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**Hong Kong International Airport**

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# Center Pivot Irrigation in the San Luis Valley of Colorado

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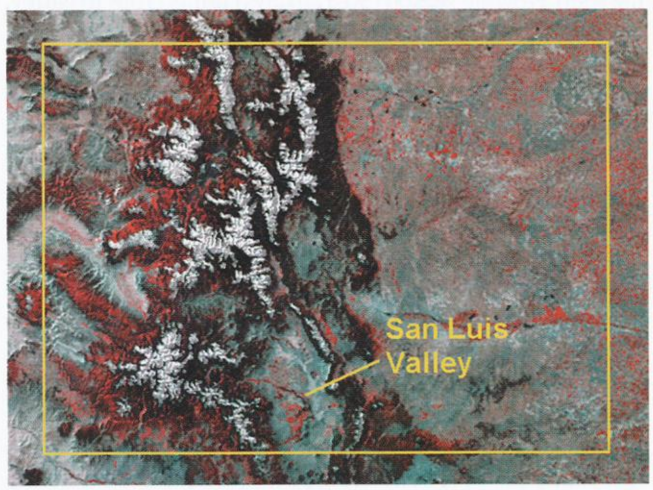
Water is one of the most precious items on the face of the Earth. It provides life to the planet. However, its uneven geographic distribution creates different ways that humans perceive it and use it to meet their various needs. In continental United States, roughly half the land is classified as arid or semiarid; land basically found west of the 100th meridian. Historically, most of the people in the United States have lived in the eastern, humid half of the country and possess little understanding of water issues in the western, drier sections of the country. Irrigation plays a significant role in shaping the land in Western United States, particularly agricultural land, and one of the more fascinating forms of irrigation is center pivot irrigation. People flying across this region frequently wonder about those large circular patterns on the ground. This paper deals with irrigation conditions, especially center pivot irrigation systems, in the San Luis Valley (Map) of south-central Colorado.




**Map** Colorado and the San Luis Valley

## Physical Setting

The San Luis Valley is a large, flat intermountain valley that varies from 40 to 65 miles (65-105 km) east to west and is about 100 miles (161 km) north to south in size. The state of Delaware could easily fit on the valley floor, not including the surrounding mountain slopes. The valley floor rests at about 7600 feet (2316 m) above sea level. Figure 1, a MODIS true-color image taken October 26, 2001, provides an overview of the Valley. The superimposed black line cutting across the image is the state boundary between Colorado and New Mexico. Outlining this huge valley are the snow-covered peaks of the Sangre de Cristo Mountains on the east and the San Juan Mountains on the west. The immensity of the Valley with the surrounding mountains provides an outstanding panoramic view. Here supposedly is the highest and largest alpine valley in the world.

The San Juan Mountains rise slowly from the valley floor and eventually reach elevations exceeding 12,000 feet (3658 m). In contrast, the Sangre de Cristo Mountains ascend dramatically and rapidly from the Valley and attain heights over 14,000 feet (4267 m). At the north end of the Valley these two mountain ranges bend toward each other and help form the Valley's elliptical shape. The ranges meet at Poncha Pass, which is the main gateway to the upper Arkansas Valley. The south end of the Valley is not as well defined but the large, rounded volcanic mounds known as Ute Peak and San Antonio Mountain, both located just slightly over the border in New Mexico, provide nice entry points into the Valley. Out of the San Juan and Sangre de Cristo mountains flow several streams that bring water to the Valley. The largest and best known is the Rio Grande, which starts up in the San Juans and moves initially eastward coming out of the mountains. In the middle of the Valley it turns southward and travels into New Mexico. Much of the northern part of the Valley is a closed basin with internal drainage.

Climatically the San Luis Valley is a cool desert. Like many deserts it receives a tremendous amount of sunshine in all seasons of the year and has beautiful blue skies during the day and clear star filled skies at night. It receives on the average around eight inches of precipitation per year, but it is not uncommon for it to get twelve inches of snow in a day or experience a sudden downpour of one or more inches of rain. Typical of many deserts the Valley's weather is one of extremes.

