banner, Morrill, Scotts Bluff and Sioux Counties by North Platte NRD (Figure 7). A total of 79 GPS points were collected for Scotts Bluff County, 3 of which were from non-irrigated fields. To compensate for the low numbers of non-irrigated field points, areas in pasture and in summer fallow were identified using the satellite imagery and incorporated into the analysis.

GPS points collected by Tri-Basin NRD included locations in Kearney, Phelps and Gosper Counties (Figure 8). Kearney County had a total of 85 GPS locations, 16 of which were from irrigated fields and the rest were collected in non-irrigated areas. Points were also collected in Gosper and Phelps Counties for possible future analysis. To compensate for the low number of irrigated field points identified in Kearny County, center pivots were identified using the satellite imagery and incorporated in the analysis.

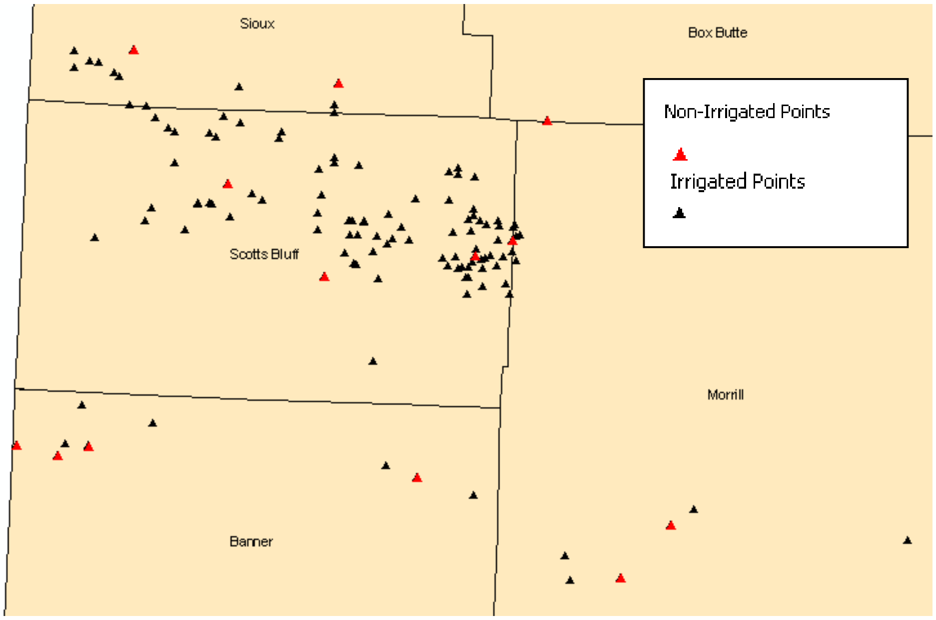

Figure 7. Field points collected by North Platte NRD

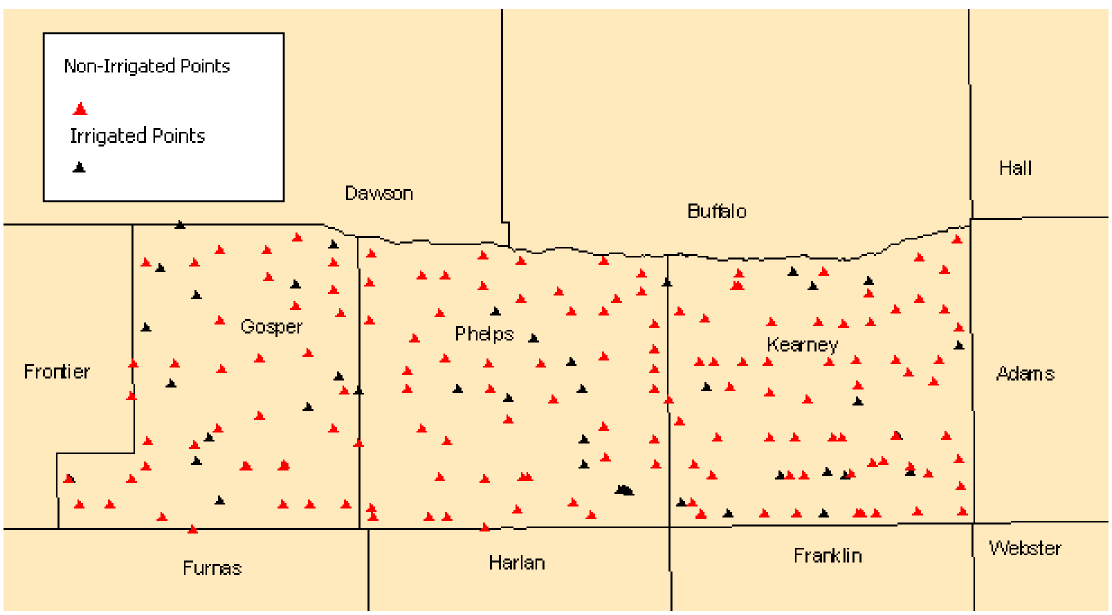

Figure 8. Field points collected by Tri-Basin NRD

Mask Creation

Since only agricultural areas have the potential to be irrigated, it was important to eliminate non-agricultural areas from the analysis. Land cover types such as riparian forests, emergent wetland vegetation, and urban vegetated areas also produce high NDVI values, so these areas have to be removed from the imagery. To do this, a non-agricultural mask was created. First, urban areas were identified using Census 2000 Topologically Integrated Geographic Encoding and Reference system (TIGER) vector data and 1993 Digital Ortho Quarter-Quadrangles (DOQQs). Urban areas were on-screen digitized and saved as polygons. The 1997 land cover classification for the COHYST study area was recoded so that all agricultural classes were merged into one class, and all non-agricultural areas were recoded to a value of 0. Other land cover data available for Nebraska, such as the USGS National Land Cover Data (NLCD), were used to check for areas missed.

The NLCD for Nebraska is based on 1992-1993 Landsat Thematic Mapper (TM) data. The NLCD was produced as part of a cooperative project between the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (USEPA). The NLCD for Nebraska was downloaded from the USGS website: (http://landcover.usgs.gov/ftpdownload.html). Originally in GeoTiff format, these datasets were imported into ERDAS Imagine and re-projected to State Plane. This data set was then recoded so that all agricultural classes were grouped into one class, and all non-agricultural areas were recoded to a value of 0.

