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Knowledge to Go Places

College of Agricultural Sciences

Department of Soil and Crop Sciences

Cooperative Extension

Center Pivot Irrigation in Colorado as Mapped by Landsat Imagery

CENTER PIVOT IRRIGATION IN COLORADO AS MAPPED BY LANDSAT IMAGERY

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Acknowledgments

Sincere gratitude goes to student employees, Susannah Greer and Chad Lampson, for their hard work at digitizing the remote imagery. Also, we appreciate GIS & statistical support from Robert Flynn, John Norman, and Robin Reich on this project.

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Introduction

An accurate estimate of the number, acreage, and location of irrigated fields in Colorado would be valuable input in various irrigation, land use, and water quality studies. Other regional and statewide irrigation maps currently exist (e.g. Fig. 1 and 2), but they vary widely in scale, accuracy and methodology (Hall, 1998; USGS, 2000; Williams and Eckhardt, 1997). Recent efforts to map the vulnerability of Colorado ground water to contamination from agricultural chemicals required improved information for areas that are predominately irrigated with center pivot irrigation systems (Ceplecha et al., 2004). Center pivot irrigation generally results in higher application efficiency, enhanced water conservation and reduced potential for leaching of agricultural chemicals compared to surface irrigation. Mapping areas predominately irrigated by center pivot ground water can significantly improve ground water vulnerability maps and aid with other water related investigations. Therefore, our objective was to produce a digital coverage of center pivot irrigation in Colorado using Landsat (TM) imagery acquired from remote sensing.

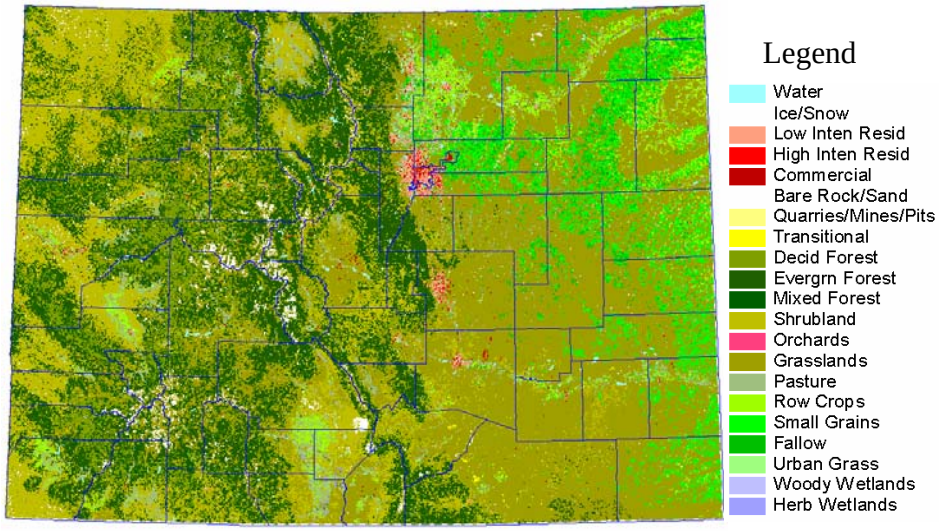

Figure 1. Land use classifications for Colorado from USGS National Land Cover Data, 2000.

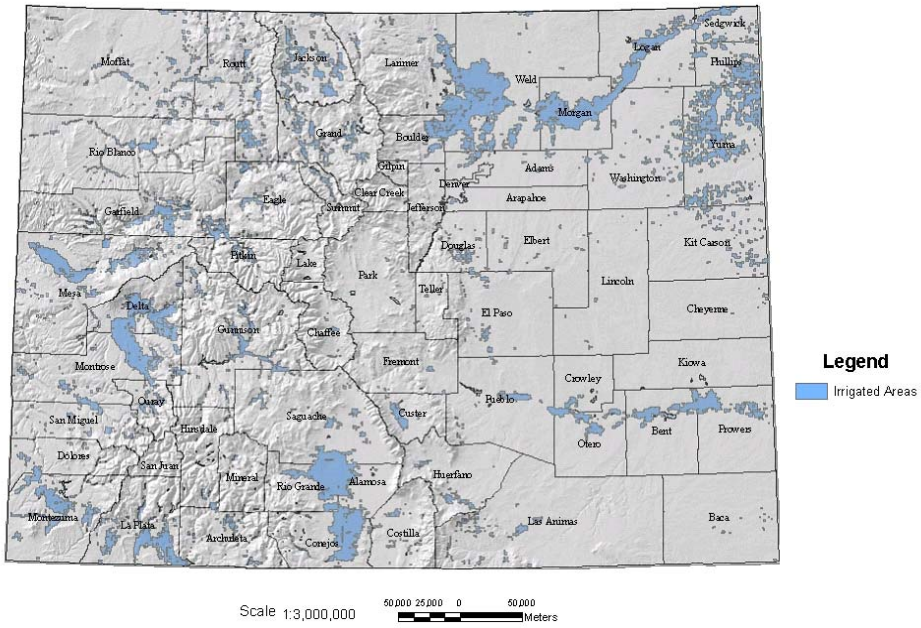

Figure 2. Map of irrigated land in Colorado. The west slope locations were obtained from U.S. Bureau of Reclamation analysis of satellite imagery and the east slope using normalized difference vegetation index (NDVI) values processed from Advanced Very High Resolution Radiometry satellite imagery (from Hall, 1998).

Methods

We used sixteen frames of the Millennium Mosiac Landsat Thematic Mapper (TM) imagery that covered the entire geographic area of Colorado (Fig 3). This imagery has 15-m panchromatic resolution and was acquired between July 1 and Nov. 4, 1999 by DigitalGlobe Inc. Using the ARC-INFO (ESRI, 2001) geographic information systems software, center pivots in the imagery were identified using manual photo interpretation technique. The center pivots were then digitized and saved as GIS polygons. An example of how the satellite imagery revealed center pivot irrigation systems is shown in Figure 4. The digitized center pivot map was summarized by the number of center pivots identified and area covered by center pivot irrigation in each Colorado county (Fig. 6 and 7).

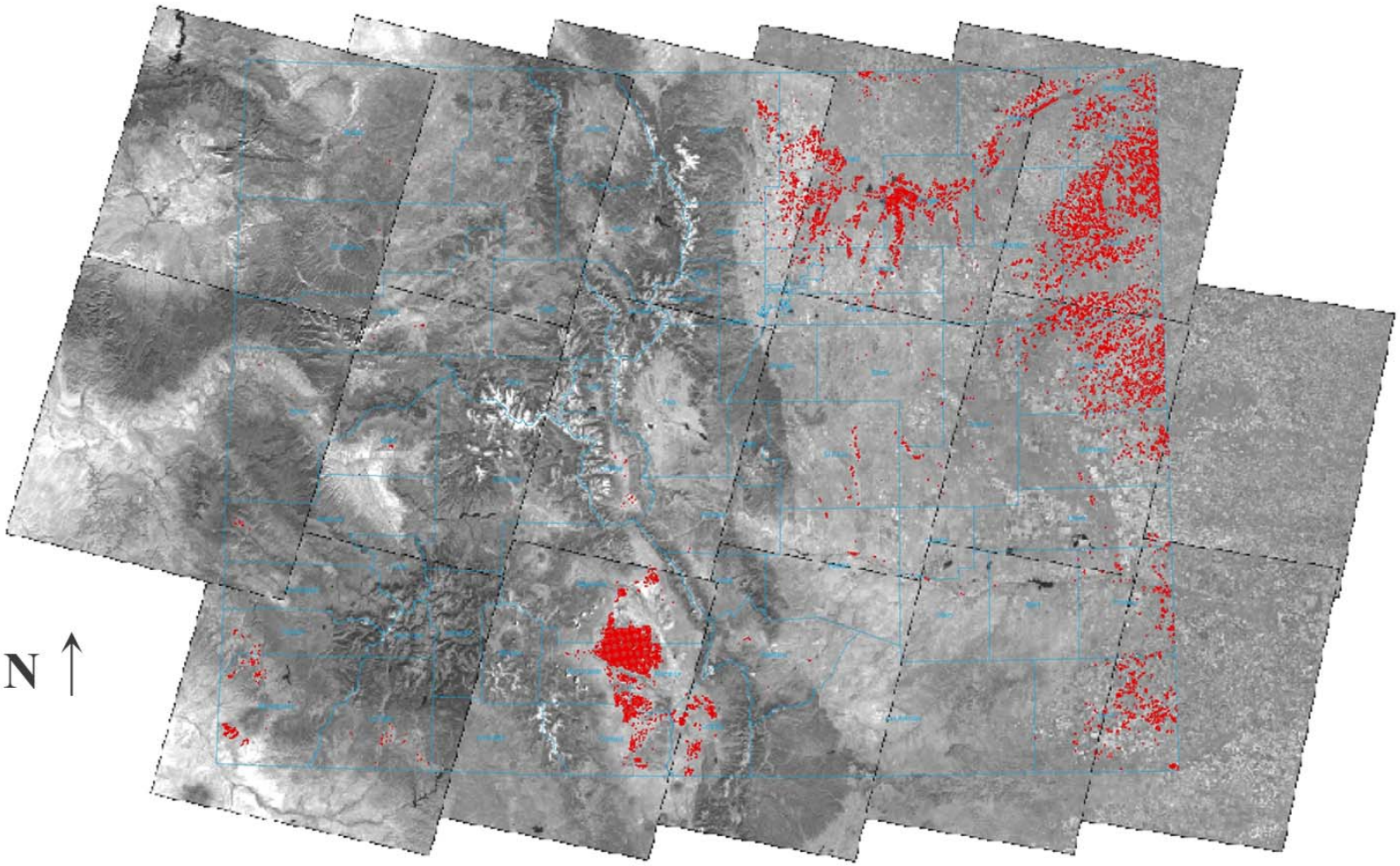

Figure 3. Center pivots (in red) over 16 frames of imagery from Millennium Mosaic Landsat Thematic Mapper (TM) acquired between July 1 and November 4, 1999.

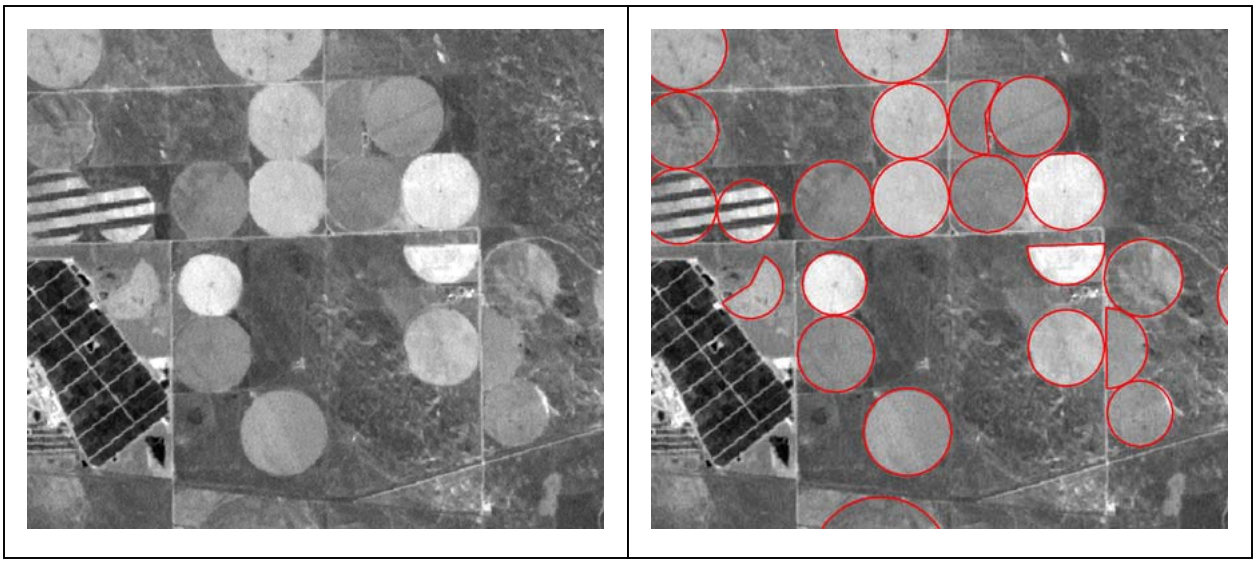

Figure 4. Example of how center pivots were identified and digitized using Landsat imagery.

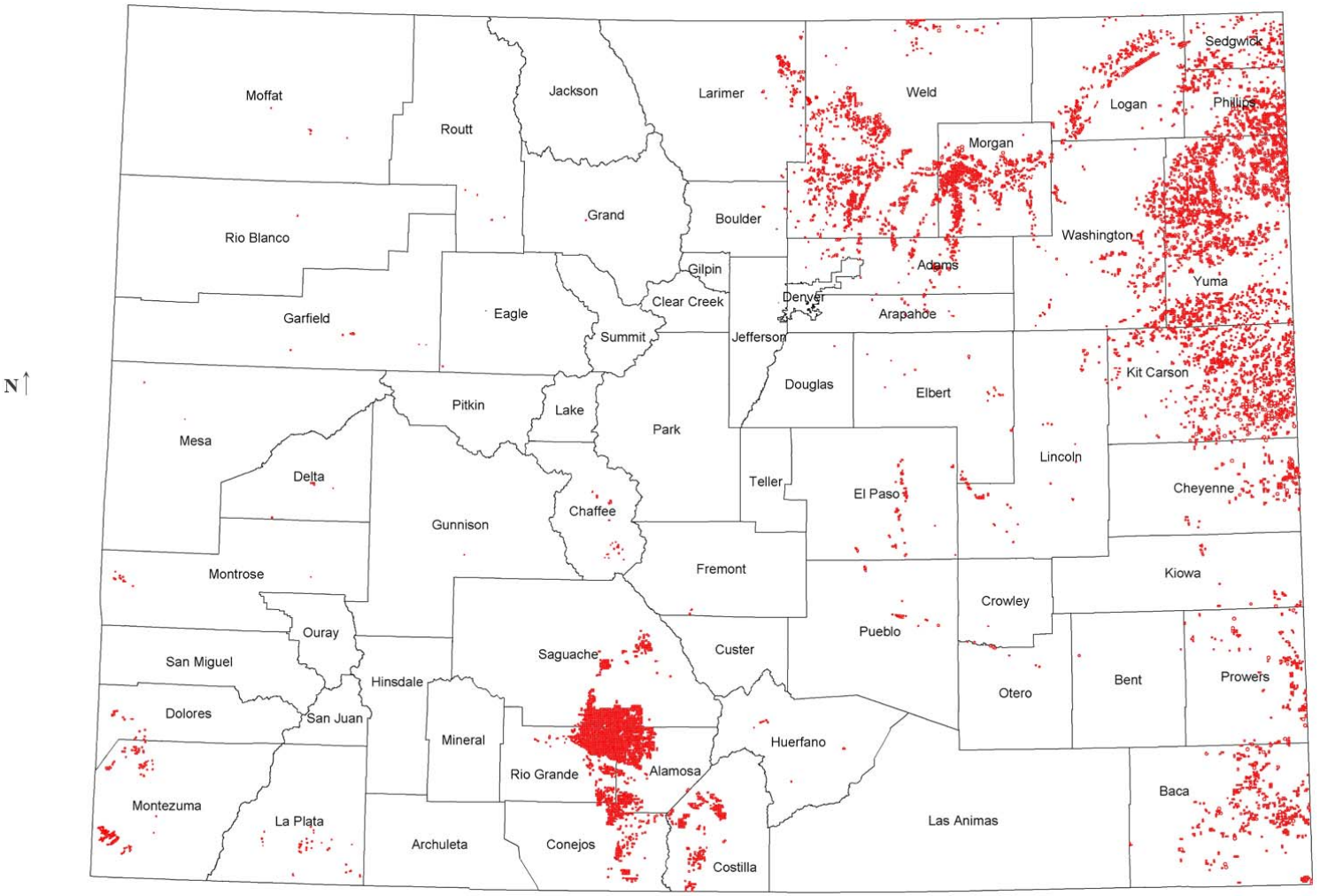

Figure 5. Map of center pivots in Colorado based upon 1999 Millennium Mosaic Landsat Thematic Mapper (TM) acquired between July 1 and November 4, 1999.