Summer daytime temperatures in the Valley are moderate. They are generally between 75ºF and 83ºF (23ºC and 28ºC). With the low humidity these temperatures are very comfortable. Temperatures rarely exceed 90ºF (32ºC). The Valley is one of the major potato growing regions within the country and the warm, sunny days and cool nights provide a perfect growing season. The cool weather also contributes to the smoothness of the potato skin. In addition to potatoes, the short growing season (90-120 days) limits crops to barley, oats, hay, and some vegetables. Winter daytime temperatures are temperate with highs being in the 40s to 50s degree level. However, with clear skies and calm winds, nighttime temperatures can reach below -30ºF (-34ºC). The Valley will often record the lowest temperature in the nation during the winter. Winter temperature inversion adds to the rawness of the winter weather in the Valley.

Rain mainly occurs in the summer from low intensity thunderstorms. The climatic table below is for Alamosa, which is located basically in the middle of the Valley. Alamosa's climate is typical for most of the valley floor. Winter precipitation is mainly from snow. Potential evapotranspiration exceeds 40 inches (1016mm) per year; thus, no surplus moisture exists. The Valley falls within the rain shadows of the surrounding mountains. Storms entering the Sangre de Cristo Mountains generally start over the Gulf of Mexico. These storms have very little moisture left by the time they reach the Valley. Air masses from the Pacific Ocean provide moisture for the San Juan Mountains. Due to the wind patterns associated with these air masses most of the moisture comes during the winter in the form of snow. See the climatic table for Wolf Creek Pass. Wolf Creek Pass is located in the San Juan Mountains and has one of the highest precipitation levels in Colorado. Again, very little moisture is left in the air once a storm enters the Valley.

## Surface Water

Approximately 2,800,000 acre-feet (344,400 hectare meters) of water circulate through the Valley each year. Precipitation accounts for about 1,220,000 acre-feet (150, 060 hectare meters) of water input but evapotranspiration accounts for about 2,420,000 acre-feet (297,660 hectare meters) of water output in the Valley per year. Surface-water inflow, at 1,580,000 acre-feet (194,340 hectare meters) of water per year, comes mainly from the surrounding mountains and provides almost all of the water for irrigation. This water is applied directly to fields through canals and laterals and indirectly to fields by recharging the Valley's aquifers that feed wells. Valley precipitation plays a minor role in supplying water to the fields (Emery).

Surface water, taken from the rivers and streams, flows out of the surrounding mountains, a watershed of about 4, 700 square miles (12,173 km2), and is distributed for irrigation use through 150 miles (241 km) of canals and laterals. Much of this water is lost to evaporation. Although the average annual surface water is 1,580,000 acre-feet (194, 340 hectare meters), the amount can vary greatly based on the amount of mountain snow pack available. In 1941, amount of surface water reached a high of 2,783,000 acre-feet (342, 309 hectare meters) but ten years later, in 1951, the amount dropped to a low of 743,000 acre-feet (91,389 hectare meters) (Emery).

## Ground Water

As water leaves the mountains large amounts of it penetrates the ground at the edge of the Valley and seeps into

| **Alamosa** | | | | | | **37º 27' N** | | **105º 52' W** | | | | | **7536 Feet** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **Y** |
| T. ºF | 17.2 | 22.8 | 31.0 | 41.2 | 50.8 | 59.6 | 65.0 | 62.7 | 55.2 | 44.1 | 29.9 | 19.2 | 41.6 |
| P. In. | 0.25 | 0.26 | 0.35 | 0.63 | 0.62 | 0.52 | 1.17 | 1.15 | 0.71 | 0.69 | 0.24 | 0.35 | 6.94 |
| S. In. | 4.9 | 3.6 | 3.7 | 5.8 | 1.3 | 0.1 | 0.0 | 0.0 | 0.1 | 1.8 | 3.4 | 2.8 | 27.5 |

T = Temperature, P = Precipitation, S = Snow

| **Wolf Creek Pass** | | | | | | **37º 29' N** | | **106º 52' W** | | | | | **9425 Feet** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **J** | **F** | **M** | **A** | **M** | **J** | **J** | **A** | **S** | **O** | **N** | **D** | **Y** |
| T. ºF | 12.4 | 16.5 | 25.3 | 35.6 | 43.5 | 49.9 | 56.9 | 56.1 | 49.4 | 39.6 | 26.3 | 13.5 | 35.4 |
| P. In. | 6.20 | 5.32 | 6.32 | 4.15 | 2.36 | 1.32 | 2.85 | 3.77 | 2.78 | 3.49 | 3.37 | 4.81 | 46.7 |
| S. In. | 87.1 | 72.3 | 80.2 | 38.2 | 5.8 | 1.4 | 0.0 | 0.0 | 1.9 | 17.1 | 40.6 | 64.0 | 408. |