Once agricultural and non-agricultural areas were identified, all of the separate files were integrated into one file. A binary mask was created by recoding all non-agricultural pixels to a value of 0 and all agricultural pixels to a value of 1. This mask was then applied to the NDVI images. Separate masks were created for Scotts Bluff and Kearney counties. After applying the masks, a majority of non-agricultural pixels were eliminated from the NDVI image. The next step was to identify which pixels represented irrigated fields and which represented non-irrigated fields.

Signature Collection

One way to classify an image is to categorize each pixel using a threshold value. The reason for selecting a threshold value is to create a binary file containing values of 1 to represent irrigated lands and values of 0 to represent non-irrigated lands. The higher the NDVI value, the more likely that pixel will represent irrigated lands. Lower NDVI values are more characteristic of non-irrigated lands. An ideal threshold value will separate non-irrigated agricultural pixels from irrigated agricultural pixels.

To determine the best threshold, many samples of NDVI values were collected from fields of known land cover. The GPS field point locations were overlaid on the NDVI image to identify irrigated and non-irrigated fields. NDVI samples were acquired by digitizing polygons within fields of known land cover. Using ERDAS Imagine software, these areas were termed 'areas of interest'. Within each area of interest, a unique signature for each field was obtained. Minimum, maximum, and mean NDVI values were calculated for each sample. These statistics were collected from the NDVI image and used to determine how to group the pixels into their respective classes. The minimum and maximum NDVI values for each sample were plotted on a graph to determine where along the scale the various samples would group for each class. This procedure was done separately for each date of imagery.

Selection of Significant NDVI Threshold Values

NDVI threshold values will be different for different image dates because each pixel's value changes temporally due to changes in soil condition, soil moisture, vegetation health, leaf area, and atmospheric effects (Qi *et al*., 2002). To find the NDVI threshold it is necessary to find the best value that selects the most irrigated fields pixels while not selecting pixels from non-irrigated fields.

After plotting the minimum and maximum NDVI values for each sample on a graph, certain trends were apparent. Samples from irrigated fields had much higher minimum and maximums NDVI values than those from non-irrigated fields. Yet, in all cases, several samples of non-irrigated fields had their maximum NDVI values within the range of minimum NDVI values of irrigated fields. This area of overlap was used to narrow the search for the significant threshold value.

In reality, it was not possible to find a single value that achieved 100% accuracy in distinguishing between the two classes. In some cases irrigated areas were classified as non-irrigated pixels and non-irrigated pixels classified as irrigated. The goal was then to find the best balance that minimizes the amount of classification error.

Scotts Bluff County: July 18th, 2002

The first NDVI image analyzed for Scotts Bluff County was for July 18th, 2002. A total of 25 NDVI samples were collected throughout the county. NDVI samples from irrigated areas were taken from center pivots, surface, and furrow irrigated fields. The types of fields selected were from irrigated corn, alfalfa, sugar beets, sorghum, and dry edible beans. Non-irrigated NDVI samples were collected for areas in pasture, summer fallow, dryland corn, and from a general category termed 'weeds'. Fields were identified in the imagery using the GPS points collected by North Platte NRD. Once the fields were selected from the imagery, statistics were generated. Minimum and maximum NDVI values for each sample were plotted on a graph (Figure 9).

The area of overlap between the two classes was identified as being between NDVI values of 92 and 106. Using the Recode function in ERDAS Imagine, the NDVI image was recoded so that values greater than 92 were given a value of one and all other values changed to 0. This was done for all NDVI values between 92 and 106. The recoded images were displayed with the GPS field point locations to determine which threshold value had that highest accuracy. After evaluating the range of values between 92-106, NDVI values greater than 98 were found to classify the most irrigated fields without significantly misclassifying non-irrigated fields

Acreages were calculated for the July NDVI image with values greater than 98. Using this method we estimated 101,161 irrigated acres for Scotts Bluff County on the July 18th date. Previous land cover estimates from our 1997 COHYST land cover work

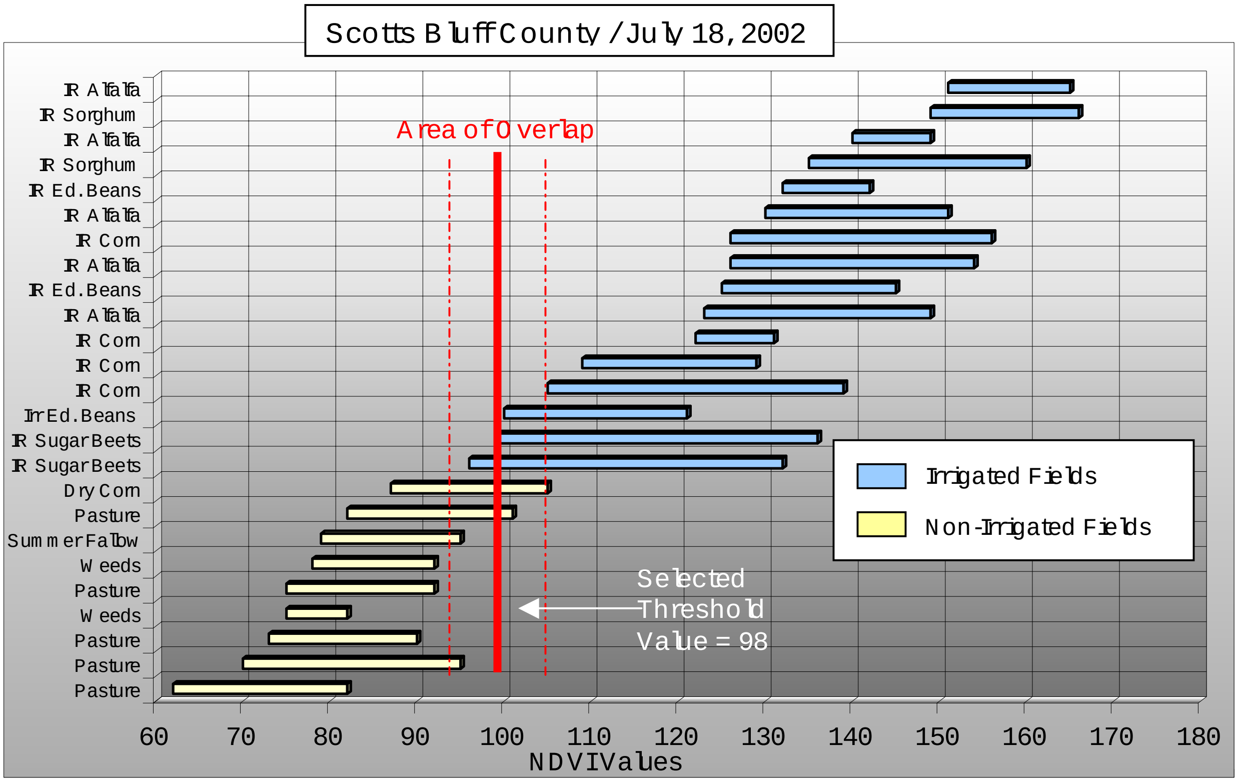

Figure 9. NDVI field sample ranges for Scotts Bluff County, July 18th, 2002

estimated 165,640 irrigated acres for Scotts Bluff County. The difference between the two was considerable at 64,479 acres.