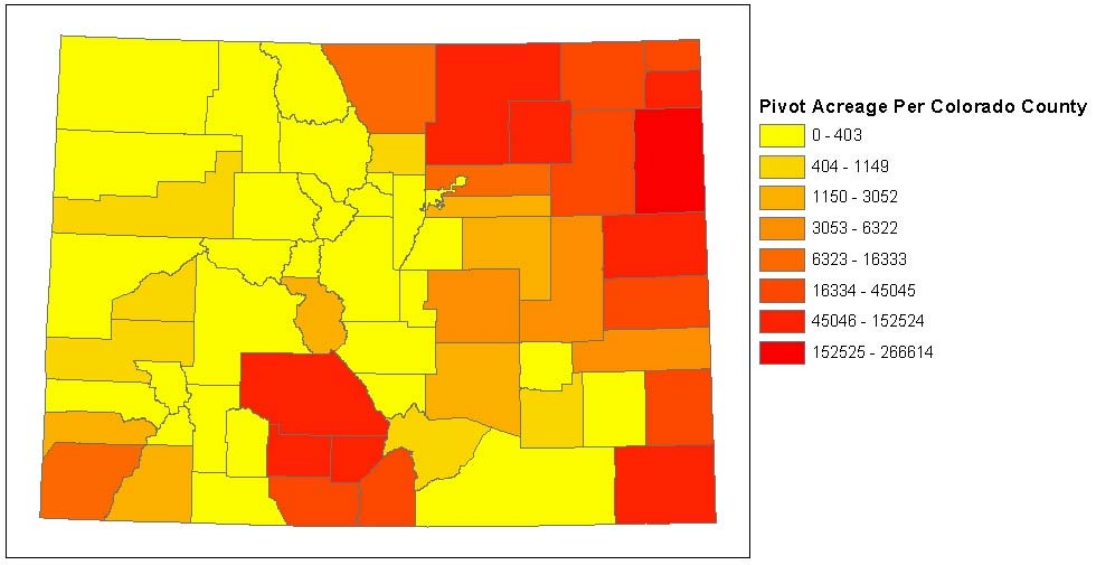

Figure 6. Center pivot acreage by Colorado county.

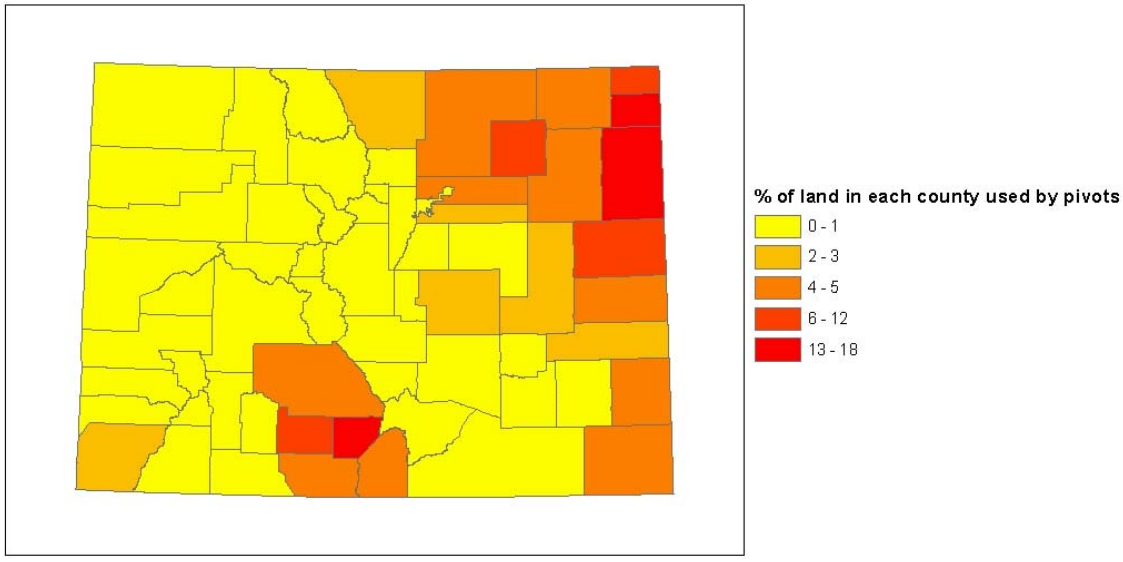

Figure 7. Percent of land area in each Colorado county under center pivot irrigation.

Validation of Map Accuracy

After the entire state center pivot map was digitized, acreages and locations of center pivots were examined on a county-by-county basis by Cooperative Extension agents and other local experts to obtain a general assessment of accuracy. Interviews with these local authorities suggested that the map was reasonably accurate, allowing us to proceed with more detailed quantitative evaluation procedures.

We designed a sampling scheme to evaluate map accuracy with respect to number and location of center pivots digitized. With assistance from Dr. Robin Reich, CSU statistician and Professor in the Department of Forest, Rangeland and Watershed Stewardship, the state was stratified based on center pivot density. Areas of high center pivot density were gridded into townships using a PLSS (Public Land Survey System) map of Colorado, and townships were randomly selected from three areas, 1) lower Platte River basin, 2) Yuma County, and 3) San Luis Valley. All quarter sections (160 acres) in each township of the selected set of townships were tallied. A tabulation was made by visiting each 160-acre parcel to verify whether presence or absence of a center pivot was correctly mapped. Center pivot counts were expanded to provide an estimate of the number of center pivots in the state, including a 95% confidence interval on the estimate. Results indicated that the total number of active center pivots in the state in 1999 was 10,175, with a 95% confidence interval of 148 center pivots.

Results and Discussion

Using the remote imagery, we digitized 10,175 center pivots irrigation systems across Colorado (Figure 4). The map revealed that approximately 1.9 percent of the total land area in Colorado, or roughly 507,943 hectares (1,255,154 acres) is serviced by center pivot irrigation systems. This compares to 1,229,033 acres that were reported irrigated by center pivot systems in 1998 by the Census of Agriculture (USDA-NASS), a difference of less than two percent. This difference most likely results from a overestimation of center pivot size during the digitizing process rather than mapping center pivots that did not exist at the time

of the imagery. In most cases, the pattern of individual center pivots was readily recognizable, but digitizing the exact edge of the irrigated field was more difficult. Producers' decision to use or shut off center pivot end guns during a particular crop year could easily account for mapped center pivot acreage variability exceeding two percent.

Center pivot irrigation systems were identified and mapped in 46 of Colorado's 64 counties (Table 1). No center pivots were found on the remote imagery in the remaining 18 counties. Individual county maps are provided in the accompanying appendix for all counties where imagery revealed center pivot irrigation systems. Table 1 provides a summary of the number and acreage of center pivots that were digitized compared to county acreage and irrigated acreage estimates. Yuma County had the highest number of center pivots and the highest percentage of county acreage covered by center pivot irrigation. Eighty percent of the acreage and 79 percent of the center pivots were mapped in ten Colorado counties.

We mapped more acreage under center pivot irrigation in certain counties (e.g. Cheyenne) than the total acreage reported by the Census of Agriculture. This discrepancy could be due to the slight overestimation of acres irrigated by center pivots described above, or an underestimation by the survey method. These results should not be interpreted as a quantification of irrigated acreage in these counties nor should the reader assume that surface irrigation does not exist in these counties. Rather, the percent of acreage serviced by center pivots is provided to give an estimation of the importance and magnitude of this type of irrigation in these areas.

Table 2 provides descriptive statistics of center pivot irrigation in Colorado. The most common size for center pivots was 120 acres. The mean was 123 acres, only slightly lower than 126 acres reported by Frasier et al., 1999. The calculated radius of most commonly sized center pivot is approximately 1,290 feet, indicating that most center pivots are irrigating approximately one quarter-section of land. Larger center pivots were most commonly found in eastern Colorado counties and smaller ones tended to be located in western counties.

The statistical sample of the field observations verified the map was accurate within two percent. The errors in the map primarily resulted from:

- new center pivots on existing irrigated land that were installed after the imagery was produced;
- center pivots that are surrounded by surface irrigation that did not produce a definite pattern on imagery;
- unusually small center pivots or systems irrigating irregularly shaped fields;
- and abandoned center pivots.

Summary

High-resolution satellite imagery proved very effective in producing an accurate center pivot irrigation map of Colorado. This map has the potential to improve existing estimates of irrigated acreage in Colorado and can be used to aid water research, including predicting aquifer vulnerability to contamination from agricultural chemicals. High-resolution imagery aids in both visual determination of center pivot location and reasonably accurate acreage estimates. Because the map is produced from imagery taken during a specific time period, it will need to be periodically updated to remain current.

Future research needs include an investigation of the information and accuracy gained by developing an extremely accurate center pivot map using 0.70-m resolution imagery. These images are currently available through DigitalGlobe, but it is not clear if enough additional information can be gained through this higher level of resolution to justify the effort involved. Additionally, expanding digitized coverage to include a high resolution surface irrigation map layer in addition to center pivot irrigation will improve the knowledge of irrigation extent in Colorado. Annual investigations would illuminate the extent that irrigated acres and total acreage fluctuates in the various basins of Colorado.

Table 1. Colorado center pivot number, size and acreage compared to county area and irrigated area by county.

Rank (by pivot #)	County Name	Total Area of County	Irrigated Area in County*	Area Irrigated by Center Pivots	Center Pivots in County	Average Pivot Size	Percent Irrigated by Pivot
		(acres)	(acres)	(acres)	#	(acres)	(%)
1	Yuma	1,516,819	274,057	267,233	2,072	129	98
2	Kit Carson	1,383,771	145,730	152,668	1,137	134	105
3	Weld	2,571,956	393,030	116,246	1,026	113	30
4	Morgan	827,623	142,212	85,449	738	116	60
5	Saguache	2,028,016	207,200	71,489	597	120	35
6	Rio Grande	584,120	136,141	67,476	592	114	50
7	Alamosa	462,751	106,104	67,031	574	117	63
8	Phillips	440,338	87,816	64,708	486	133	74
9	Baca	1,637,142	65,068	65,320	464	141	100
10	Logan	1,180,508	109,198	45,143	372	121	41
11	Washington	1,615,094	55,568	43,344	341	127	78
12	Costilla	786,804	44,010	27,599	228	121	63
13	Conejos	825,732	130,581	25,982	220	118	20
14	Sedgwick	351,891	51,698	26,243	215	122	51
15	Cheyenne	1,140,406	20,632	25,632	181	142	124
16	Prowers	1,052,915	111,091	24,019	169	142	22
17	Montezuma	1,307,841	61,081	12,875	154	84	21
18	Adams	766,010	27,140	16,333	144	113	60
19	Larimer	1,684,418	77,695	10,825	99	109	14
20	El Paso	1,361,906	6,135	6,322	62	102	103
21	Lincoln	1,654,648	4,509	6,029	52	116	134
22	Kiowa	1,143,097	5,922	4,791	32	150	81
23	La Plata	1,088,766	71,855	2,944	32	92	4
24	Elbert	1,183,792	15,010	3,052	28	109	20
25	Pueblo	1,533,383	35,638	2,571	24	107	7
26	Chaffee	649,232	24,406	1,827	21	87	7
27	Arapahoe	515,109	3,901	1,926	18	107	49
28	Dolores	684,667	7,508	1,967	17	116	26
29	Montrose	1,437,232	85,040	1,149	13	88	1
30	Huerfano	1,018,952	16,208	912	10	91	6
31	Garfield	1,893,225	51,383	730	9	81	1

Table 1. Colorado center pivot number, size and acreage compared to county area and irrigated area by county. (continued)

Rank (by pivot #)	County Name	Total Area of County	Irrigated Area in County*	Area Irrigated by Center Pivots	Center Pivots in County	Average Pivot Size	Percent Irrigated by Pivot
32	Otero	812,251	63,001	1,125	7	161	2
33	Bent	986,248	62,709	1,348	6	225	2
34	Delta	735,586	70,981	645	6	108	<1
35	Boulder	480,494	39,464	461	5	92	1
36	Moffat	3,043,784	29,576	403	5	81	1
37	Routt	1,515,414	49,920	310	4	78	<1
38	Douglas	538,928	3,645	129	3	43	4
39	Crowley	511,949	21,647	188	2	94	<1
40	Fremont	980,992	19,272	271	2	136	1
41	Mesa	2,141,240	87,648	103	2	52	<1
42	Eagle	1,082,448	16,637	92	2	46	<1
43	Grand	1,195,875	39,778	96	1	96	<1
44	Gunnison	2,086,276	51,397	42	1	42	<1
45	Rio Blanco	2,064,919	35,905	94	1	94	<1
46	Jefferson	497,300	3,277	12	1	12	<1
	Archuleta	866,923	16,764	0	0	NA	NA
	Clear Creek	253,554	NR	0	0	NA	NA
	Custer	473,174	19,633	0	0	NA	NA
	Denver	99,005	14	0	0	NA	NA
	Gilpin	96,088	NR	0	0	NA	NA
	Hinsdale	718,961	2,324	0	0	NA	NA
	Jackson	1,036,910	123,645	0	0	NA	NA
	Jefferson	497,637	3,277	0	0	NA	NA
	Lake	245,587	3,917	0	0	NA	NA
	Las Animas	3,054,574	24,020	0	0	NA	NA
	Mineral	561,724	183	0	0	NA	NA
	Ouray	347,239	18,349	0	0	NA	NA
	Park	1,413,863	17,998	0	0	NA	NA
	Pitkin	622,701	9,650	0	0	NA	NA
	San Juan	248,658	NR	0	0	NA	NA
	San Miguel	825,813	12,341	0	0	NA	NA
	Summit	396,094	10,939	0	0	NA	NA
	Teller	357,449	1,646	0	0	NA	NA
	Total	67,117,819	3,433,124	1,255,155	10,175		

***Acreage identified by Ag. Census**

Table 2. Descriptive statistics for statewide center pivots in Colorado

	Center Pivot Characteristics
	--- acres ----
Mean Center Pivot Size	123
Median Center Pivot Size	122
Most Common Center Pivot Size	120
Standard Deviation	52
Minimum Center Pivot size	5
Maximum Center Pivot size	539
Total Center Pivot Acreage	1,255,154
Count	10,175

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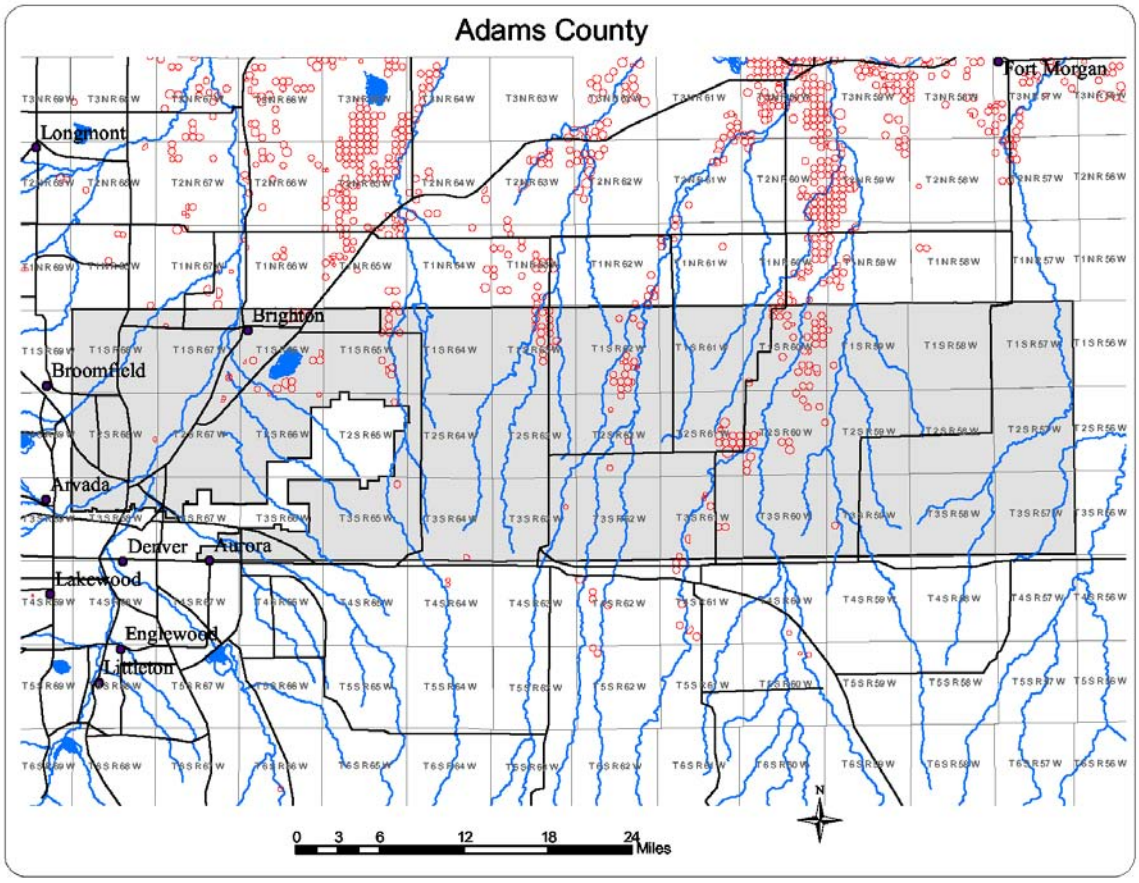

Figure 8. Center pivot irrigation in Adams County.