T = Temperature, P = Precipitation, S = Snow aquifers. The aquifers contain an estimated two billion acre-feet (2,460,000 hectare meters) of water. Two basic types of aquifers exist within the Valley. The first are referred to as *unconfined aquifers*. Water in such aquifers is very near the ground surface and flows freely through the loose mineral material of the aquifers. Since the water is near the surface, little water pressure exists in the aquifer. These aquifers are generally recharged from precipitation, streams, and canals. Within the Valley unconfined aquifers are found less than twelve feet from the ground surface and can be tapped easily by wells. However, in the southern sections of the Valley, wells can exceed 300 feet (91.4 m). Unconfined aquifers provide water for 80 percent of all large capacity wells and represent the principal source of ground water irrigation in the Valley.*

The second type of aquifer exists when a permeable layer in the ground is enclosed above and below by impermeable layers. This is a *confined aquifer*. As water accumulates in a confined aquifer, water pressure builds until breaks occur in the impermeable layers creating artesian seepage. The first drilled artesian well in the Valley occurred in 1887 and within ten years, over 3,000 wells existed. Confined aquifers are found in the upper 6,000 feet (1829 m) of the Valley sediment, making them much deeper than unconfined aquifers. This water is available under one-half of the Valley. Artesian wells in the Valley are frequently drilled between 100 and 200 feet (30.5 and 60.9 m) in order to obtain enough water. However, of the 650 large-capacity, confined aquifer wells, 99 are between 1,000 and 2,000 feet (304.8 and 609.6 m) and 21 exceed 2000 feet (609.6 m). These wells generally exceed 3,000 gpm. Due to the abundance of water most artesian wells were not capped until the 1960s when farmers were finally ordered to stop wasting the water. Confined aquifers have played a key role in the development of central pivot irrigation in the valley.

## Water Rights

In the more humid, eastern half of the United States, the riparian doctrine, obtained from the English, gives landowners the right to use any water on their property. Under these rights water naturally flowing on a person's property cannot be diminished. The abundance of water generally permits it to be shared equally by all users. However, in most of the western half of the United States, water is a precious resource that needs to be appropriated. People in the West have to deal with the law of prior appropriation. The first person to put a water source to "beneficial use" has the first right to water from that source when water is scarce. A water right is a property right, which is not connected to the land on which the water occurs. A water right can be transferred to a farmer or city miles away from where it exists. However, the transfer of water is highly regulated. In Colorado, the state engineer and the seven water courts throughout the state oversee the transfer of water.

## Water Problems

By the 1880s water conflicts were occurring as more farmers entered the Valley and started taking water for irrigation. A need arose to adjudicate water rights. In 1888, a General Adjudication of water rights occurred with supplements being added over the years. Water conflicts were particularly bad during drought periods. A severe drought hit the Valley and other areas in 1893, resulting in bank failures, farmers leaving the Valley, and some small communities disappearing. The Rio Grande dried up along the Texas-Mexican border. However by 1896, the situation had changed and a water surplus existed. This surplus situation created a different set of water problems. The unconfined aquifers were being recharged by irrigation, leakage from canals and ditches, and direct precipitation. In the north-central portion of the Valley the problem was compounded by the lack of any natural drainage in the enclosed basin. The water table in the unconfined aquifers rose to a level where the roots of crops were being saturated. The situation also resulted in drawing salt to the surface, which ruined the soil. Fields were abandoned but the water continued to rise to the surface where evaporation of the standing water resulted in more salt or alkali conditions. By the 1920s many acres had become waterlogged and/or alkalinized, and had been taken over with greasewood and rabbit brush. This condition still exists today (Ogburn).