After analyzing these results, it was determined that a later date might improve the estimation of irrigated acres. In Scotts Bluff County there were approximately 35-40,000 acres of dry edible beans that would not have reached full canopy until the first week of August. Those areas would have been missed in July 18th image. Alfalfa would have been cut or recently harvest by July 18th, so another date may identify these fields. In light of these observations, a second image was ordered for Scotts Bluff County. A cloud free date of August 19th, 2002 was selected.

Scotts Bluff County: August 19th, 2002

By August 19th a majority of the crops were at full canopy. In comparing the two dates (Figure 10), it is understandable why the July date had a low irrigation estimate. In

Figure 10, healthy vegetation appears as red, areas with little vegetation appear as blue, and areas with no vegetation appear as white. With a majority of crops at full canopy by August 19th, the range of NDVI values was much higher than the July 18th image.

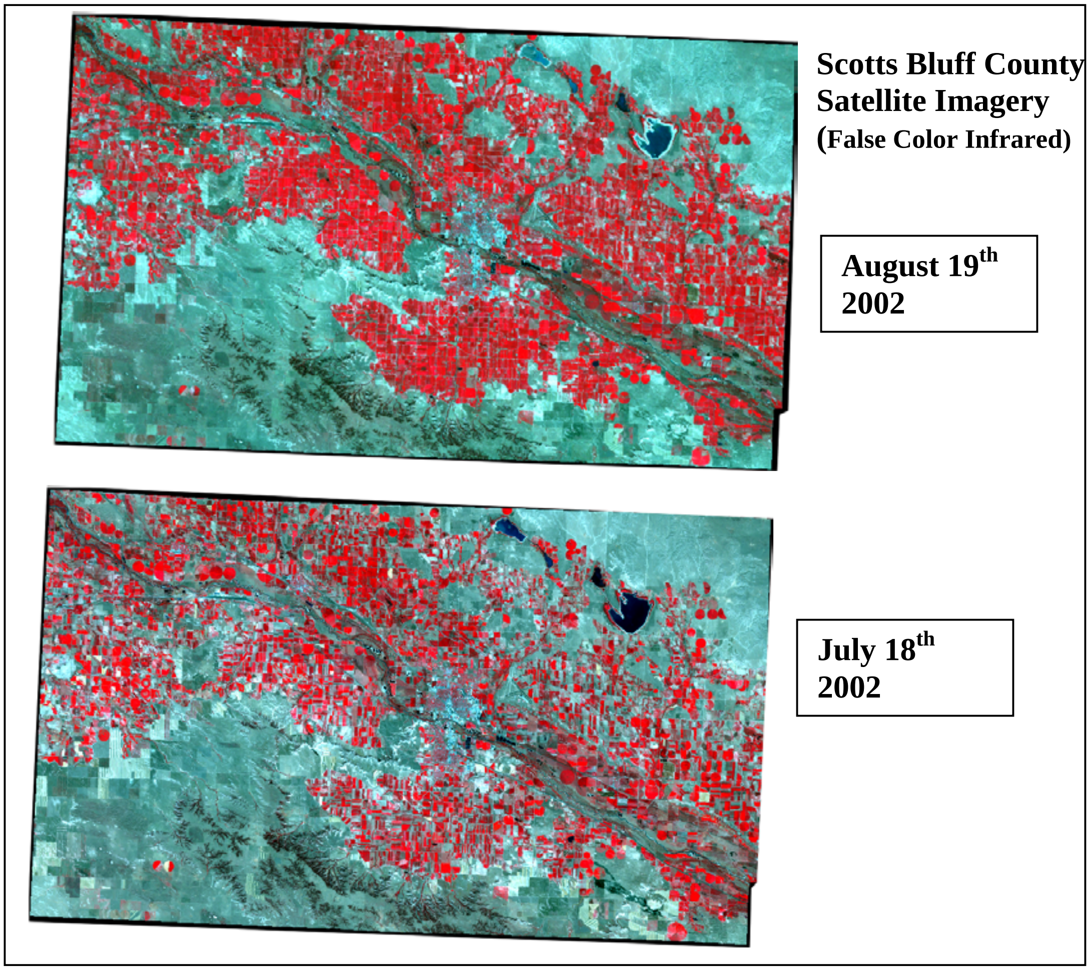

Figure 10. Landsat Satellite Imagery for Scotts Bluff County (July and August)

A total of 31 NDVI samples were collected for the August image. Samples from irrigated areas were taken from center pivots, surface, and furrow irrigated fields.

The types of fields selected from the August date were similar to those collected from the July date. Irrigated NDVI samples came from irrigated corn, alfalfa, sorghum, sugar beets, and dry edible beans. Non-irrigated NDVI samples were collected for areas in pasture, summer fallow, dryland corn, and dryland sorghum. Fields were identified in the imagery using the GPS points collected by North Platte NRD. Once the fields were selected from the imagery, statistics were generated. Minimum and maximum NDVI values for each sample were plotted on a graph (Figure 11). The area of overlap between the two classes was identified as being between NDVI values of 112 and 125. Using the Recode function in ERDAS Imagine, the NDVI image was recoded so that values greater than 112 were given a value of one and all other values changed to 0.