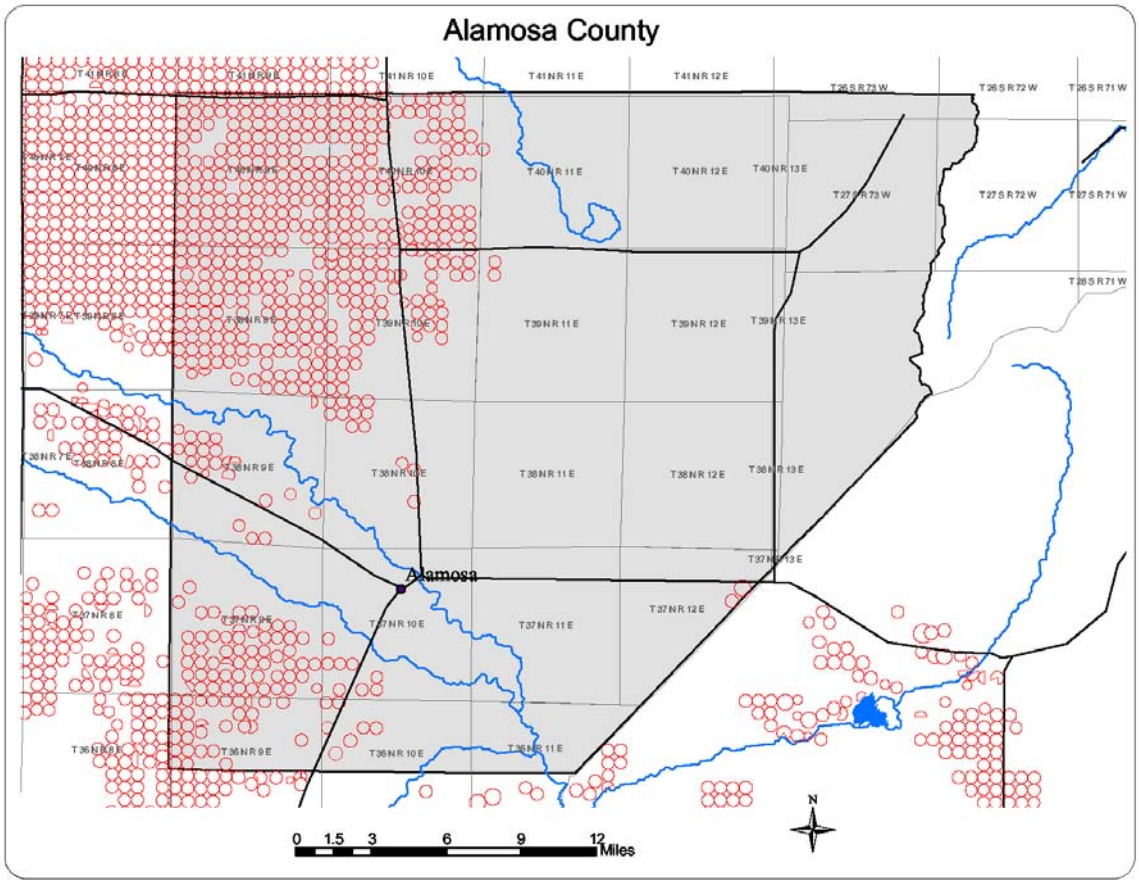

Figure 9. Center pivot irrigation in Alamosa County.

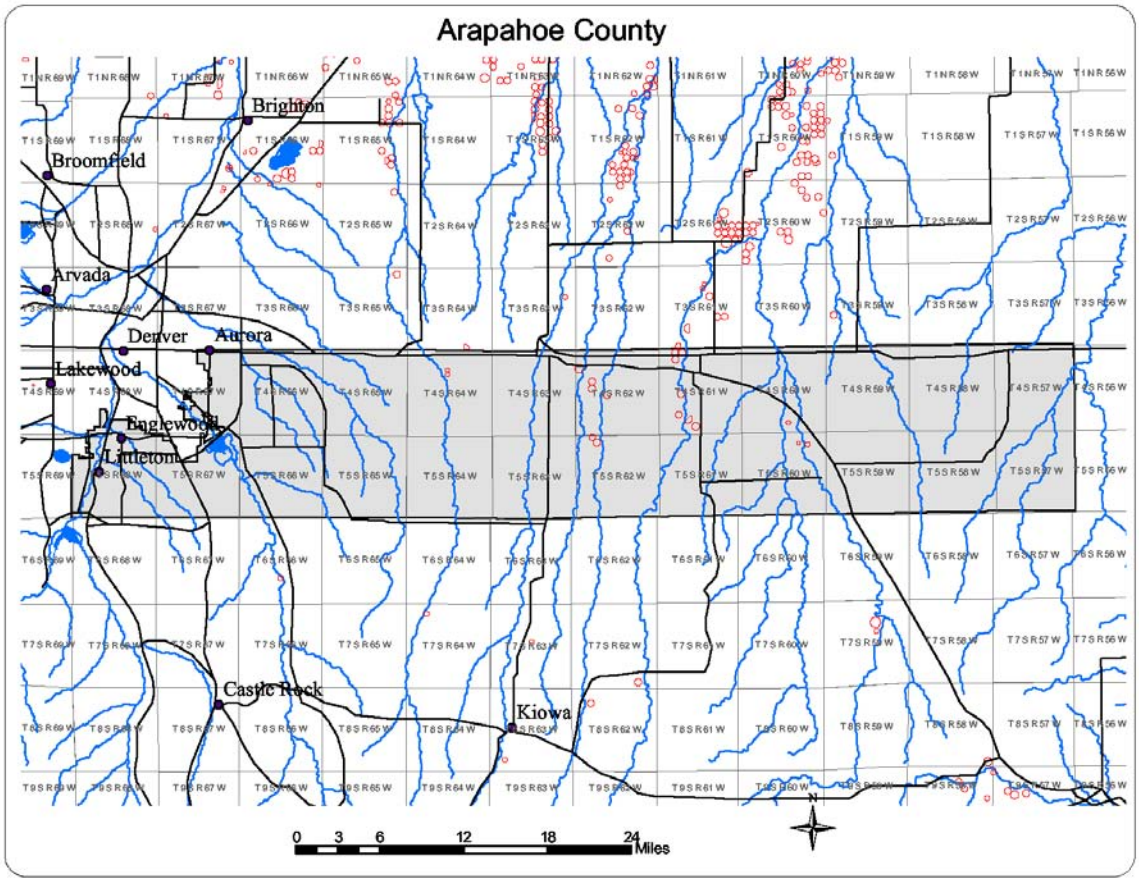

Figure 10. Center pivot irrigation in Arapahoe County.

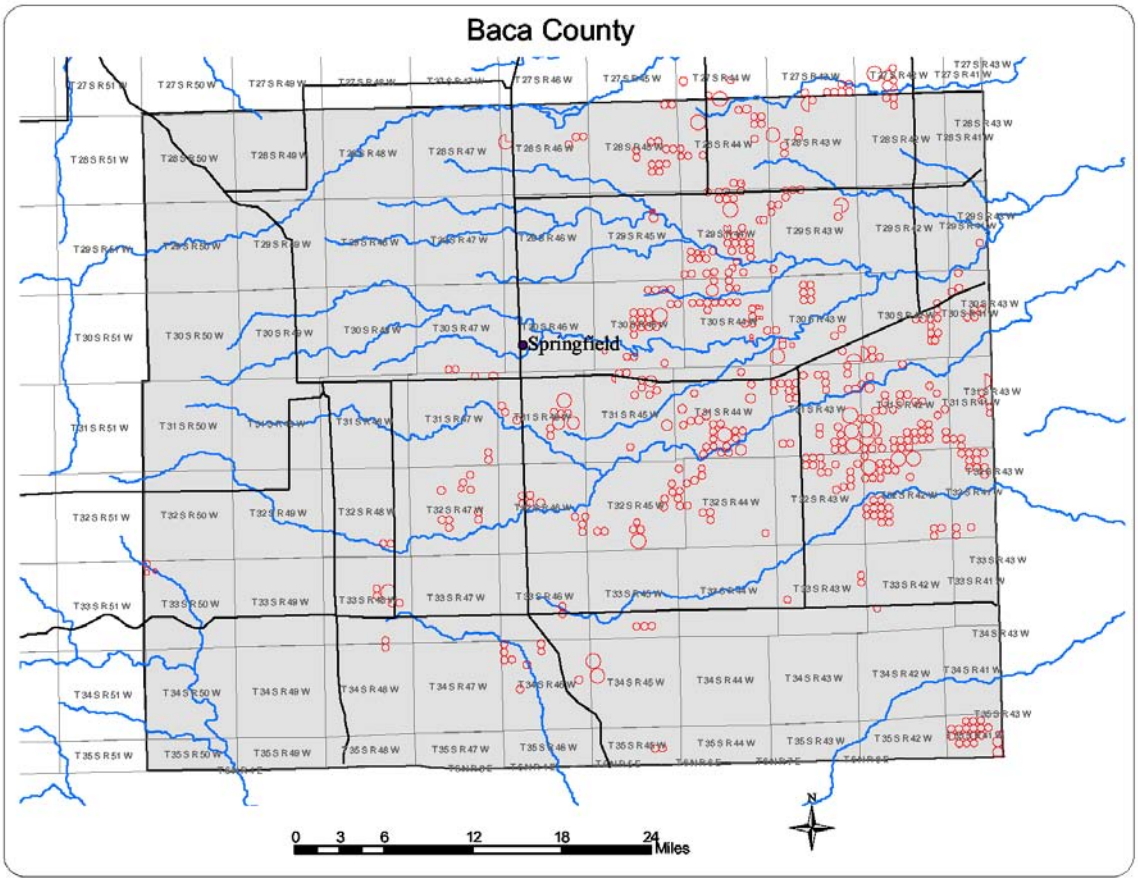

Figure 11. Center pivot irrigation in Baca County.

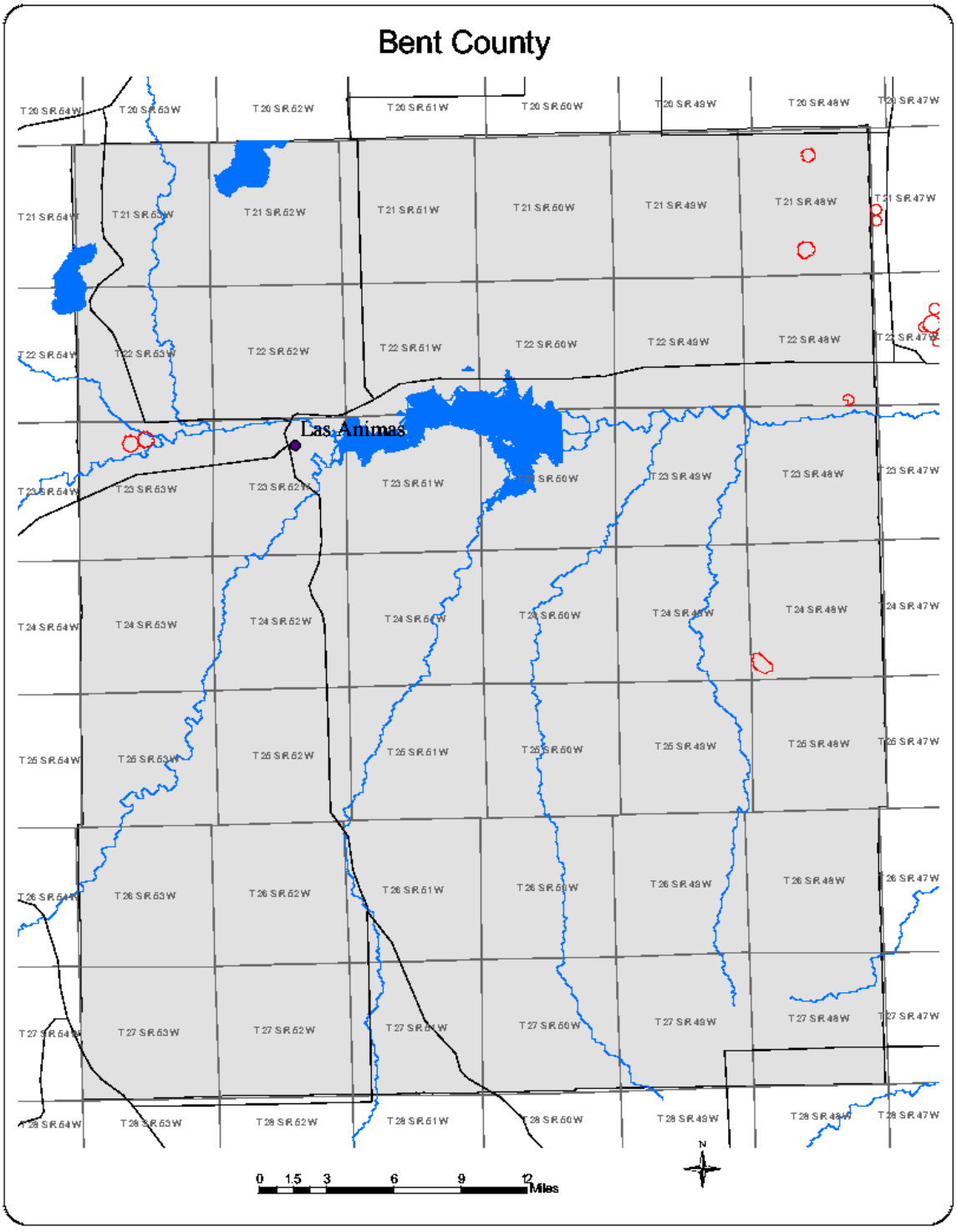

Figure 12. Center pivot irrigation in Bent County.

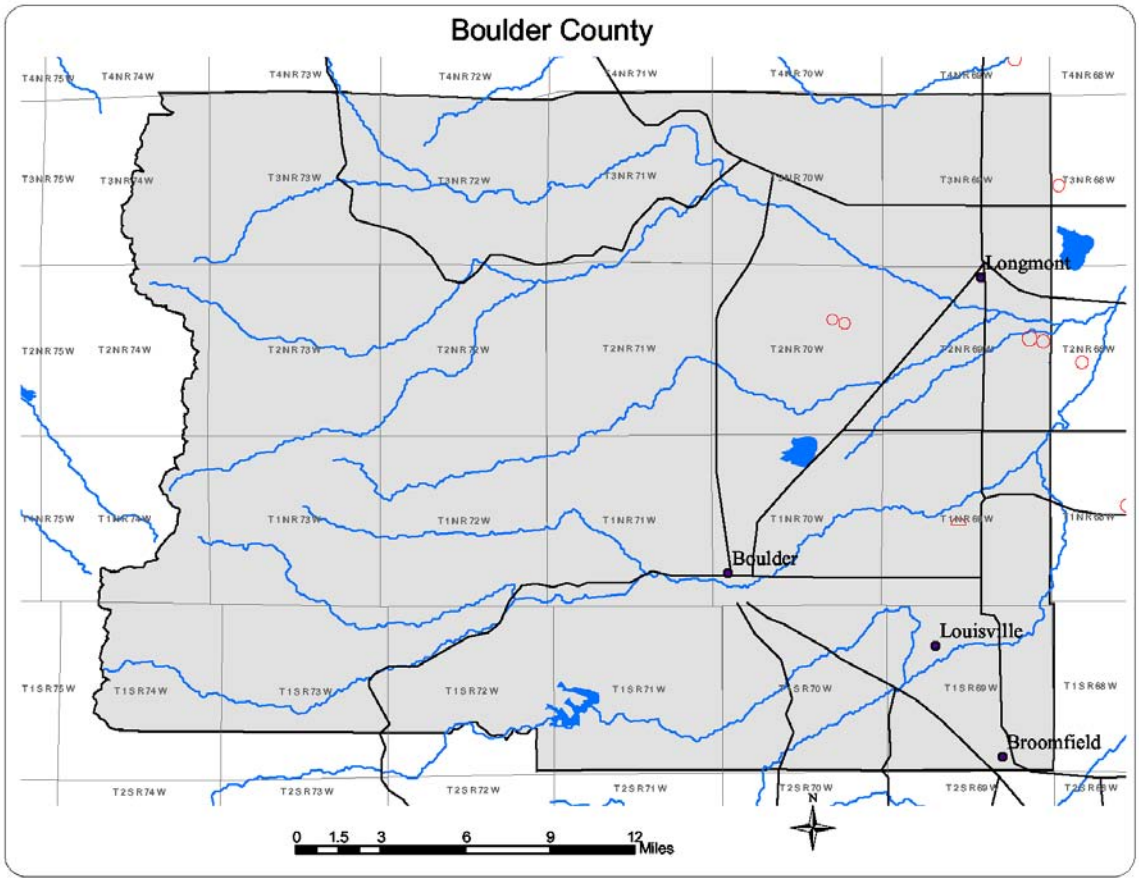

Figure 13. Center pivot irrigation in Boulder County.