The water shortages and soil problems of the 1890s reached beyond the Valley. Increased farming in the Valley had resulted in less water for farmers in New Mexico and beyond. By the time the 1893 drought occurred, the Rio Grande riverbed at El Paso was dry. In the Valley all of the canals except the Rio Grande Canal were empty. The Rio Grande Canal was using all of the water in the Rio Grande to deal with the earliest of prior appropriations. Later appropriations were receiving no water. In 1896, an International Boundary Commission was established for the purpose of developing a plan where water would be equitably distributed between Colorado, New Mexico, Texas, and the Republic of Mexico. Even though Colorado controlled the headwaters of the Rio Grande, an embargo on developing any water diversion projects on the upper Rio Grande occurred in 1906. The people in the Valley were discovering that they had to share the Rio Grande water. A treaty was signed in 1906 by the United States and Mexico that allowed Mexico to receive 60,000 acre-feet of water every year. To fulfill this commitment and the commitment to New Mexico and Texas, the Elephant Butte Reservoir was built on the Rio Grande in southern New Mexico in 1916. This reservoir has a storage capacity of 2,600,000 acre-feet (319,800 hectare meters).

* A large-capacity well yields more than 300 gpm (gallons of water per minute).

However, Colorado has often not been able to provide water to meet its commitments to the areas south of it (Ogburn).

## Center Pivot Irrigation

Surface flood irrigation was the primary method of distributing water to the field during the period from the 1890s to the early 1960s. Large siphon tubes were used to draw water from the irrigation ditches into the fields In the 1960s, *center pivot sprinkler systems* started to replace most of the surface flood irrigation by tapping the tremendous amount of water available in the confined aquifers. Center pivot sprinkler systems use less than half the water of surface flood irrigation systems and decrease water loss by canal leakage. Figure 2 shows the layout of the typical center pivot field. This system is based on a well being in the center of a field and an irrigation pipe mounted on wheels gradually moving around the well, an arrangement, which forms a circular field pattern. The concentric circles shown in Figure 2 correspond to the paths of the wheels.

Most of the center pivot systems are found in the northwest portion of the Valley, mainly in Saguache, Rio Grande, and Alamosa counties. Unlike the Valley's southern counties that were developed around large Spanish Land Grants, these northern counties were organized under the Public Land Survey system with the basic land parcel being the quarter section. A quarter section covers 160 acres. Since the initial center pivot systems were designed chiefly for quarter section land parcels on the Great Plains, it was relatively easy to apply the technology to similar areas under the Public Land Survey system. An examination of Figure 3, a Landsat 7 false color composite taken on August 26, 2002 over the northwest portion of the Valley, shows how the circular fields are arranged in the neat grid pattern associated with the Public Land Survey. Each circle rests inside a 160-acre quarter section.* The crops grown in these fields are mainly potatoes and alfalfa with some lettuce and spinach as secondary crops. Potatoes, lettuce, and spinach are produced for the national market. Alfalfa is grown for the dairy farms