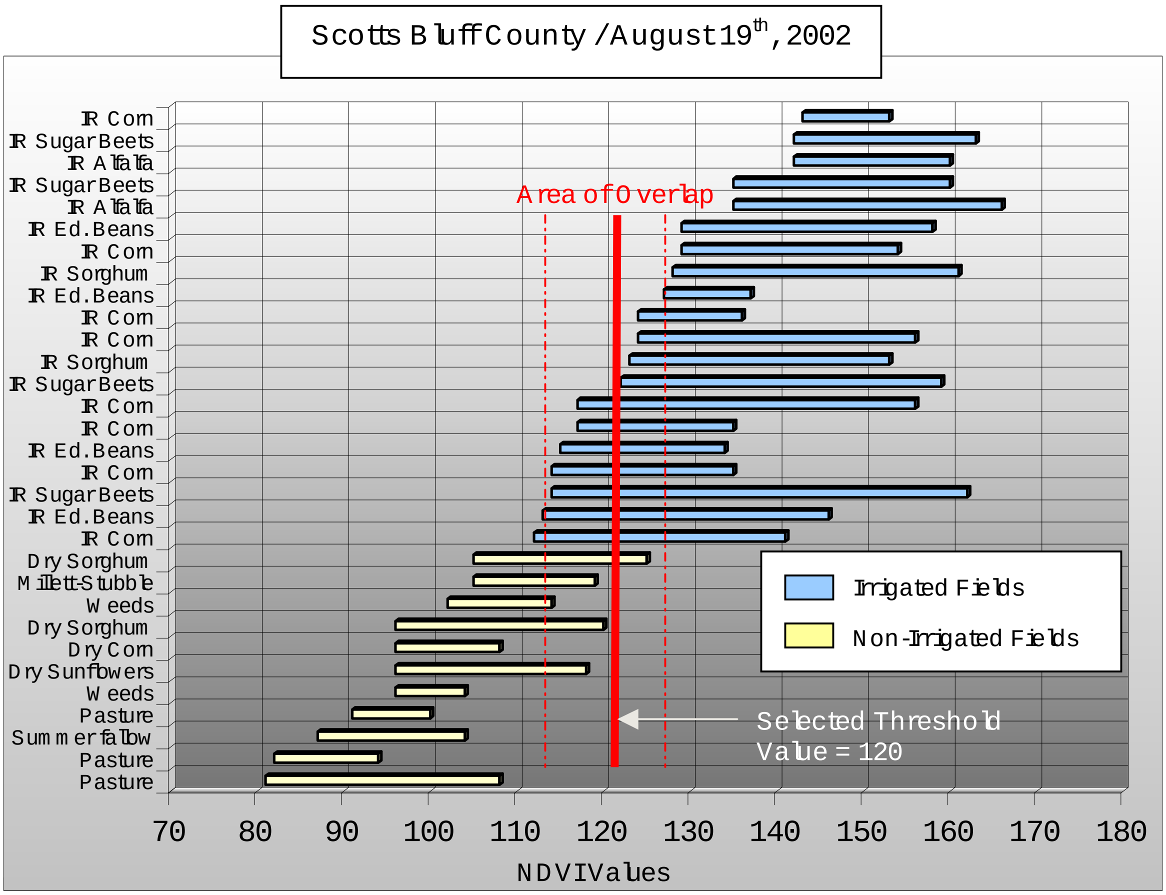

Figure 11. NDVI field sample ranges for Scotts Bluff County, August 18th, 2002

This was done for all NDVI values between 112 and 125. The recoded images were displayed with the GPS field point locations to determine which threshold value had the highest accuracy. After evaluating the range of values between 112-125, NDVI values greater than 120 were found to classify most irrigated fields without significantly misclassifying non-irrigated fields.

Kearney County: August 14th, 2002

The only date selected for Kearney County was August 14th, 2002. Based on the results of the August 19th image for Scotts Bluff County, it was assumed that by this date the majority of crops in Kearney County would be at full canopy.

A total of 33 NDVI samples were collected for the August image. Samples from irrigated areas were taken from center pivots and furrow irrigated fields. Irrigated NDVI samples came from irrigated corn and irrigated soybeans. Of the 79 field points collected in Kearney County, only 16 were from irrigated fields. To make up for this shortfall, center pivots were incorporated into the sample selection. Because of their distinctive shape, center pivot irrigation systems are easily identifiable in the satellite imagery. These areas were labeled as being irrigated, but the type of crop unknown. In these cases the samples were just labeled as center pivot.

Non-irrigated samples were collected for areas in dryland soybeans, dryland corn, pasture, and wheat stubble. Fields were identified in the imagery using the GPS points collected by Tri-Basin NRD. Minimum and maximum NDVI values for each sample were plotted on a graph (Figure 12). The area of overlap between the two classes was identified as being between NDVI values of 118 and 137. Again, using the Recode function in ERDAS Imagine, the NDVI image was recoded so that values greater than 118 were given a value of one and all other values changed to 0. This was done for all NDVI values between 118 and 137. The recoded images were displayed with the GPS field point locations to determine which threshold value had that highest accuracy. After evaluating the range of values between 118-137, NDVI values greater than 129 were found to classify the most irrigated fields without significantly misclassifying non-irrigated fields.