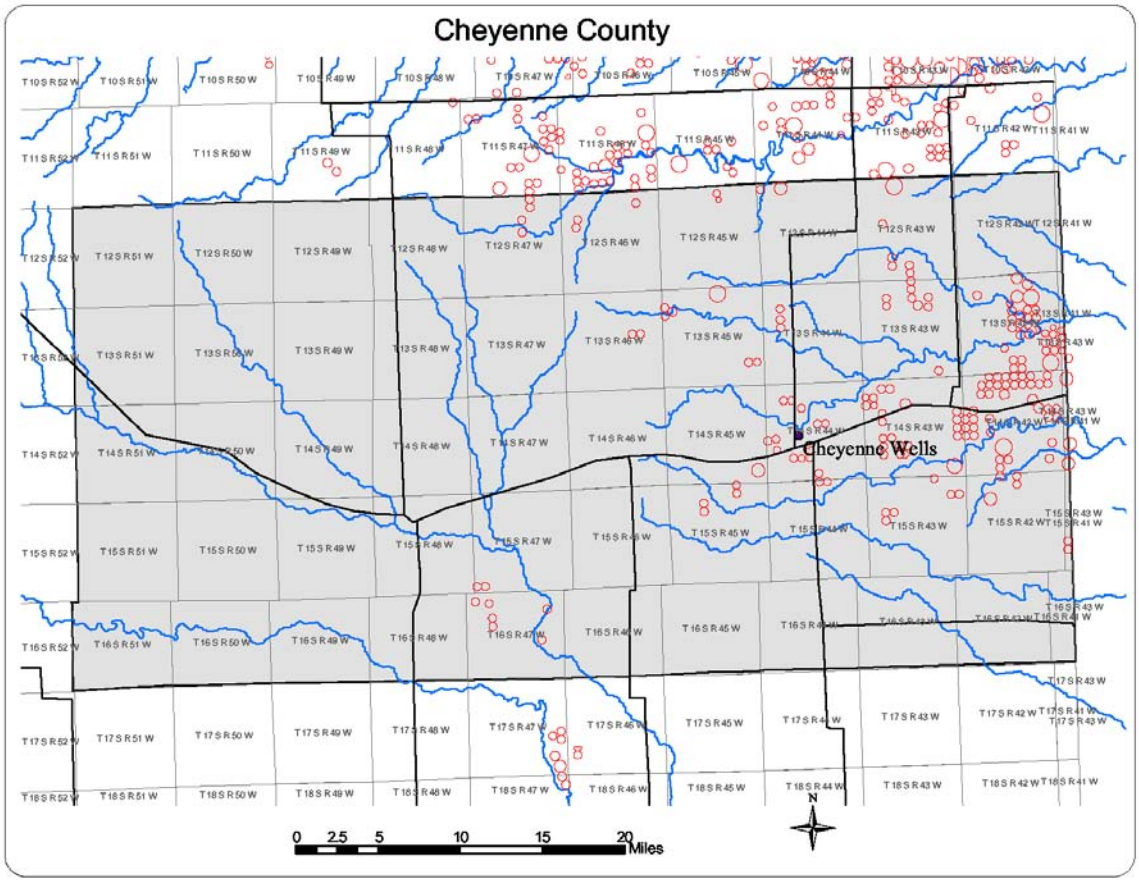

Figure 14. Center pivot irrigation in Cheyenne County.

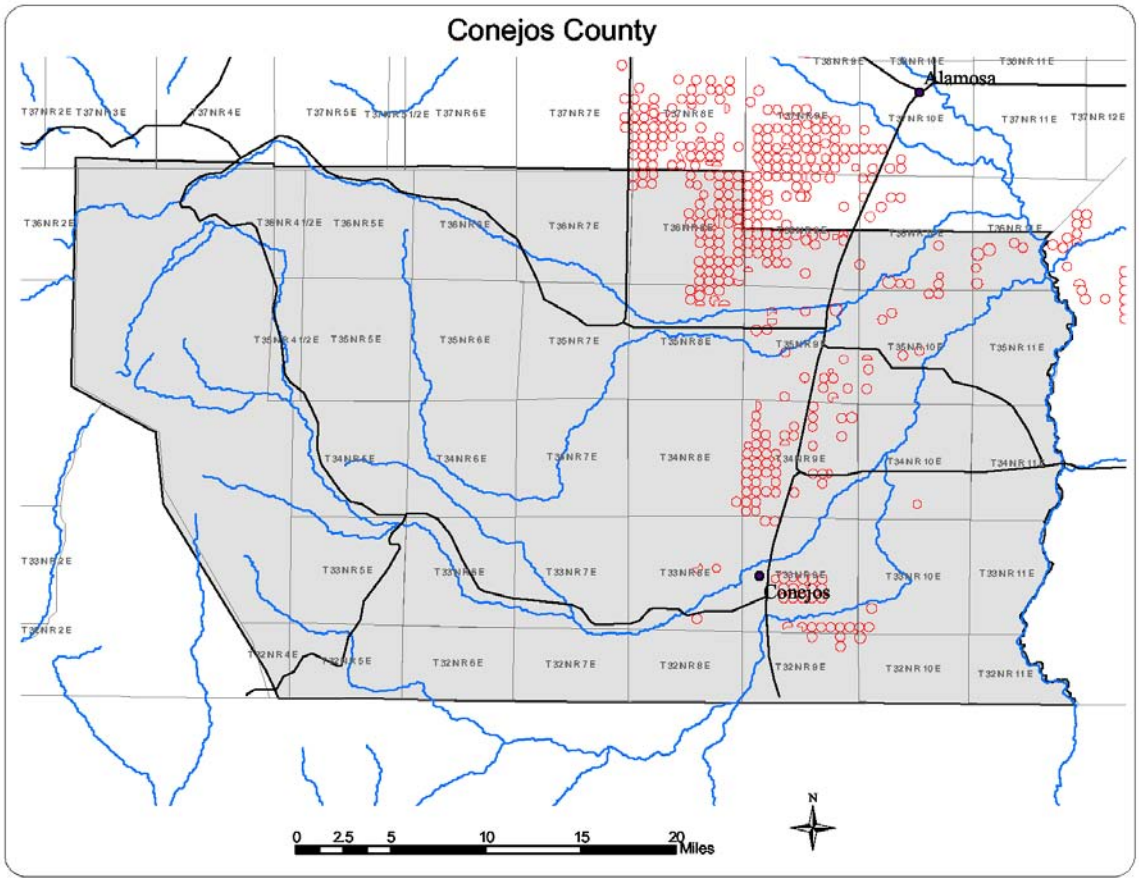

Figure 15. Center pivot irrigation in Conejos County.

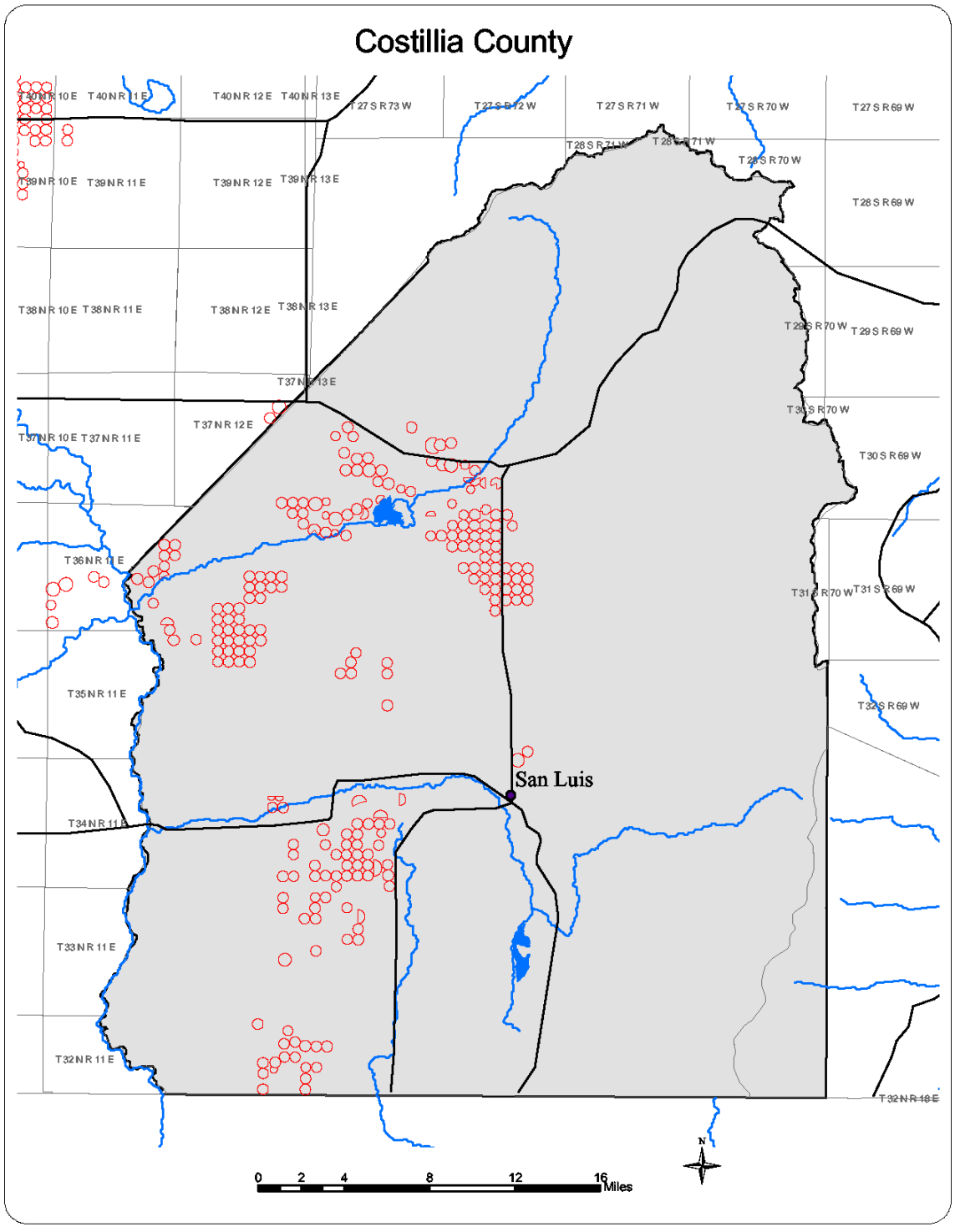

Figure 16. Center pivot irrigation in Costillia County.

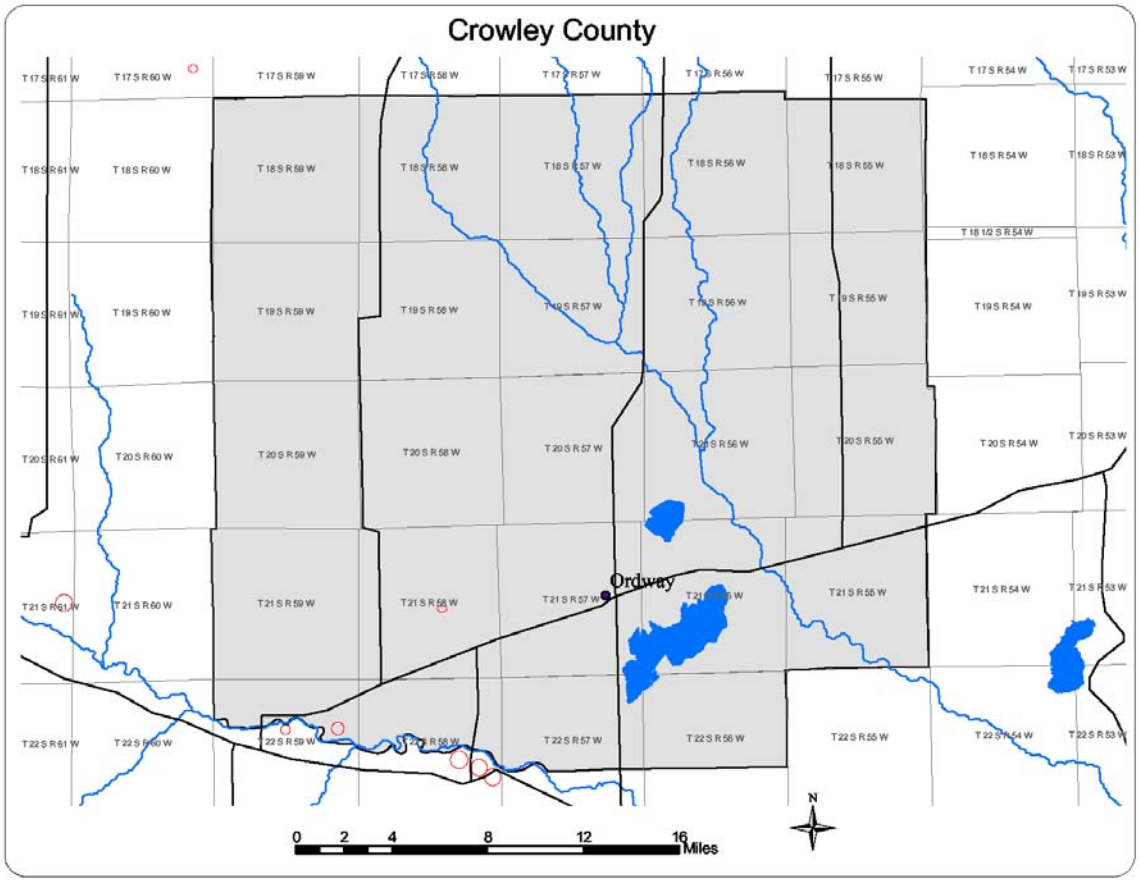

Figure 17. Center pivot irrigation in Crowley County.

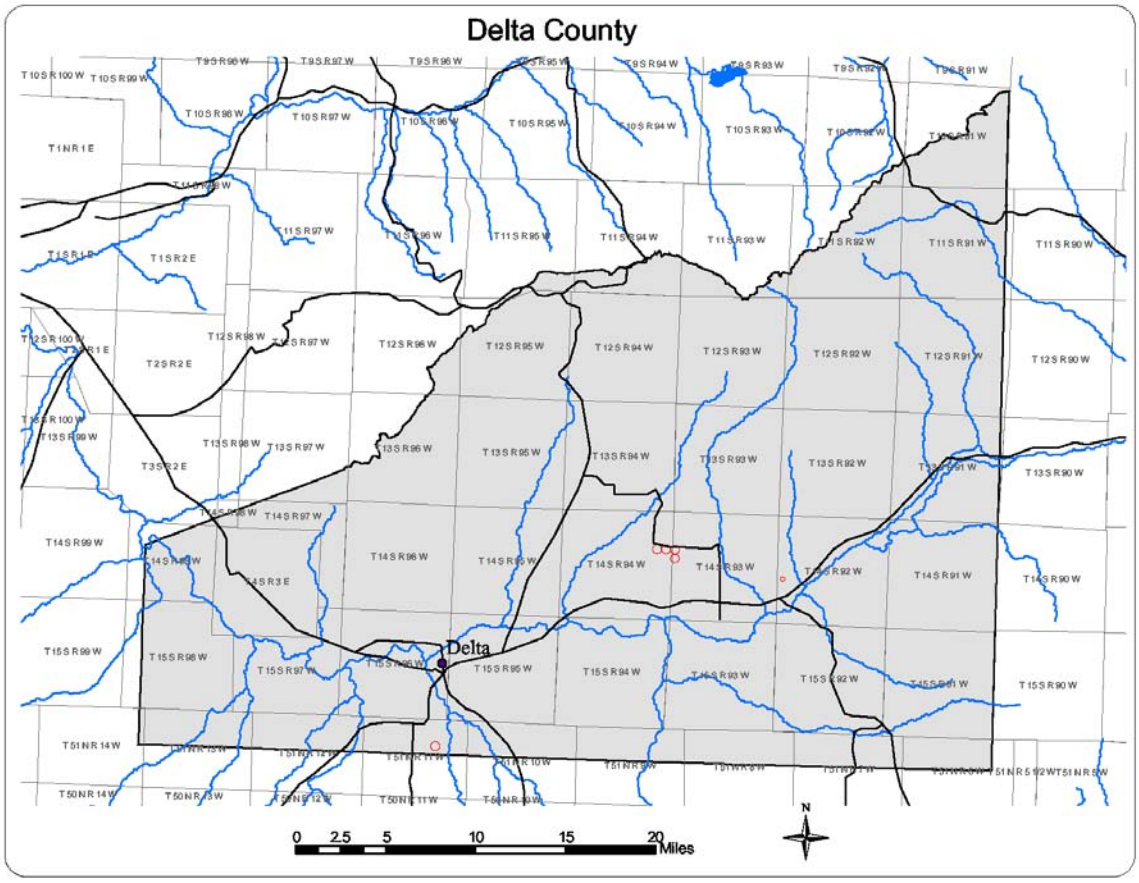

Figure 18. Center pivot irrigation in Delta County.

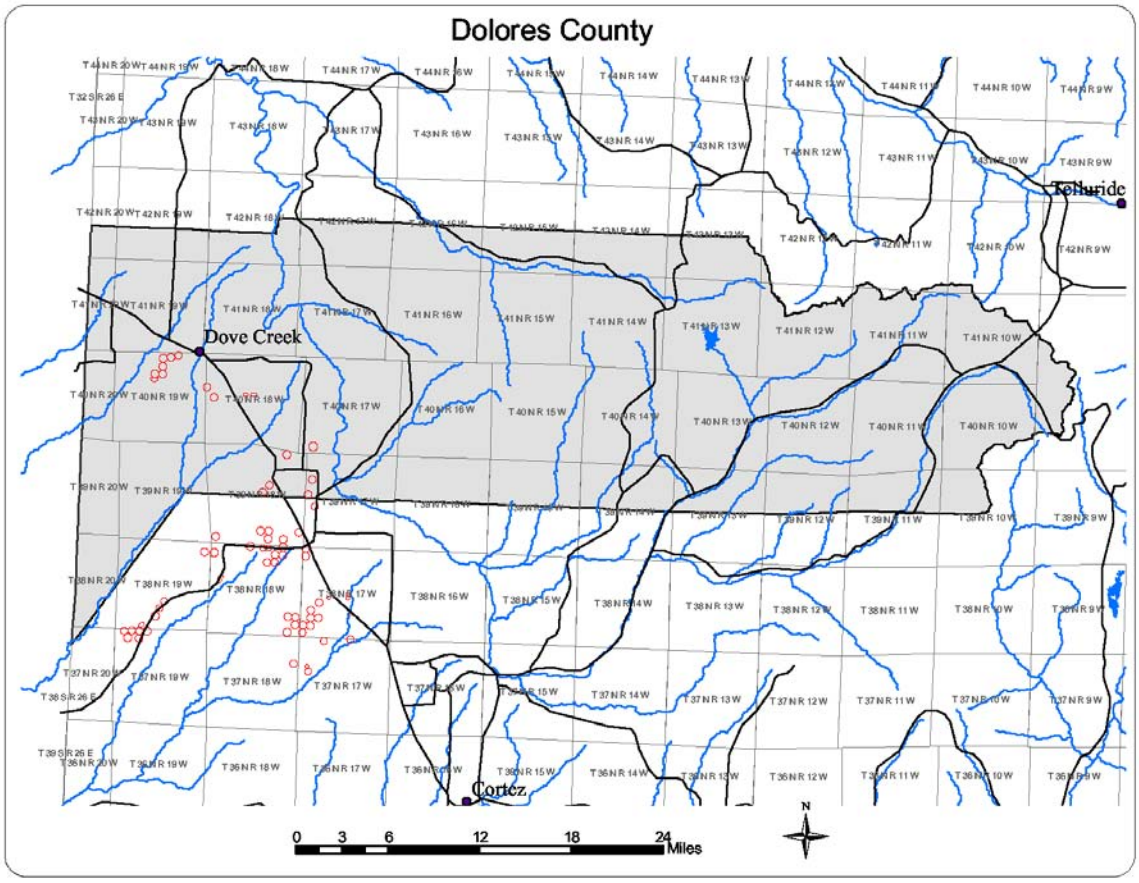

Figure 19. Center pivot irrigation in Dolores County.