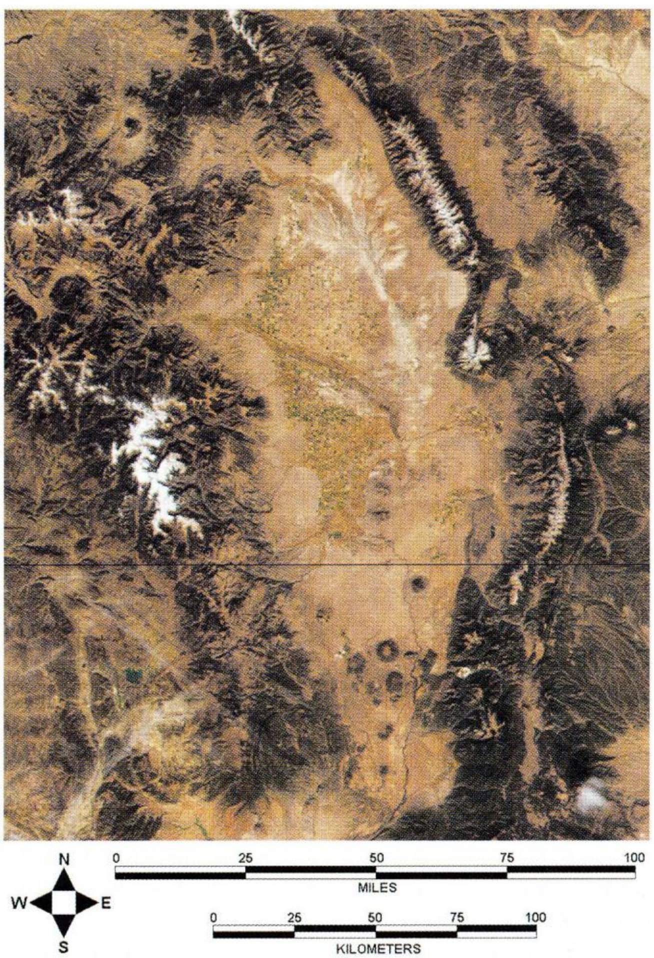



**Figure 1** The San Luis Valley outlined by the San Juan and Sangre de Cristo mountains. Image prepared by Jacques Descloitres, MODIS Land Rapid Response Team, NASA GSFC.

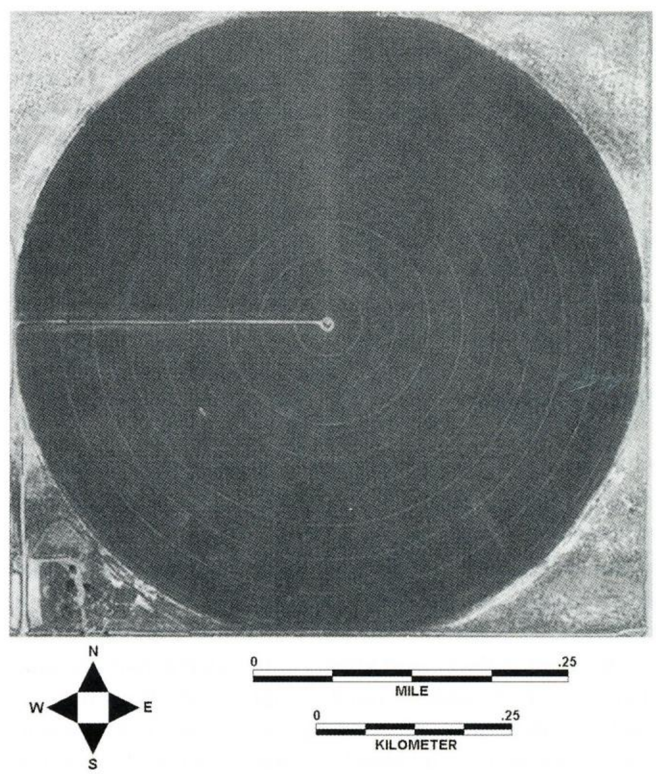



**Figure 2** A typical center pivot irrigation field. The line directly west of center is the access route to the well and pump. The pipeline is directly north of the well. The pipeline cannot be seen but the mist of the water being sprayed from the line can be detected.

* A quarter section is a half-mile in length with the radius of a circular field being one-fourth of a mile. A fourth of a mile is 1320 feet (403 m). Using the standard formula for determining the area of a circle, $\pi r^2$, the area of a center pivot field is calculated to be 125.66 acres (51 ha).