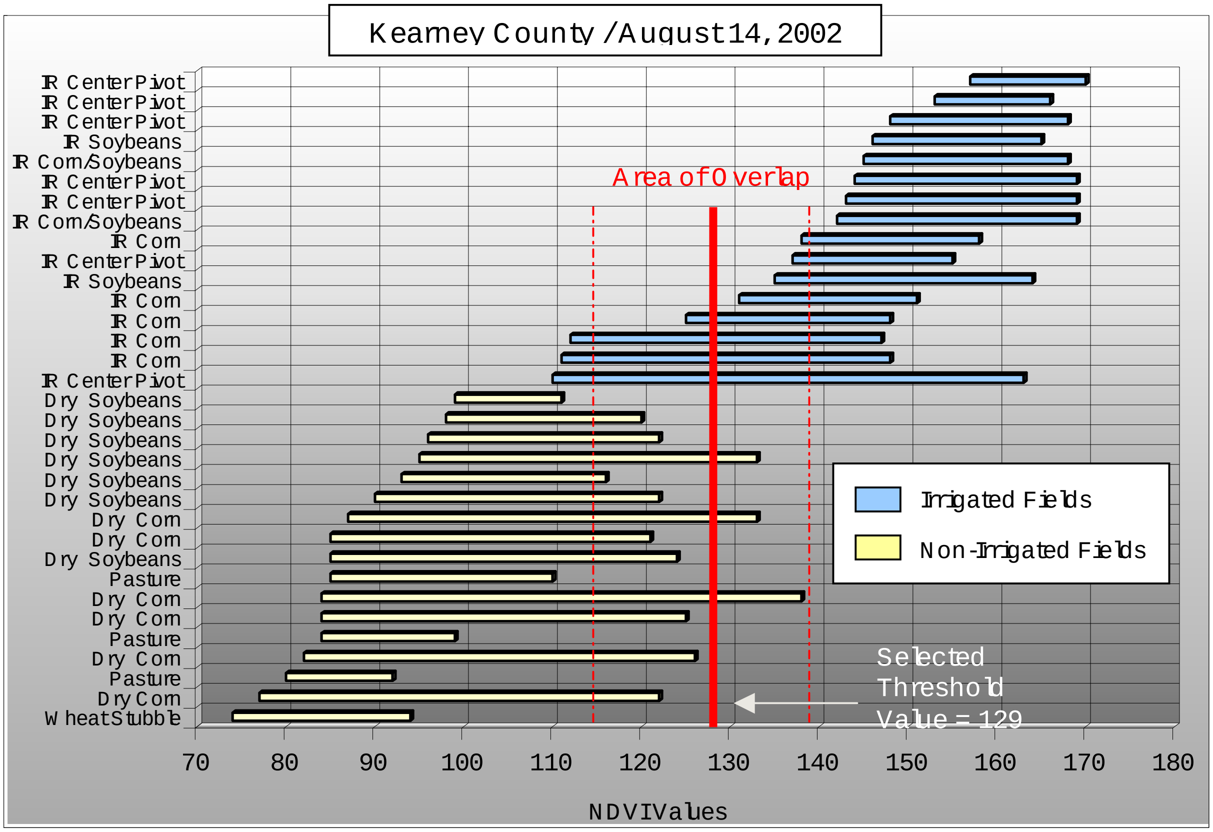

Figure 12. NDVI field sample ranges for Kearney County, August 14th, 2002

RESULTS

Classification Results

Scotts Bluff County

After selecting a threshold value for the July 18th NDVI image, the image was recoded so that values greater than 98 were assigned a value of 1 and areas less than 98 were given a value of 0. Using this method, an estimated 101,161 irrigated acres for Scotts Bluff County was calculated for July. The second date, August 19th, was also recoded based on the selected NDVI threshold value of 120. Values greater than 120 were assigned a value of 1 and values less than 120 assigned a value of 0. The August irrigation estimate was much higher, at 172,781 acres. To get a better estimate of irrigated lands, the two separate irrigation files were merged. Pixels classified as being irrigated on both dates were only counted once, to prevent an overestimation of irrigated areas.

Because irrigated fields are not perfectly homogeneous in terms of overall plant health, there were pixels within irrigated fields that fell below the NDVI threshold and were classified as non-irrigated. There were also some pixels identified as being irrigated when they were obviously not. These small areas of mixed pixels were cleaned up using a series of eliminate and fill filter passes within ERDAS Imagine. The eliminate filter was performed using a minimum area of 10 contiguous pixels. This process eliminated a majority of the small irrigated pixels outside of field boundaries that were most likely misclassified. The fill function was applied using a 3x3 neighborhood analysis using a majority function. The shape of the neighborhood analysis was set in the shape of a '+' so that roads would be preserved. This method cleaned up the image while preserving the field boundaries.

After combining the July and August images and applying the filters, the new irrigation estimate for Scotts Bluff County totaled 180,003 acres. This irrigation estimate is slightly higher than that calculated for the 1997 COHYST land cover classification and the 1997Agricultural Census. The 2002 estimate was slightly lower than what was reported in the 2001 Agricultural Statistics (Table 4). At the time this report was written, 2002 Agricultural Statistics and 2002 Agricultural Census data were not available.

Table 4. Irrigation Comparisons for Scotts Bluff County

Scotts Bluff County	
Source	Irrigated Acres
2002 NDVI Irrigation Study	180,003
1997 COHYST Land Cover Classification	165,640
1997 Agricultural Census	173,159
2001 Agricultural Statistics	185,000

An example of the 2002 irrigation estimate for Scotts Bluff County is found in Figure 13. Areas estimated as irrigated are shaded in green while areas in white are non-irrigated. The county boundary is represented in black. These figures can be compared to the July 18th Landsat 7 satellite image found in Figure 10.