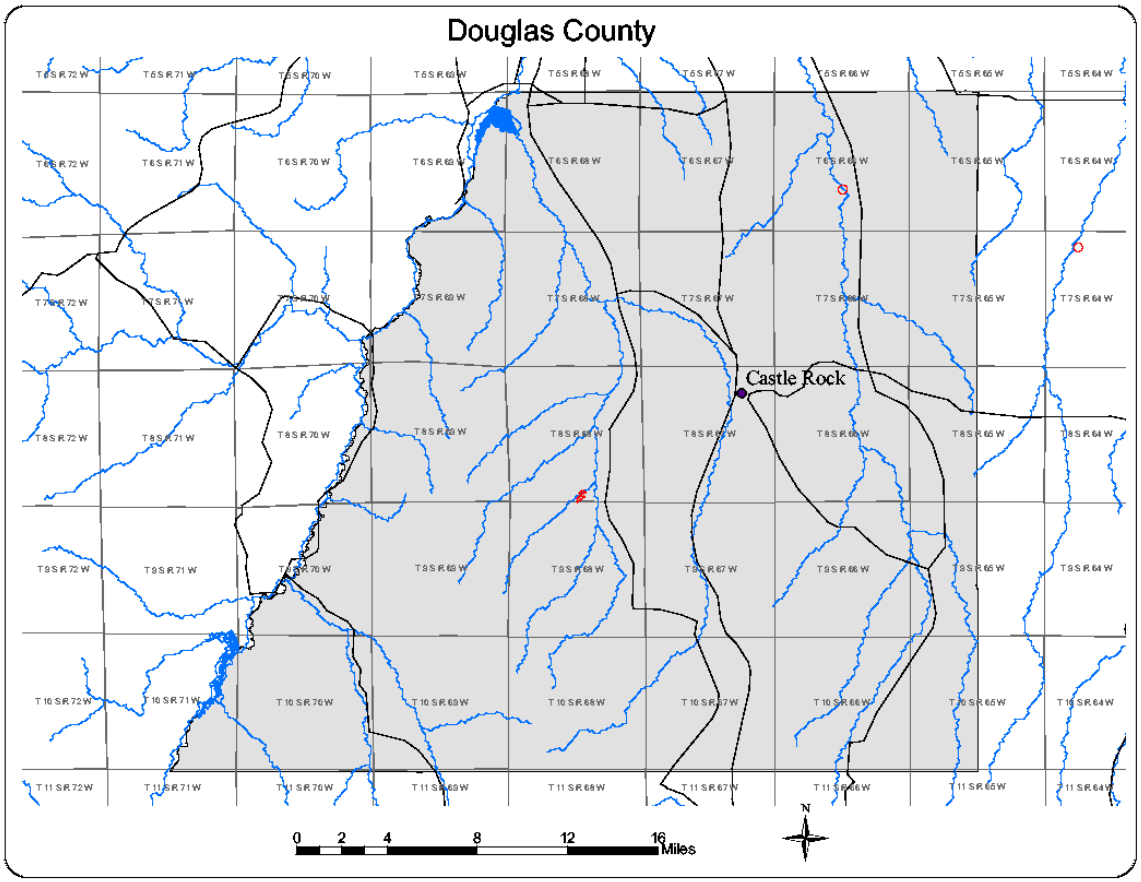

Figure 20. Center pivot irrigation in Douglas County.

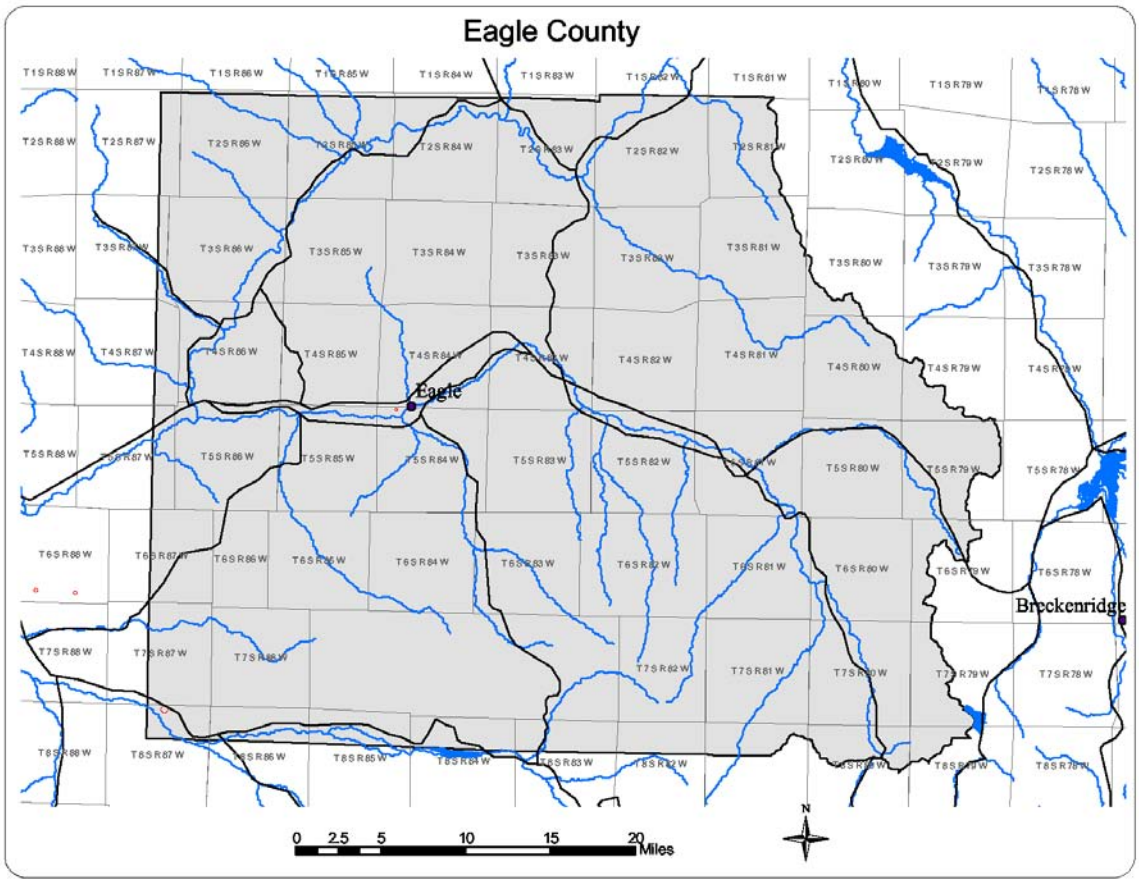

Figure 21. Center pivot irrigation in Eagle County.

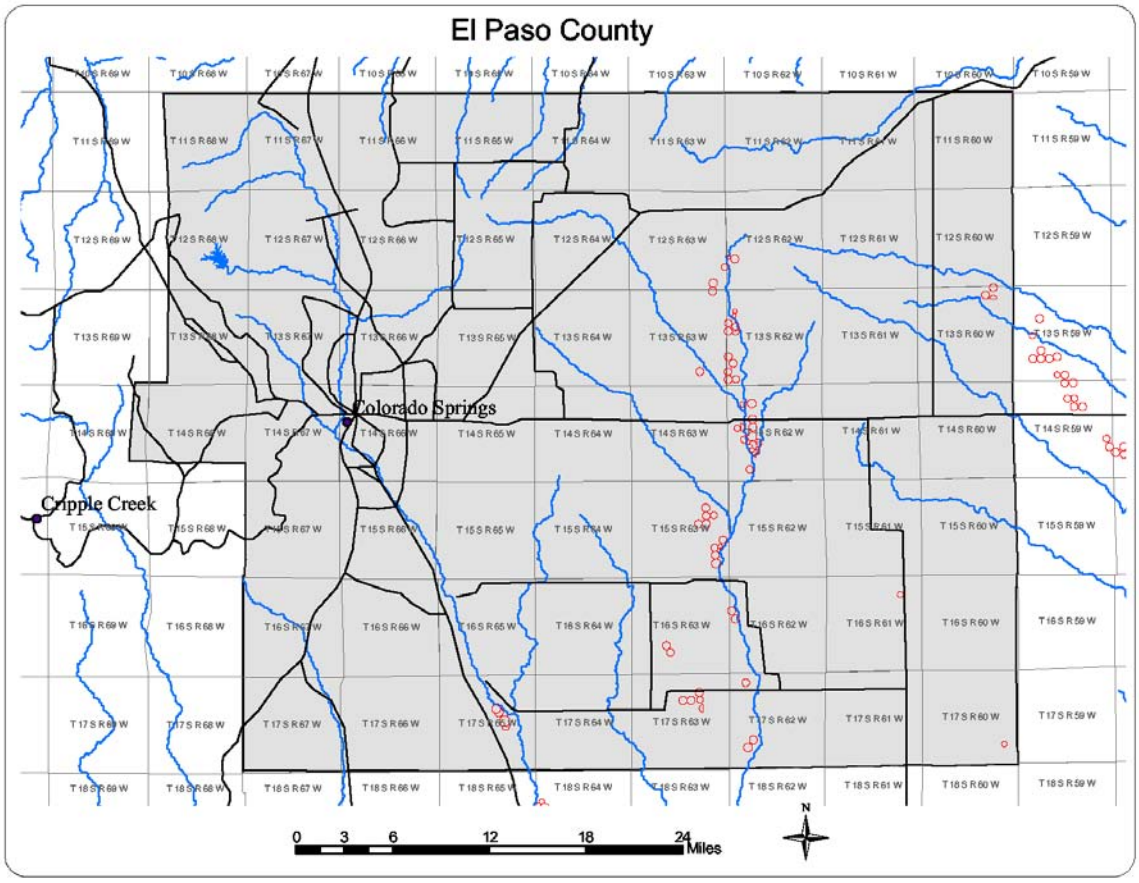

Figure 22. Center pivot irrigation in El Paso County.

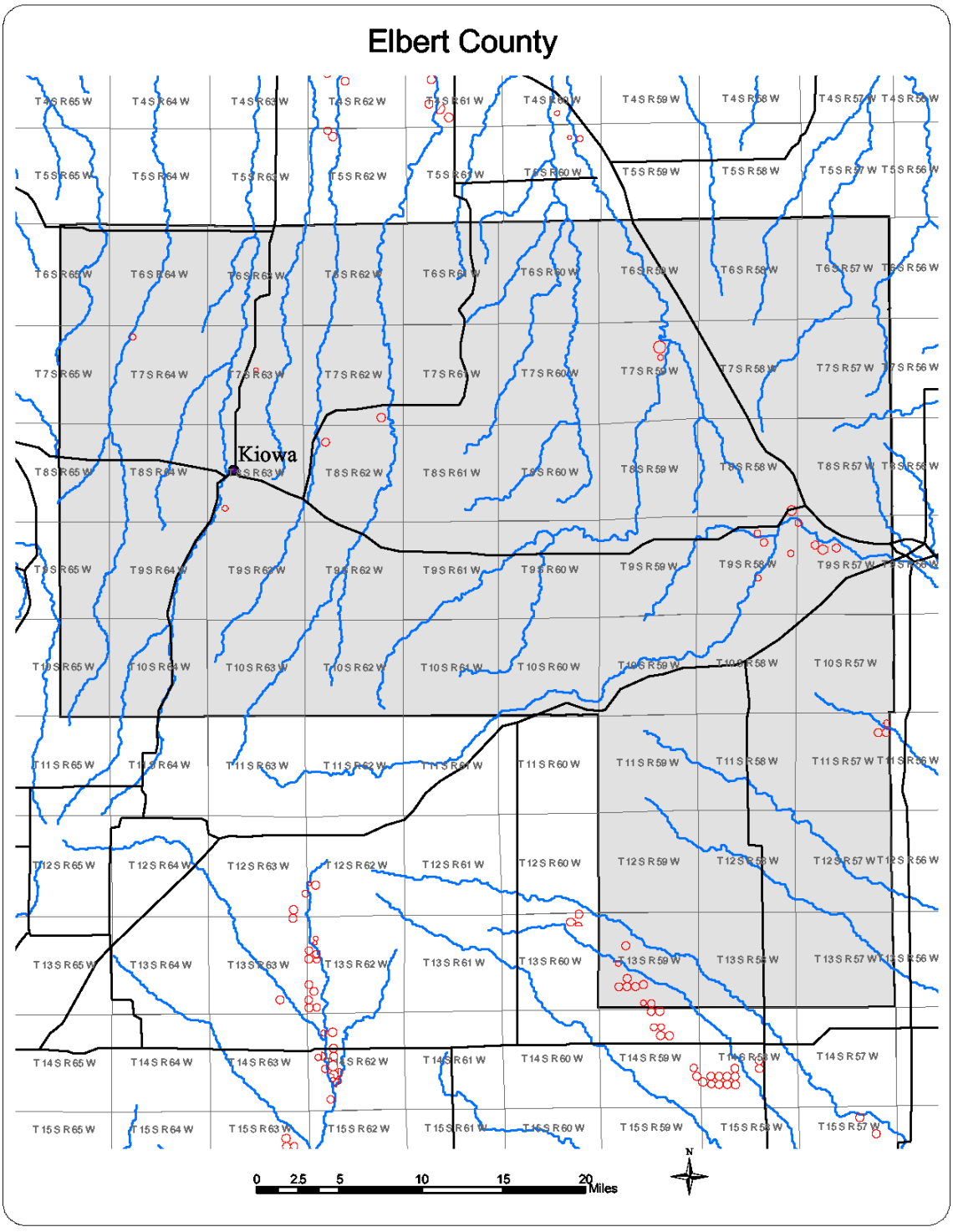

Figure 23. Center pivot irrigation in Elbert County.

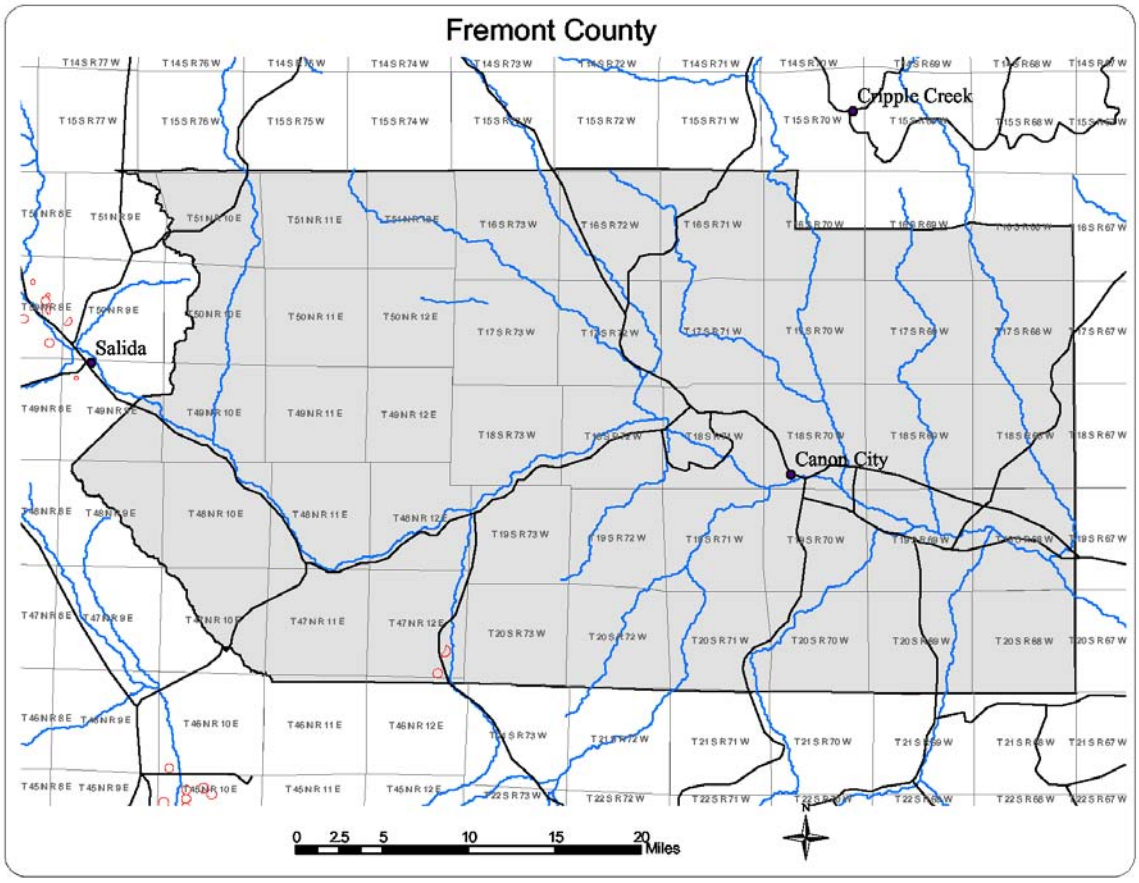

Figure 24. Center pivot irrigation in Fremont County.