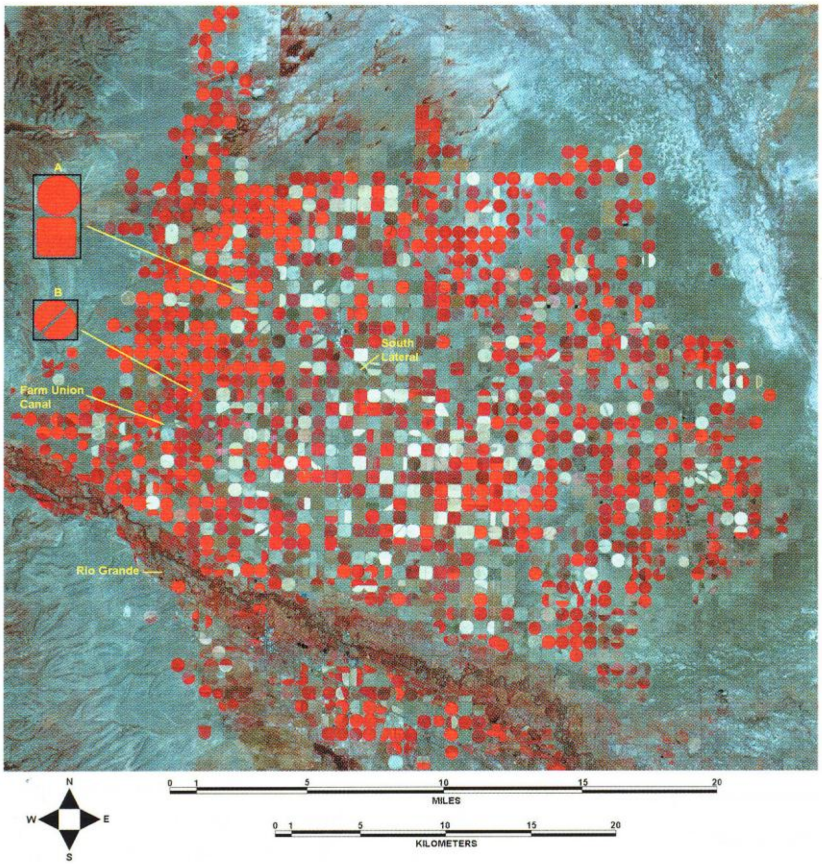



**Figure 3** Landsat 7 false color composite (Band 4 - Red, Band 3- Green, and Band 2 - Blue) of center pivot irrigation fields around the community of Center.

**Figure 4** Irrigation pipe spraying water over a field.

in New Mexico and Texas. Some fields are owned by Coors for the production of barley.

Initially, the sprinklers on the irrigation pipes shot water up into the air in a whirling motion spraying large areas (Figure 4) but it was discovered that large amounts of the water were lost due to evaporation. Today, lines drop down from the irrigation pipe to within a foot or two of the plants and spray immediately above the plants. This drop line method significantly reduces the amount of water needed. Also, water to these lines is highly computerized. If the drop line sprinklers near the center of a field were permitted to distribute the same amount of water as the sprinklers on the edge of the field, the center of the field would be flooded. Such flooding would be a waste of water and could result in the alkalization of the center of the field.

Figure 3 shows the high concentration of center pivot fields around Center, Colorado. Also shown is the Rio Grande River and just south of the river is the community of Monte Vista. The northeast diagonal line from the river to Center is the Farmers Union Canal and the southeast diagonal line from Center back to the river is the South Lateral.

Some of the fields shown on Figure 3 are not absolute circles. On the sides of the fields the edges of the circles are truncated. In many cases what the farmer is doing is allowing water to shoot out at the end of the irrigation pipe. This action results in water being sprayed into adjacent fields and the roads separating the fields. It also permits water to reach more into the corners of the fields thus using more of the land for production. This approach wastes water and the farmer could be heavily fined for creating dangerous road conditions. A few of the irrigated fields are almost rectangular in shape. See inset A in Figure 3. Buried around the edge of these fields, at about four feet down, are sensor wires. These wires are used to control the speed of the last section of the irrigation pipe. Rather than the entire length of the pipe being straight, the last section is at an angle when the pipe moves along the edges of the field and then the last section straightens out when the pipe goes into the corners. The last section is frequently referred to as the "tail dragger." This approach represents the best use of the field space, and since only drop line spraying is required, it also represents the best use of the water.

Some narrow straight lines can be detected in some of the fields. Frequently these are service roads that allow farmers access to a well and pump. The Farmers Union Canal and the South Lateral cut diagonally through some fields. See inset B in Figure 3. Some of the farmers who have these fields have two center pivot irrigation systems, one on each side of the ditch. Other farmers have put small bridges across the ditches to accommodate the wheels of the irrigation pipe. When the pipes cross over the ditches using these bridges the drop line sprinklers are programmed to stop working and then start up again once across a ditch.