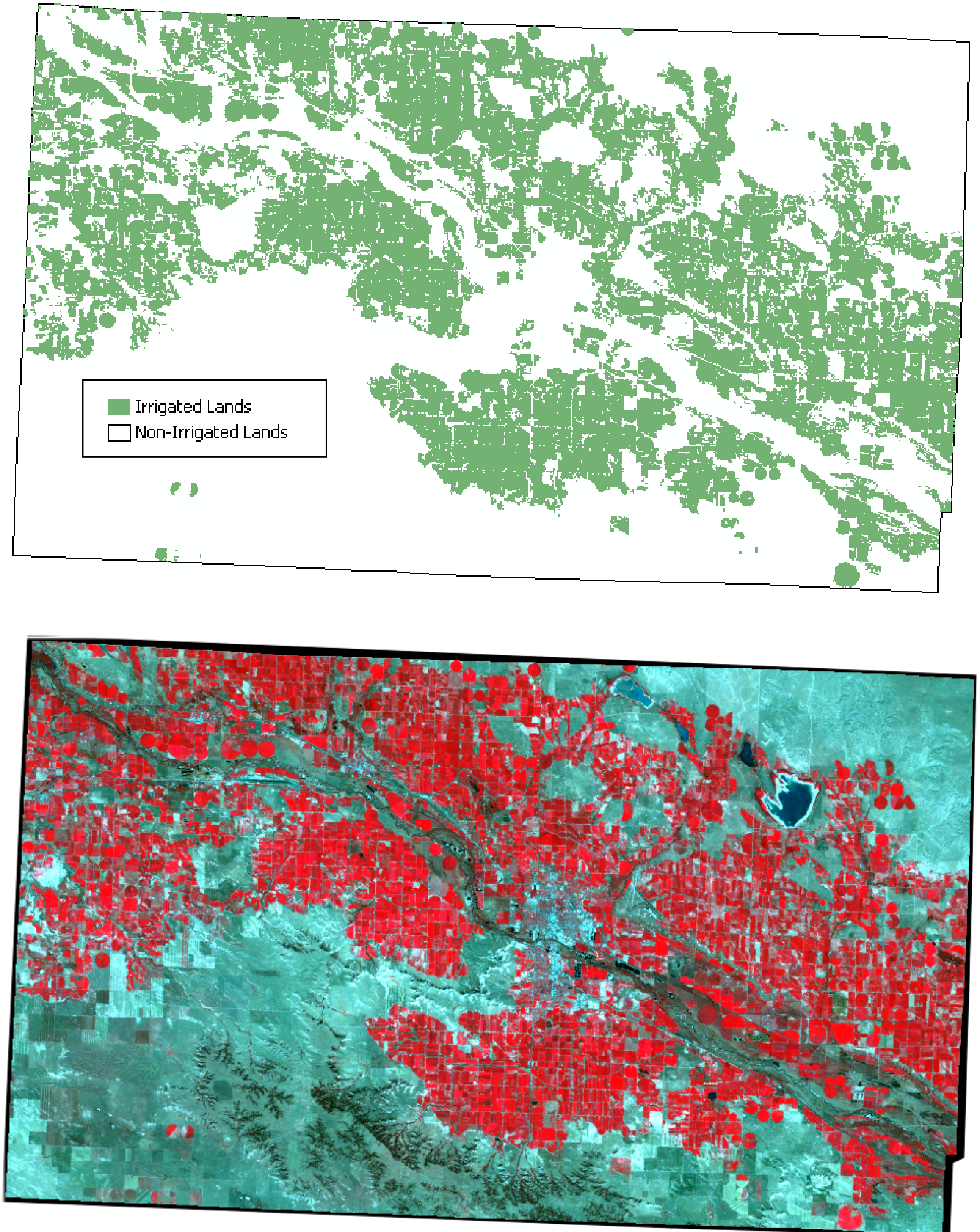

Figure 13. Irrigation estimate for Scotts Bluff County and August 19th Landsat 7 satellite imagery.

Kearney County

After selecting a threshold value for the August 14th NDVI image, the image was recoded so that values greater than 129 were assigned a value of 1 and areas less than 129 were given a value of 0. After the image was recoded, the eliminate and fill functions were applied using the same methods applied to the Scotts Bluff image. Using this method, an estimated 206,579 irrigated acres were calculated for Kearney County. This irrigation estimate is slightly higher than that calculated for the 1997 COHYST land cover classification and the 1997Agricultural Census. This estimate is less than that reported in the 2001 Agricultural Statistics (Table 5). At the time this report was written, 2002 Agricultural Statistics and 2002 Agricultural Census data were not available.

The irrigation estimate is compared to the original August Landsat 7 satellite image in Figure 14. Areas calculated as irrigated are shaded in green while areas in white are not irrigated. The Kearney County boundary is indicated in black.

Table 5. Irrigation Comparisons for Kearney County

Kearney County	
Source	Irrigated Acres
2002 NDVI Irrigation Study	206,579
1997 COHYST Land Cover Classification	197,299
1997 Agricultural Census	188,959
2001 Agricultural Statistics	211,000

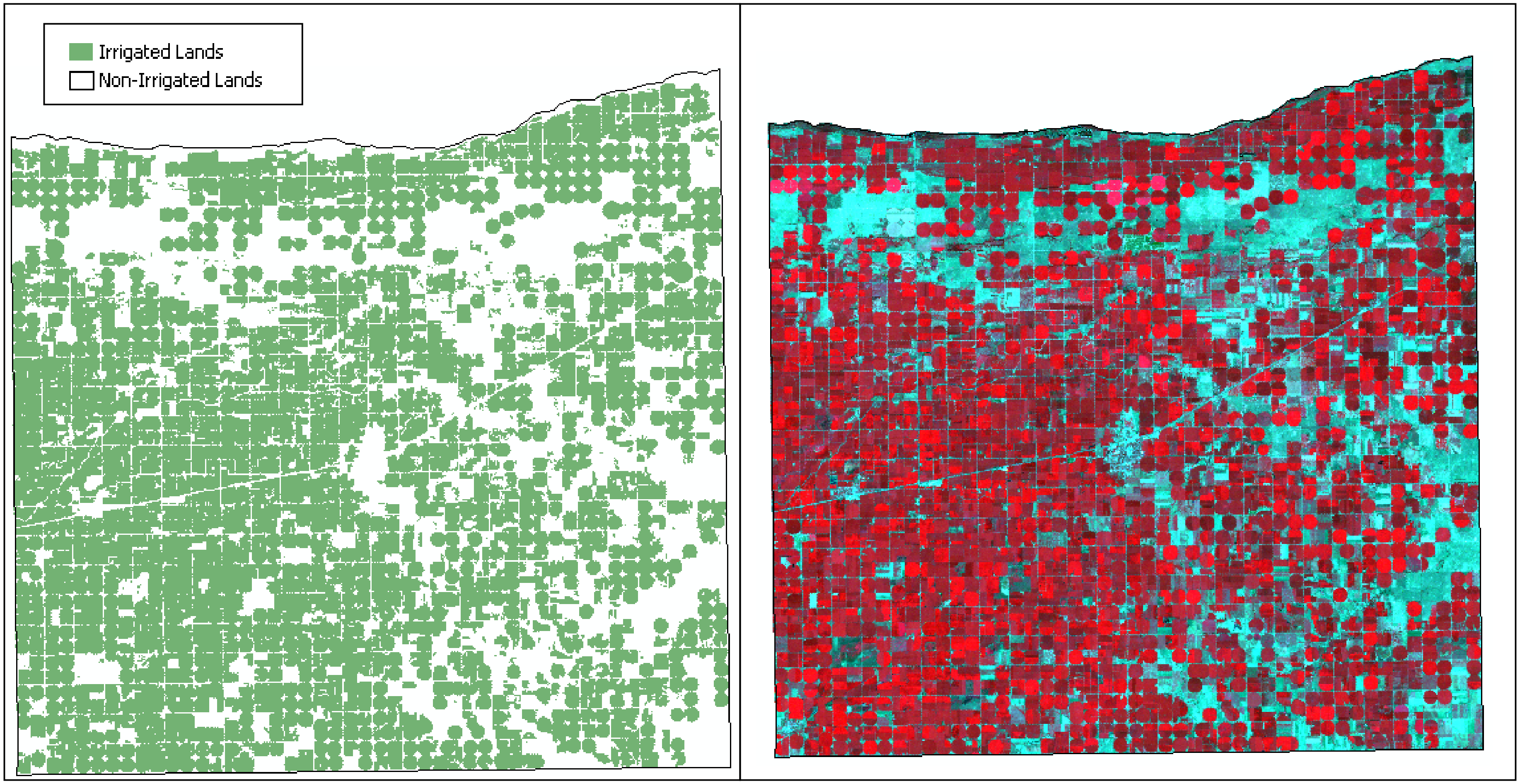

Figure 14. Irrigation estimate for Kearney County and August 14th Landsat 7 satellite imagery

Accuracy Assessment

To determine the accuracy of the irrigation classification, an accuracy assessment was performed on data for both counties. Reference data are key to determine the accuracy of the classified image, as they are the benchmarks for identifying correctly versus incorrectly classified pixels. Reference data, collected by the North Platte and Tri-Basin NRDs, did not allow for a more thorough statistical analysis. Scotts Bluff County only had 3 of 79 points from non-irrigated fields and Kearney had only 16 of 79 points from irrigated fields. A general rule of thumb is to have at least 50 samples per land cover class (Congalton and Green, 1999). In spite of the uneven numbers of land cover samples from each class, a general accuracy assessment was performed.