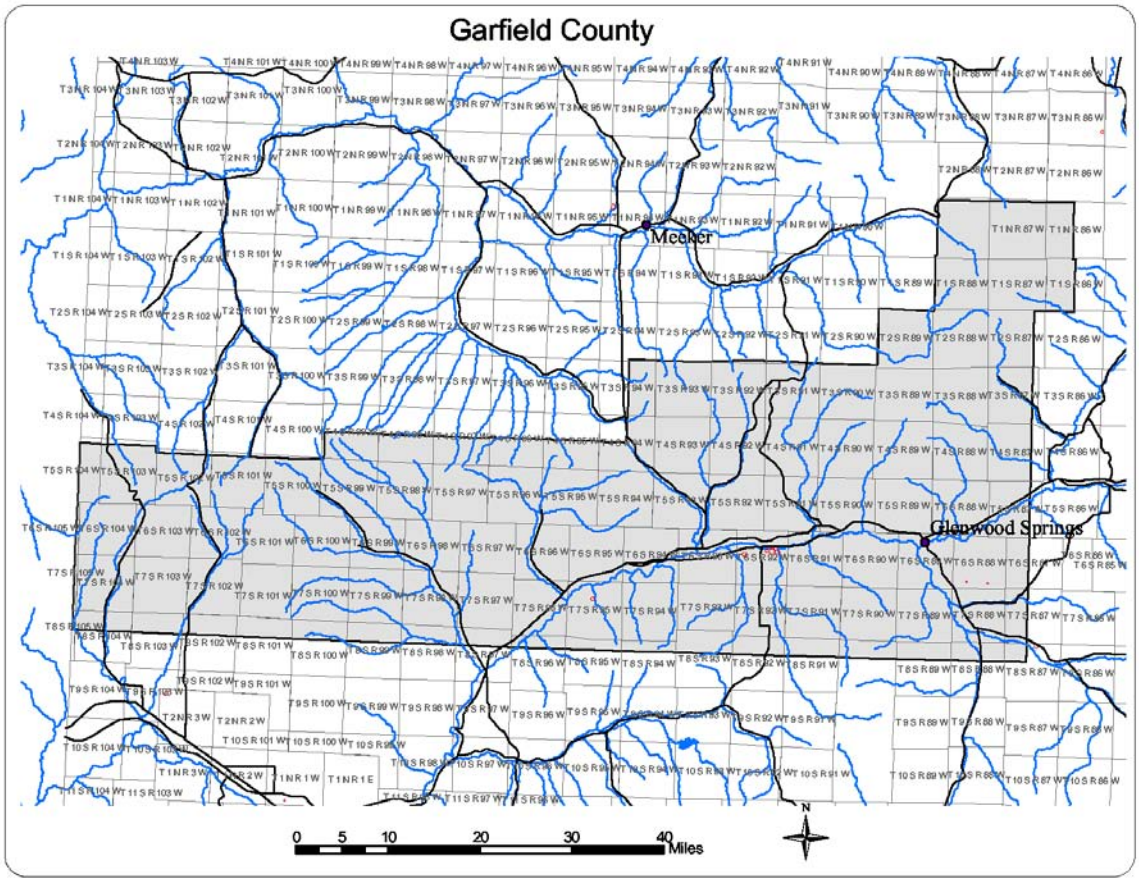

Figure 25. Center pivot irrigation in Garfield County.

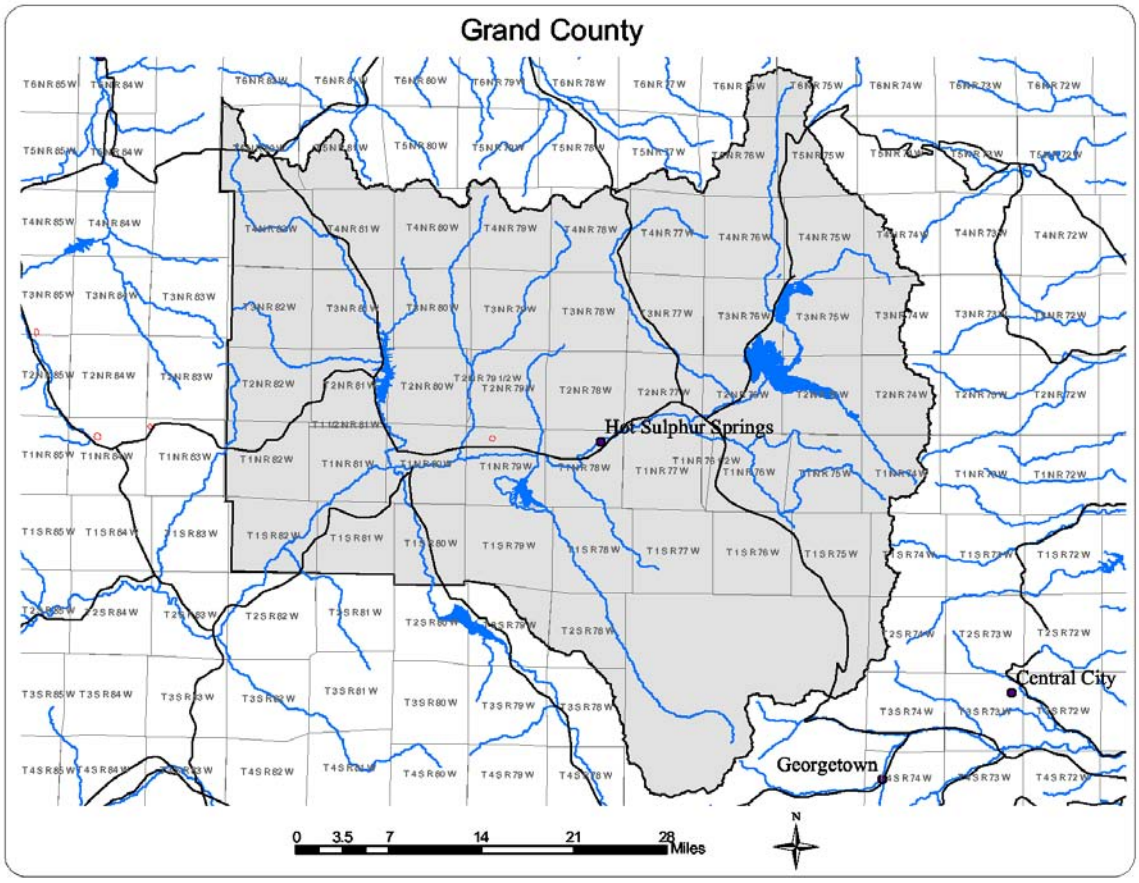

Figure 26. Center pivot irrigation in Grand County.

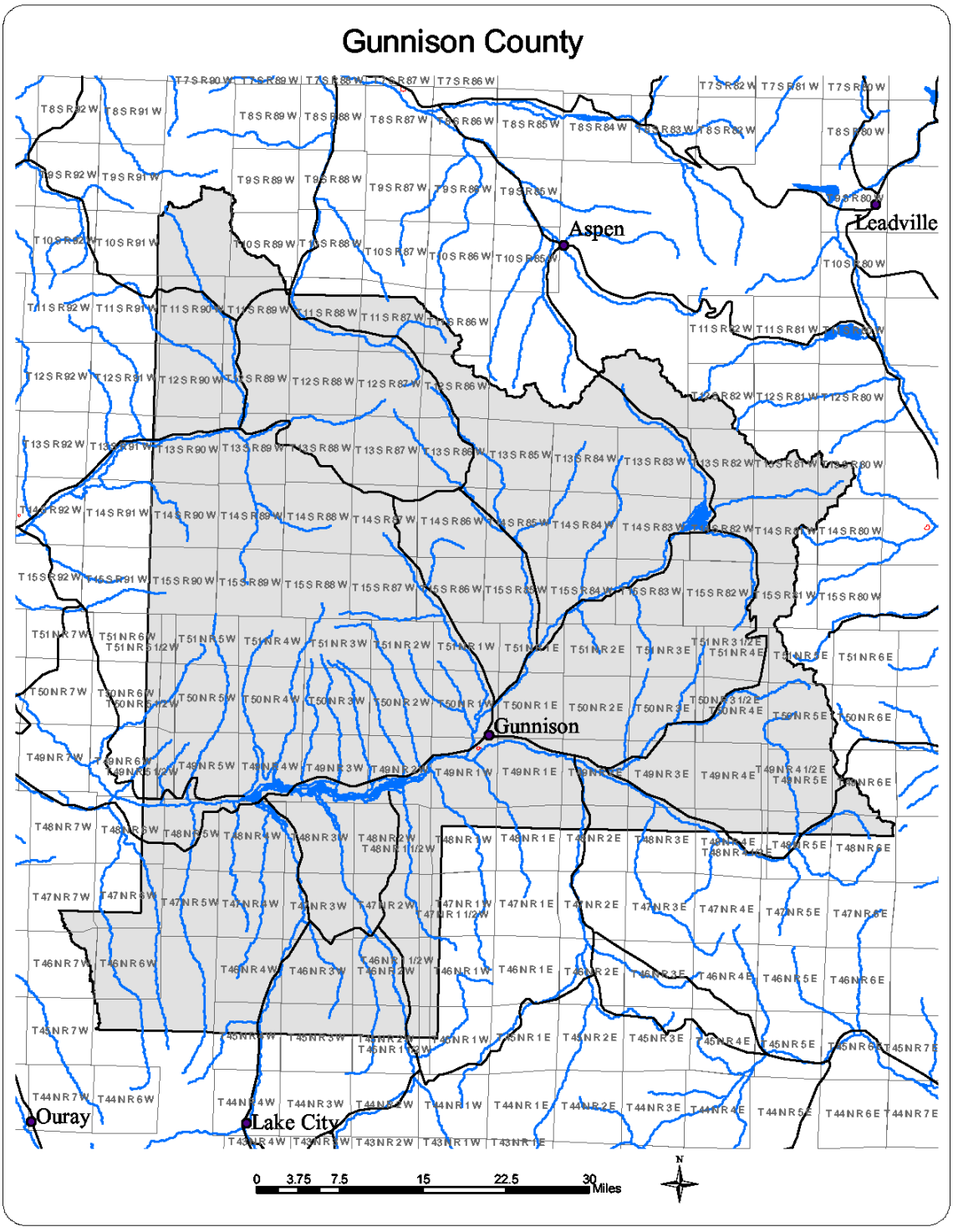

Figure 27. Center pivot irrigation in Gunnison County.

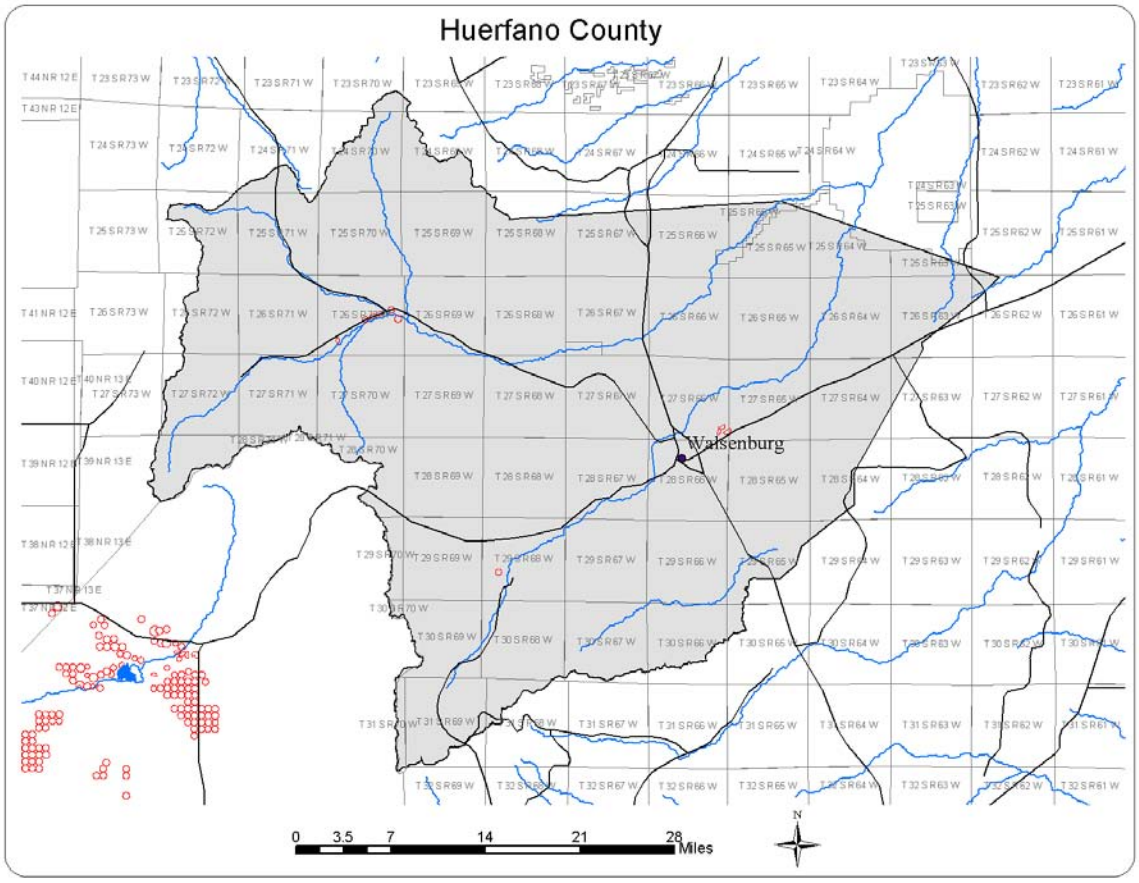

Figure 28. Center pivot irrigation in Huerfano County.

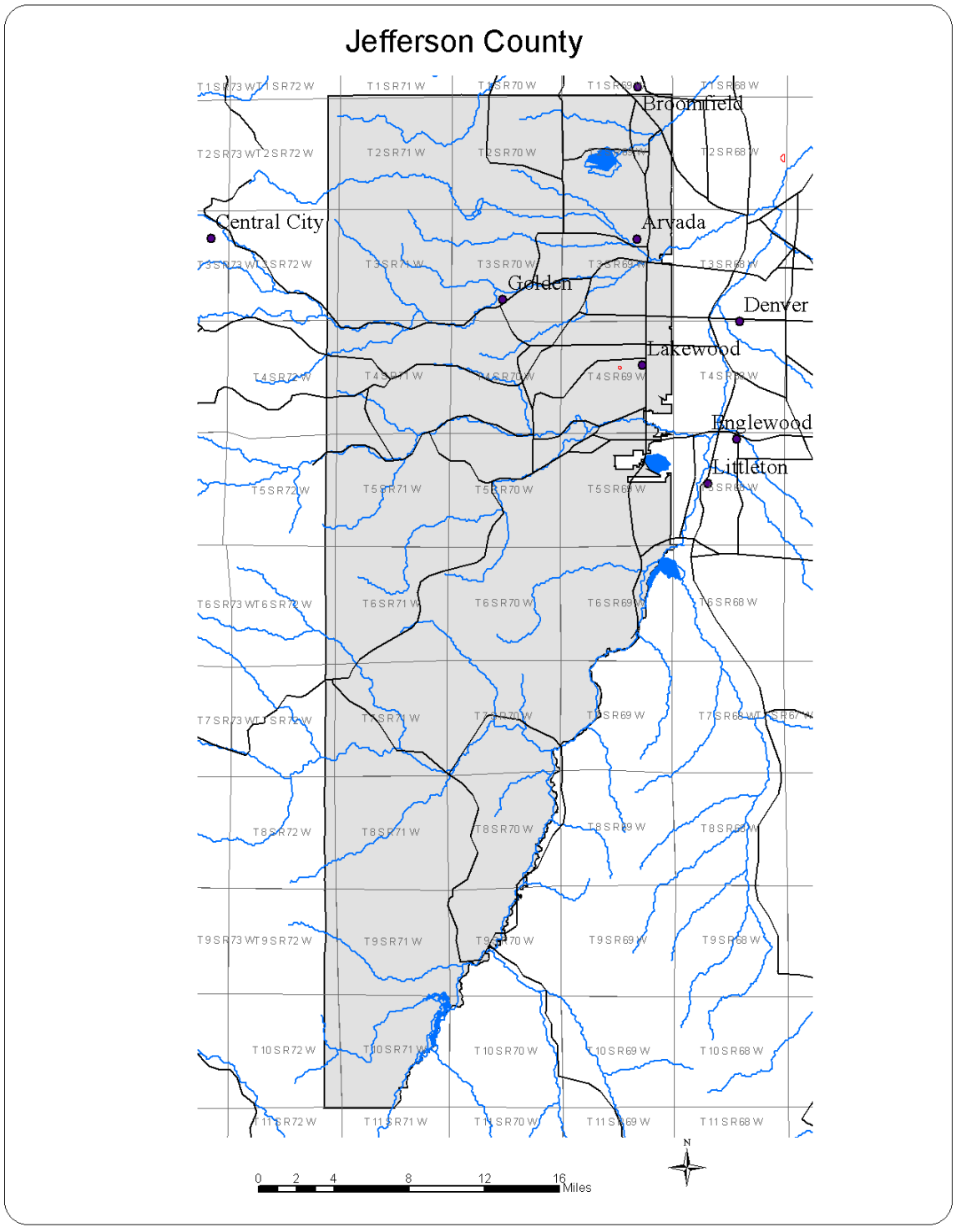

Figure 29. Center pivot irrigation in Jefferson County.