Figure 5 is taken from the same data set

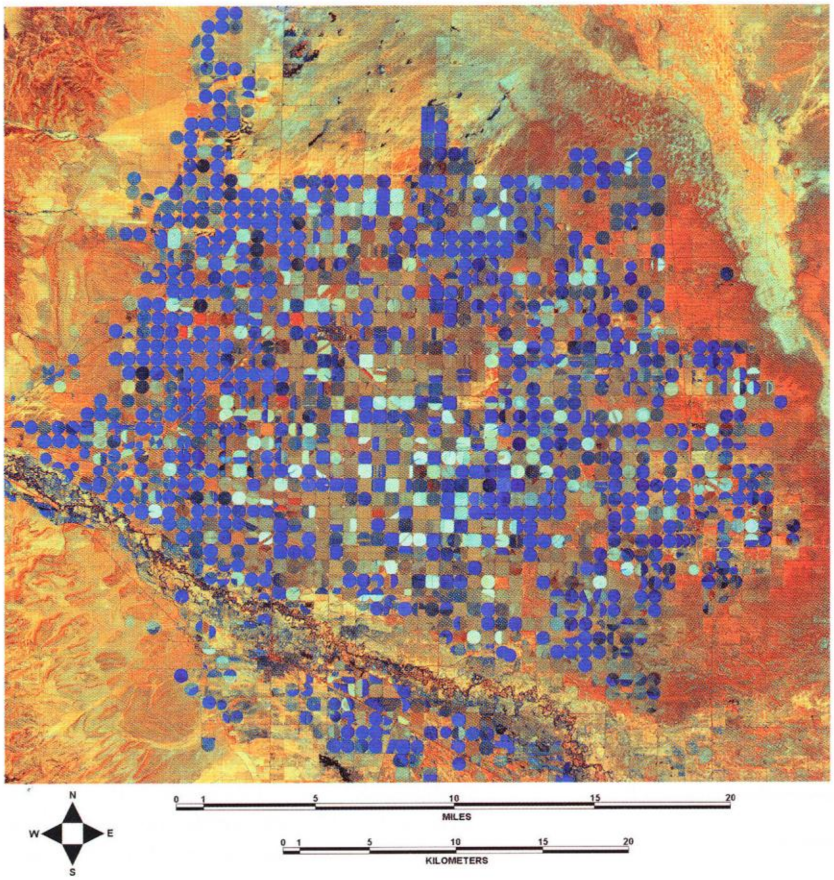



**Figure 5** Landsat 7 false color composite based on the ratio drought index (Red), Band 5 (Green), and Band 4 (Blue).

as Figure 3 but is based on the ratio drought index (RDI) (Pinder and McLeod). This index is developed by dividing a near infrared band into a mid-infrared band. In the case of Landsat, TM bands 5/4 are utilized. High index values identify dry areas and low values wet areas. Figure 5 is a false color composite consisting of the RDI (Red), Band 5 (Green), and Band 4 (Blue). The reddish-orange areas, mainly the non-irrigated land, are dry areas. However, the Rio Grande and the Farmers Union Canal are also red. As previously indicated the satellite image was recorded in late August, 2002. In general, by the end of a normal summer the water levels in the river and canals are very low. In addition, 2002 was an extremely dry year. The bright blue colored fields have been recently irrigated. They have very low RDI values indicating moist conditions. The brown and tan colored fields are most likely harvested fields, and thus, no longer need to be irrigated. Some moisture still exists in these fields. The red colored fields were not planted, and like the surrounding non-irrigated land, are very dry.

Two major problems exist in using center pivot irrigation in the Valley. First, the water from the confined aquifers brings to the surface large amounts of salts. When the water evaporates on the surface or evapotranspires through the plants, salt is left behind in the soil. If the salt is allowed to build up, it can destroy the capability of the soil. Excess water must be used on the fields to break up the salt and carry it back below the ground level. The second problem relates to energy costs. To pump large amounts of water over long periods of time and to move large irrigation pipes around the field takes a tremendous amount of energy. Since energy prices fluctuate, a farmer finds it difficult to judge energy costs, which is a major item in the overall production of a crop.

## Final Remarks

As stated in the introduction, people perceive water usage differently. About half of the total water available in the Valley annually is used by vegetation that has no economic value. This is the natural vegetation of the area. In a world with a growing population and increasing demand for food, policy makers and agriculturists consider this water as being wasted. This wasted water is a problem that must be addressed. In a world with a growing population demanding a quality environment, ecologists view the native vegetation as being necessary for a healthy ecosystem in the Valley. Thus, the water is not wasted. Battle lines are being established and what occurs in the Valley might represent future development in other sections of the West. Remote sensing can assist people in understanding the problem. People who live in the Valley know that irrigation and agriculture represent a large portion of the landscape; however, they view this landscape from the ground. If they would have a synoptic view such as the one provided by Figure 5, they might appreciate how much of the land is already consumed by irrigated farming. Unfortunately, few people see the land from this perspective, and those who do, have little understanding what is occurring.

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