The descriptive statistics generated by an accuracy assessment include the overall accuracy, producer's accuracy, and user's accuracy. The overall accuracy is computed by dividing the total number of correctly classified pixels by the total number of reference pixels. The producer's accuracy, also a measure of omission error, indicates the probability of a reference pixel being correctly classified. Producer's accuracy is calculated by dividing the total number of correct pixels in a category by the total number of reference pixels of that category. User's accuracy, a measure of commission error, indicates the reliability that the pixel classified in the image actually reflects that category on the ground. This value is found by dividing the total number of correct pixels in a category by the total number that was classified in that category (Congalton, 1991).

Scotts Bluff County had an overall accuracy of 77.22% (Table 6). Non-irrigated fields had an overall accuracy of 38.60%. Two of the three reference pixels were classified correctly, but 19 fields checked as being irrigated were classified as non-irrigated. The low accuracy of non-irrigated fields could result from the low number of reference points for those areas. Irrigated fields had a higher overall accuracy at 87.98%, with 59 of 76 reference pixels classified correctly.

Table 6. Scotts Bluff County Accuracy Totals

Scotts Bluff County						
Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Overall Accuracy
Non-Irrigated Fields	3	19	2	66.67%	10.53%	38.60%
Irrigated Fields	76	60	59	77.63%	98.33%	87.98%
Pixel Totals	79	79	61			
Overall Classification Accuracy = 77.22%						

Kearney County had a higher accuracy at 86.08% (Table 7). Non-irrigated fields had an overall accuracy of 91.00% with 56 of 63 field points being correctly classified. Irrigated fields had a lower overall accuracy at 69.08% (12 of 16 points were correctly classified). Again, the lower accuracy of irrigated fields could result from the low numbers of irrigated reference pixels. Overall, Kearney County achieved a higher percentage of accuracy than Scotts Bluff County.

Table 7. Kearney County Accuracy Totals

Kearney County						
Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Overall Accuracy
Non-Irrigated Fields	63	60	56	88.89%	93.33%	91.11%
Irrigated Fields	16	19	12	75.00%	63.16%	69.08%
Pixel Totals	79	79	67			
Overall Classification Accuracy = 86.08%						

Causes of Lower Accuracies and Sources of Error

While error matrices produce a percentage of accuracy, there are other sources of error they cannot measure. Error can enter into a project during steps such as data acquisition, processing, analysis, and conversion. In this project, the sources of error were different in each county but in general there were some similarities.

One problem with this project's field data was that some of the field points fell too close to field boundaries. If this project were repeated, reference points should be collected at least 150 meters within the field boundary, not 50 meters. With a pixel size of 30 meters, this did not leave enough buffer to compensate for the mixed pixels common at field boundaries. While not all points were collected at the edge of fields, those on the edge were most often were labeled incorrectly.

Another problem arises from the types of crops. Alfalfa is a difficult crop to capture. Since it averages three cuttings a season, there is the potential to miss areas based on the date of image collection. Some areas field checked as irrigated alfalfa were classified as non-irrigated simply because the field had been cut before the date of the imagery. To compensate for this and to capture all alfalfa fields, one would need to analyze a minimum of two to three dates of imagery acquired during the growing season.

The accuracy estimate is only as good as the ground or sampling information used to compare known land cover types to the results of the classification. Classification systems fail to categorize mixed classes and transition zones. When dealing with mixed pixels or polygons in transition zones, labeling inconsistencies will occur with all classification systems (Lunetta et al, 1991). This introduces an element of error that is difficult to quantify.

Conclusion

This study showed promising results for Kearney and Scotts Bluff Counties. Due to the severity of drought conditions during the summer of 2002, the majority of healthy crops that grew to full canopy were irrigated. Most crops without irrigation did not grow to full canopy and could be easily distinguished from irrigated crops. This fact allowed the satellite-derived vegetation index, NDVI, to provide a good estimate of irrigated fields. Scotts Bluff County had an overall accuracy of 77.22% and Kearney had an overall accuracy of 86.08%

This study would not have been as successful if it was performed during a growing season with normal precipitation rates. NDVI provides a measure of vegetation health and vigor, but it does not offer a foolproof method for distinguishing irrigated from non-irrigated lands. With the right amount of precipitation, non-irrigated crops may have similar NDVI values as irrigated crops. The weather in 2002 was unusual, but appropriate for testing NDVI in this study.

While NDVI provided a fair estimate of irrigated fields, it may over estimate the amount of irrigated acres even in drought conditions. Reviewing the acreage totals for both counties, they both appeared slightly higher than average. For Scotts Bluff County, the 2002 irrigation estimate was calculated at 180,003 acres. This estimate was higher than what was reported from the 1997 Agricultural Census (3.9%) and the 1997 COHYST land cover classification (8.6% higher). This estimate is lower than what was reported from the 2001 Agricultural Statistics (2.7%). For Kearney County, the 2002 irrigation estimate was calculated at 206,579 acres. This estimate was higher than what was reported from the 1997 Agricultural Census (9.3%) and the 1997 COHYST land cover classification (4.7%). This estimate is lower than what was reported from the 2001 Agricultural Statistics (2.1%). With the severe drought in 2002, farmers may have irrigated more acres than they would during a normal year. The products derived from this study should only be considered estimates of irrigated lands for Scotts Bluff and Kearney Counties.

REFERENCES

Benedetti, Roberto and Paolo Rossini, 1993. On the Use of NDVI Profiles as a Tool for Agricultural Statistics: The Case Study of Wheat Yield Estimate and Forecast in Emilia Romagna, *Remote Sensing of the Environment*, 45: 311-326.

Congalton, Russel G., 1991. A review of assessing the accuracy of classifications of remotely sensed data, *Remote Sensing of Environment*, 37:35-46.

Congalton, Russel and Kass Green, 1999. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*, New York, NY: Lewis Publishers.