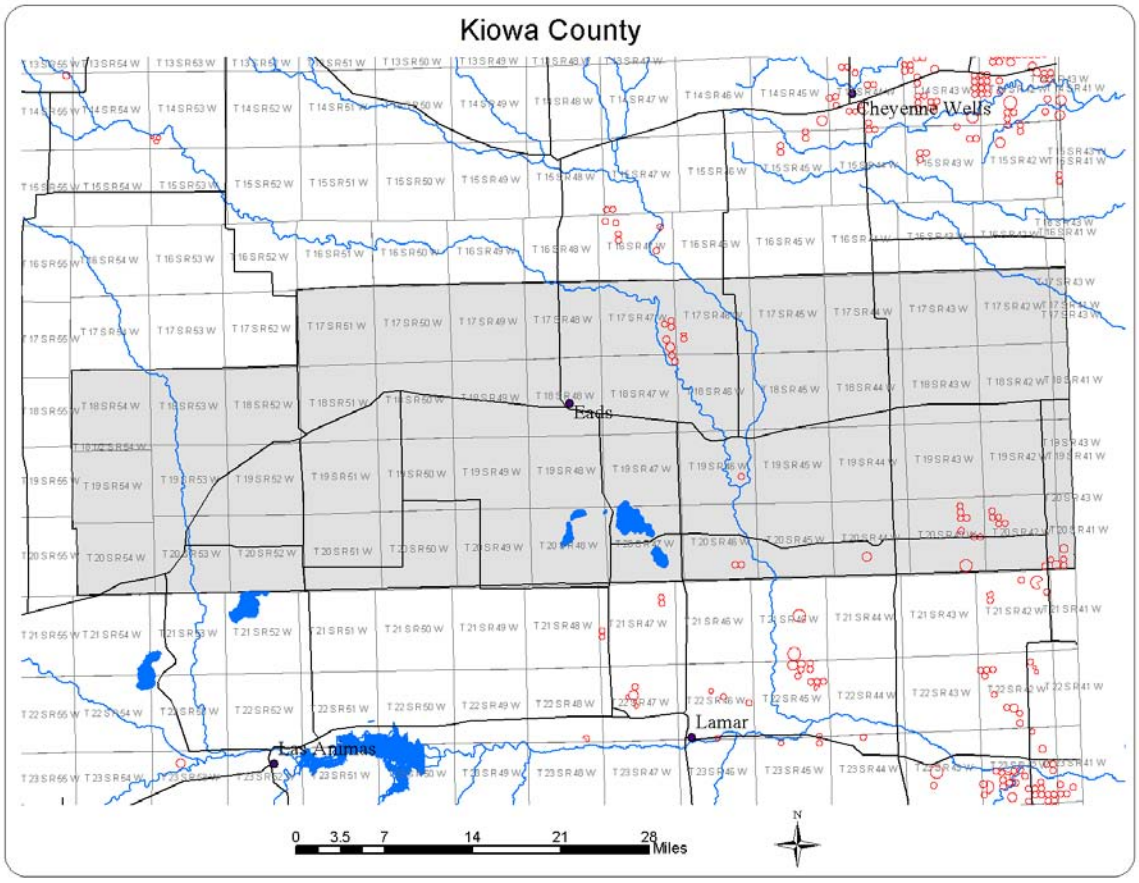

Figure 30. Center pivot irrigation in Kiowa County.

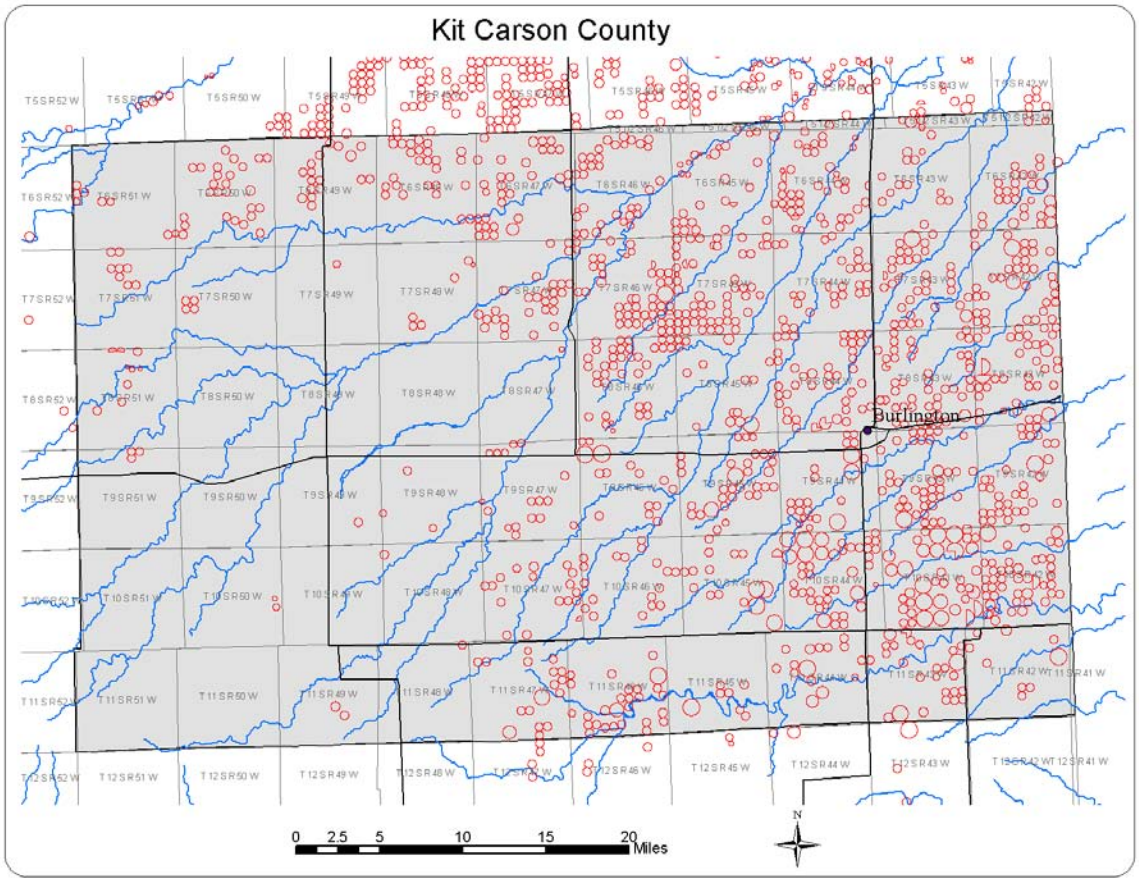

Figure 31. Center pivot irrigation in Kit Carson County.

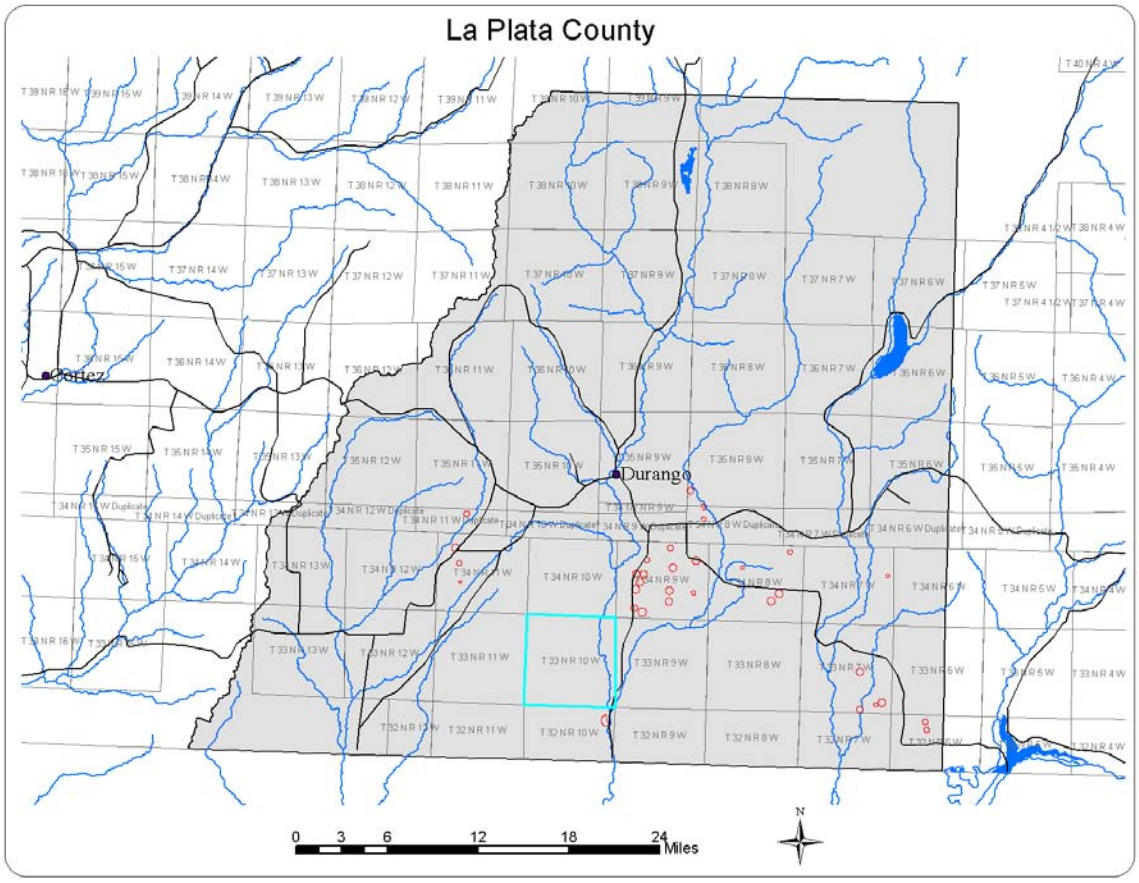

Figure 32. Center pivot irrigation in La Plata County.

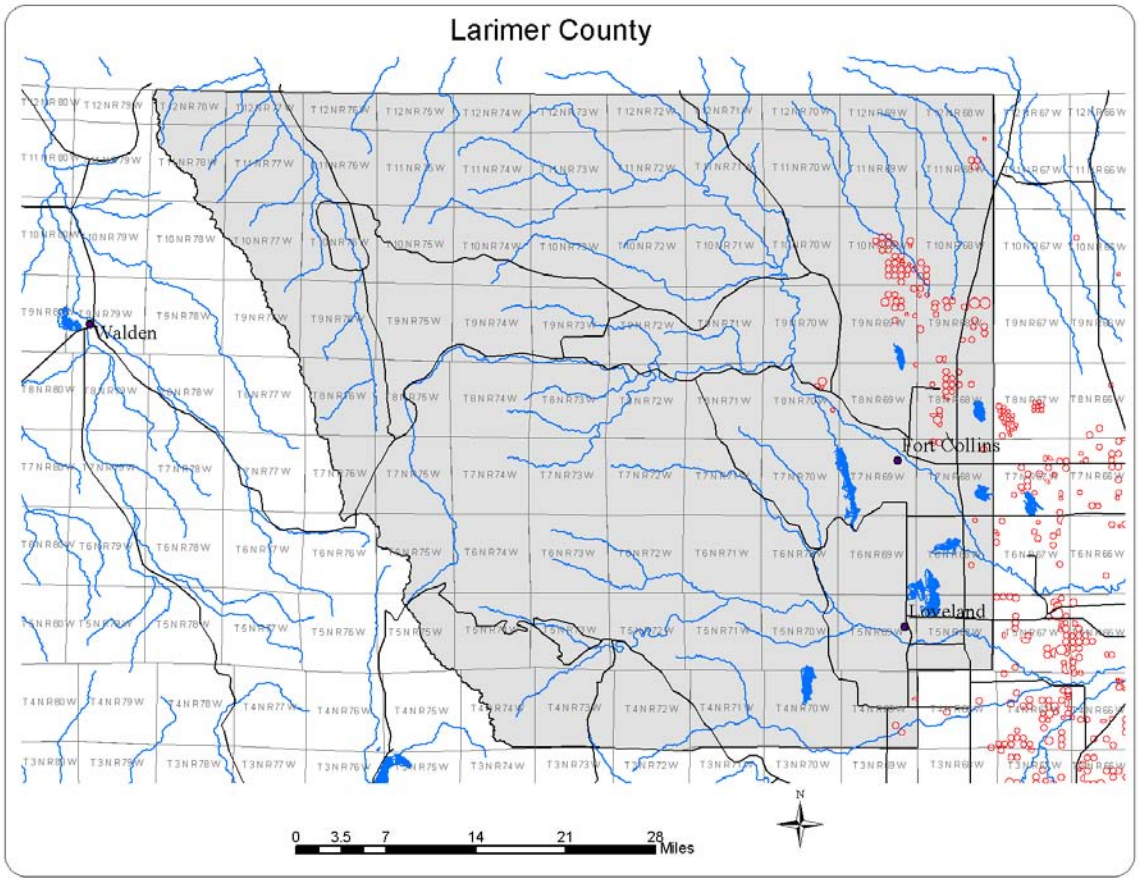

Figure 33. Center pivot irrigation in Larimer County.

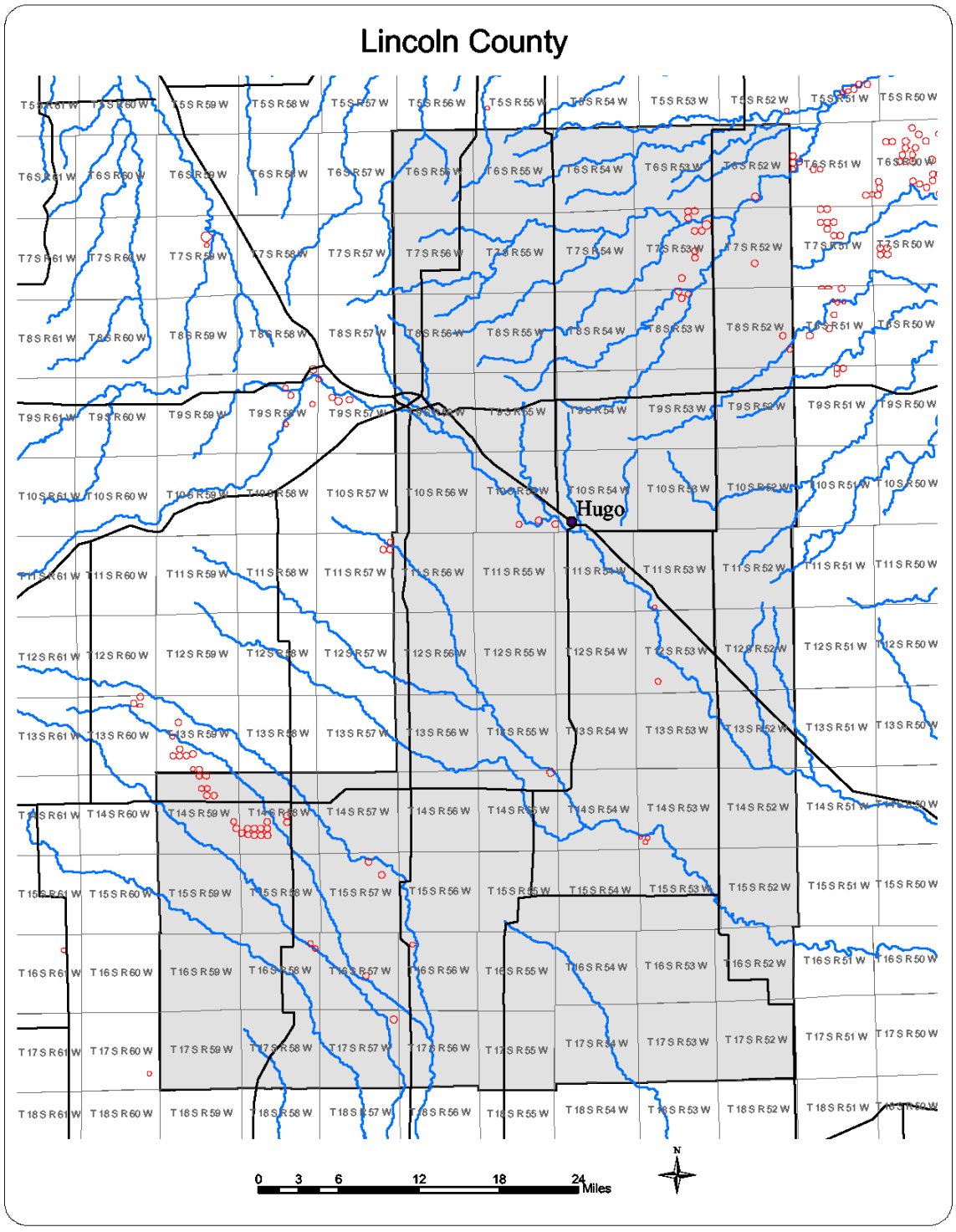

Figure 34. Center pivot irrigation in Lincoln County.