Dappen, Patti and Marcus Tooze, 2001. *Delineation of Land Use Patterns for the Cooperative Hydrology Study in the Central Platte River Basin: Final Report.* <http://www.calmit.unl.edu/cohyst/1997/media/documents/cohyst_finalreport_1997.pdf>

Eve, Marlen David, 1995. *High Temporal Resolution Analysis of Land Degradation in the Northern Chihuahuan Desert using Satellite Imagery*, Ph. D. Dissertation. New Mexico State University, Las Cruces

Goetz, S.J., 1997. Multi-Sensor Analysis of NDVI, Surface Temperature and Biophysical Variables at a Mixed Grassland Site, *International Journal of Remote Sensing*, 18(1): 71-94

Institute of Agriculture and Natural Resources (IANR), 2002. *Drought Impact Always in Flux*, <http://ianrnews.unl.edu/static/0210171.shtml>.

Institute of Agriculture and Natural Resources (IANR), 2002. *Options Available To Ease Tax Planning After Drought*, <http://ianrnews.unl.edu/static/0211121.shtml>.

Institute of Agriculture and Natural Resources (IANR), 2003. *Nebraska Experiences Third Driest Year in 2002*, <http://ianrnews.unl.edu/static/0301162.shtml>.

Lillesand, Thomas & Ralph Kiefer, 1994. *Remote Sensing and Image Interpretation*, Third Edition. New York, New York: John Wiley and Sons, Inc.

Lunetta, Ross S., Russell Congalton, Lynn Fenstermaker, John Jensen, Kenneth McGwire, and Larry Tinney, 1991. Remote sensing and geographic information system data integration: error sources and research issues, *Photogrammetric Engineering and Remote Sensing*, 57(6):677-587.

Meyer-Roux, J. and C. King, 1992. European Achievements in Remote Sensing: Agriculture and Forestry. *International Journal of Remote Sensing*, 13: 1329-1341.

Moulin, S., A. Bondeau, and R. Delecolle, 1998. Combining Agricultural Crop Models and Satellite Observations: From Field to Regional Scales, *International Journal of Remote Sensing*, 19(6): 1021-1036

Peters, Albert, E.A. Walter-Shea, L. Ji, A. Vina, M. Hayes and M. Svoboda, 2002. Drought Monitoring with NDVI-Based Vegetation Index, *Photogrammetric Engineering & Remote Sensing*, 68(1): 71-75.

Qi, Sharon, Alexandria Konduris and David Litke, 2002. *Using Satellite Imagery to Map Irrigated Land*. 22nd Annual ESRI International User Conference, San Diego California, July 2002. <http://gis.esri.com/library/userconf/proc02/pap0507/p0507.htm>

Sabins, Floyd F., 1987. *Remote Sensing Principles and Interpretation*, New York: W.H. Freeman and Company.

Schwartz, M.D., 1994. Monitoring Global Change with Phenology: The Case of the Spring Green Wave, *International Journal of Biometeorology*, 38:18-22.

Tucker, C.J., 1979. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation, *Remote Sensing of Environment*, 8: 127-150

Tucker, Compton, and Bhaskar Choudhury, 1987. Satellite Remote Sensing of Drought Conditions, *Remote Sensing of the Environment*, 23: 243-251.

USDA, 1999. National Agricultural Statistics Service, 1997 Census of Agriculture <http://www.nass.usda.gov/census/>.

APPENDICES

Appendix A. Temperature and Precipitation Values for Kearney, Nebraska 2000-2002.
(National Oceanic and Atmospheric Administration, 2000-2002)

WEATHER STATION	PARAMETER	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
KEARNEY 4 NE	Monthly average temperature (F)	2000	28.39	33.45	41.18	48.62	62.24	68.42	74.85	76.77	65.43	53.52	27.02	17.47	49.78
KEARNEY 4 NE	Monthly average temperature (F)	2001	26.69	21.75	33.95	52.28	61.44	69.62	78.21	73.45	63.47	51.13	45.13	31.26	50.70
KEARNEY 4 NE	Monthly average temperature (F)	2002	30.34	29.98	30.45	50.52	56.47	75.62	78.39	73.84	65.00	N/A	N/A	N/A	N/A
KEARNEY 4 NE	1931-2001 Normal		23.59	28.38	37.13	50.12	61.23	71.66	77.46	75.30	65.47	53.54	37.73	27.57	50.82
KEARNEY 4 NE	Monthly total precipitation (In.)	2000	0.53	1.79	2.19	1.12	2.68	3.63	3.34	0.93	1.21	2.23	1.59	0.32	21.56
KEARNEY 4 NE	Monthly total precipitation (In.)	2001	1.02	1.03	0.86	3.55	4.18	0.84	4.62	3.16	4.36	1.15	1.50	0.24	26.51
KEARNEY 4 NE	Monthly total precipitation (In.)	2002	0.21	0.38	0.57	1.23	3.39	1.19	0.43	1.66	0.80	N/A	N/A	N/A	N/A
KEARNEY 4 NE	1931-2001 Normal		0.53	0.67	1.58	2.37	4.01	4.03	3.22	2.66	2.35	1.45	0.89	0.59	24.23

Appendix B. Temperature and Precipitation Values for Scottsbluff, Nebraska 2000-2002.
(National Oceanic and Atmospheric Administration, 2000-2002)

WEATHER STATION	PARAMETER	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
SCOTTSBLUFF AP	Monthly average temperature (F)	2000	29.84	35.78	40.03	47.15	59.55	67.10	76.27	75.76	62.55	49.92	26.77	23.84	49.55
SCOTTSBLUFF AP	Monthly average temperature (F)	2001	28.89	25.59	38.89	47.58	56.81	67.67	76.58	73.73	64.38	48.98	38.70	29.82	49.80
SCOTTSBLUFF AP	Monthly average temperature (F)	2002	29.26	31.29	30.03	48.50	55.56	72.77	77.48	70.74	61.60	N/A	N/A	N/A	N/A
SCOTTSBLUFF AP	1949-2001 Normal		25.52	30.89	37.24	47.31	58.29	68.61	75.34	73.27	62.85	50.54	36.51	27.70	49.51
SCOTTSBLUFF AP	Monthly total precipitation (In.)	2000	0.48	0.89	1.04	2.80	1.48	0.68	1.70	0.33	2.31	2.47	0.37	0.24	14.79
SCOTTSBLUFF AP	Monthly total precipitation (In.)	2001	0.28	0.29	0.42	3.03	2.22	1.70	2.79	0.04	1.01	0.94	0.30	0.00	13.02
SCOTTSBLUFF AP	Monthly total precipitation (In.)	2002	0.05	0.03	0.66	0.44	0.73	0.59	0.08	3.48	0.69	N/A	N/A	N/A	N/A
SCOTTSBLUFF AP	1949-2001 Normal		0.46	0.47	0.99	1.64	2.83	2.92	2.10	1.08	1.20	0.93	0.61	0.49	15.72