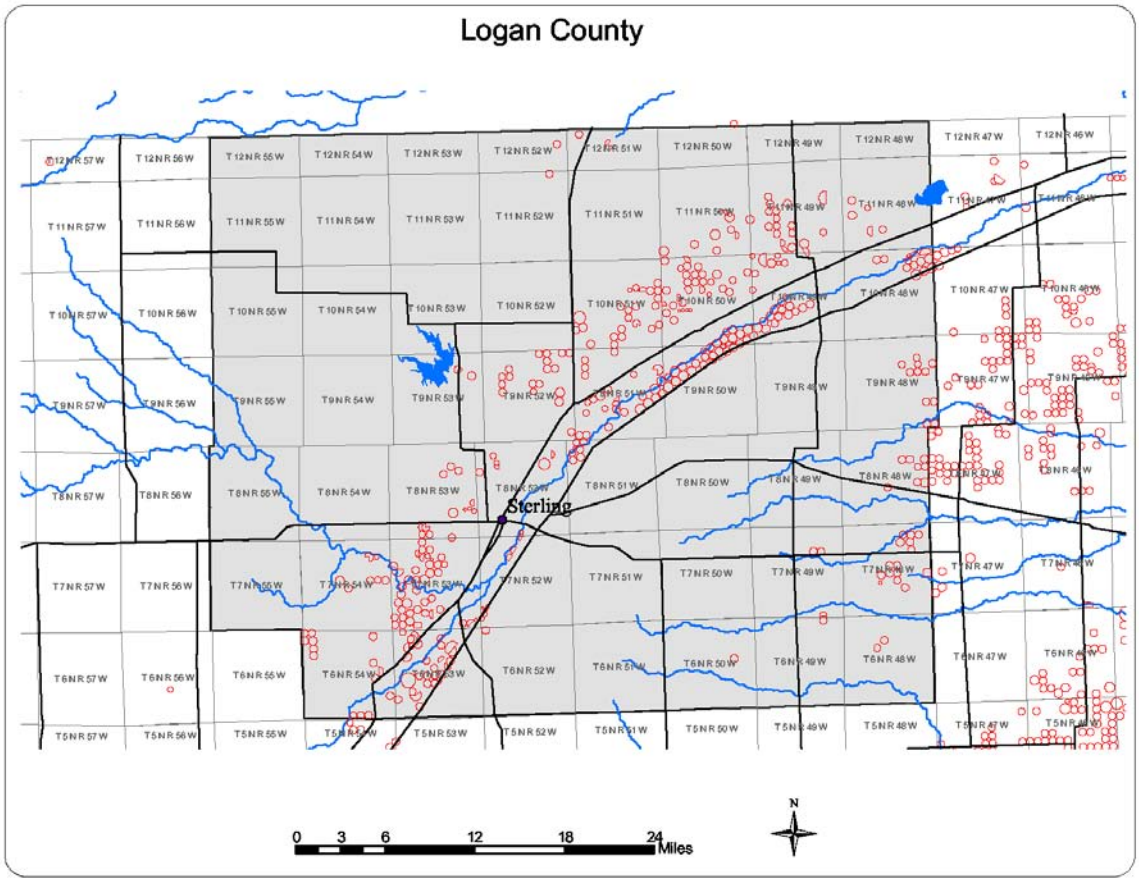

Figure 35. Center pivot irrigation in Logan County.

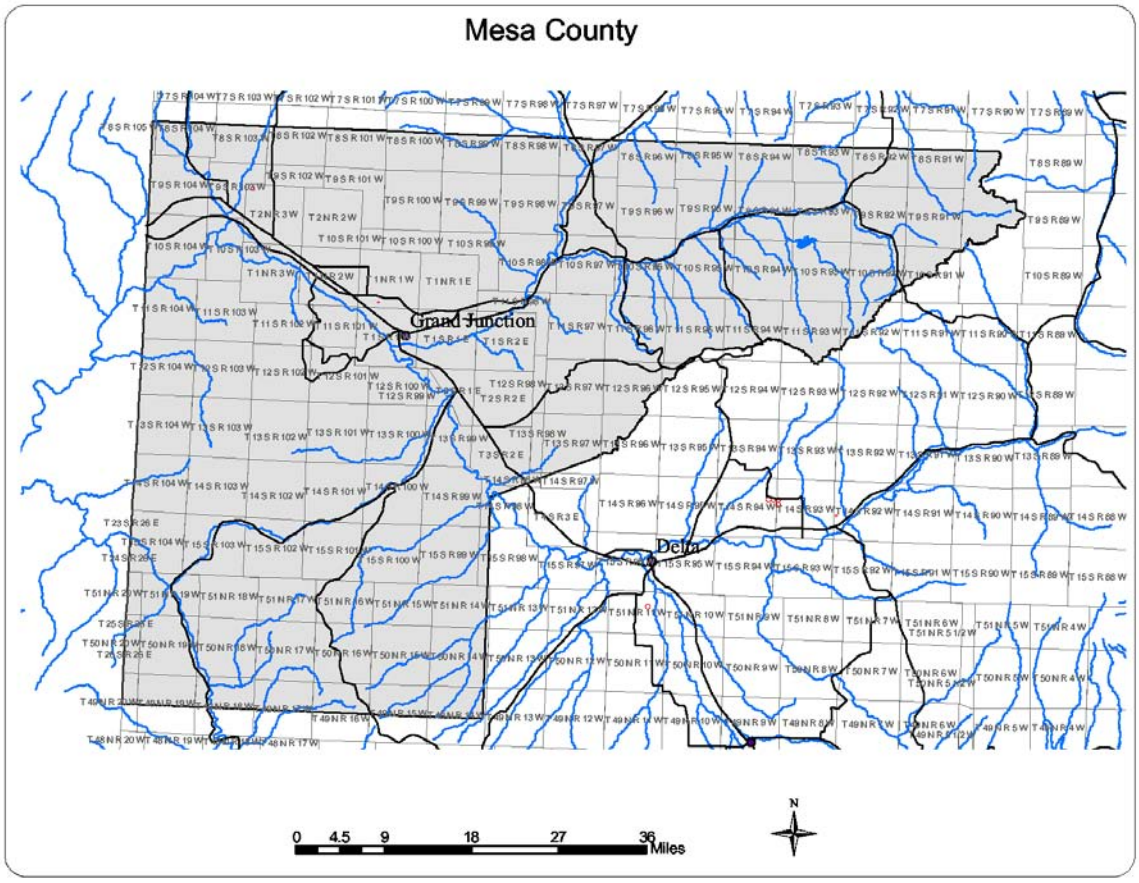

Figure 36. Center pivot irrigation in Mesa County.

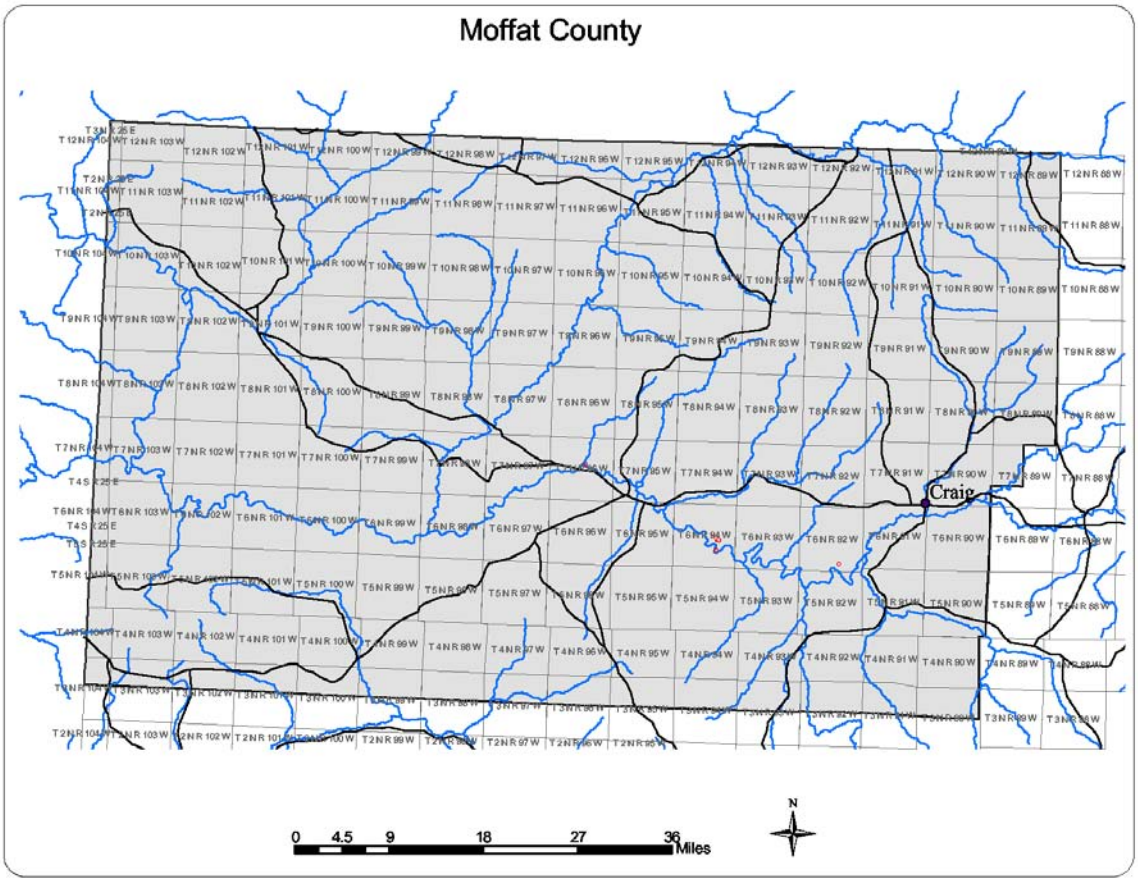

Figure 37. Center pivot irrigation in Moffat County.

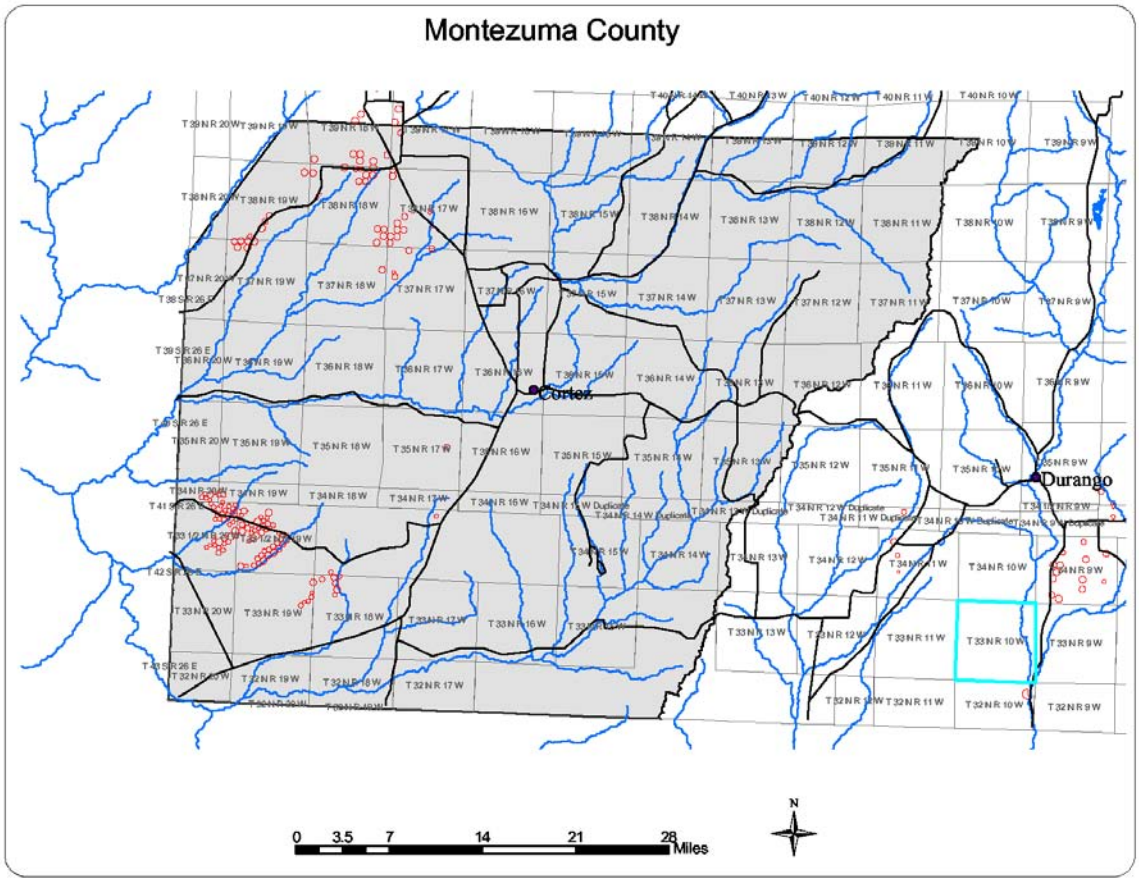

Figure 38. Center pivot irrigation in Montezuma County.

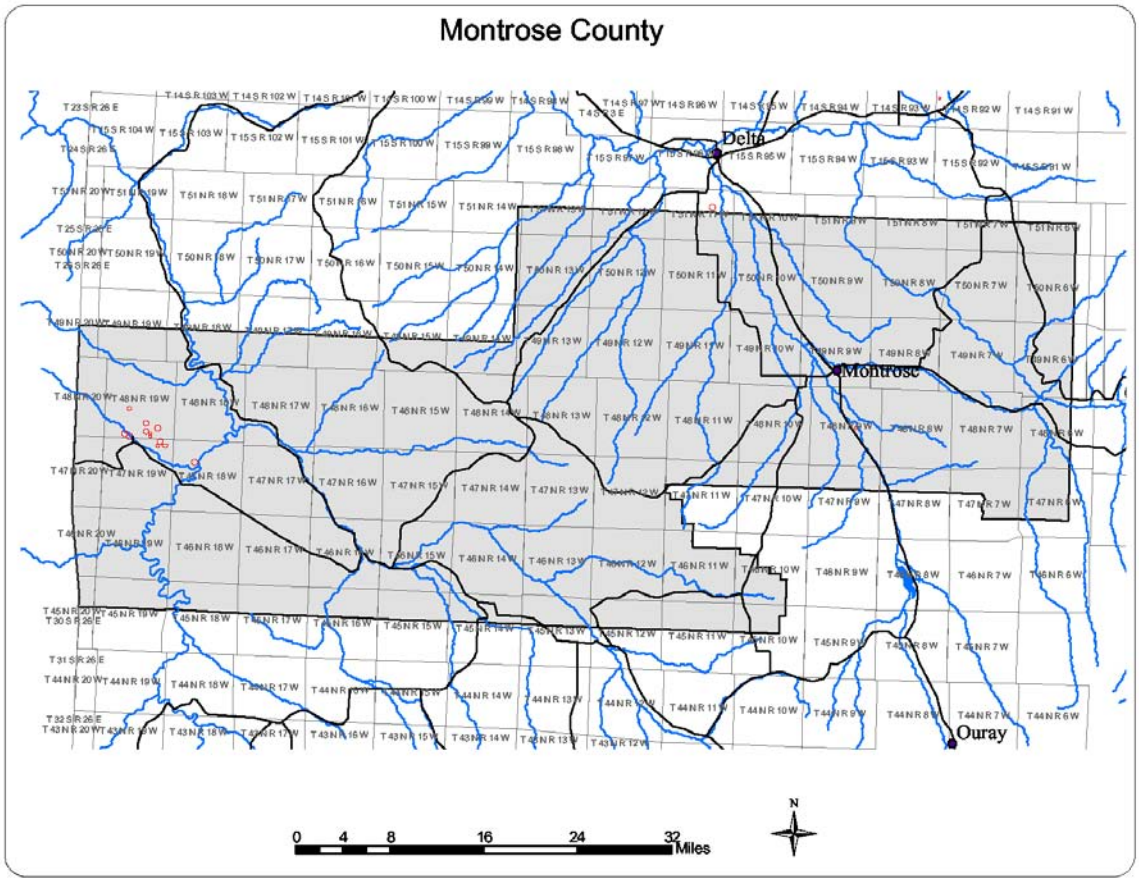

Figure 39. Center pivot irrigation in Montrose County.

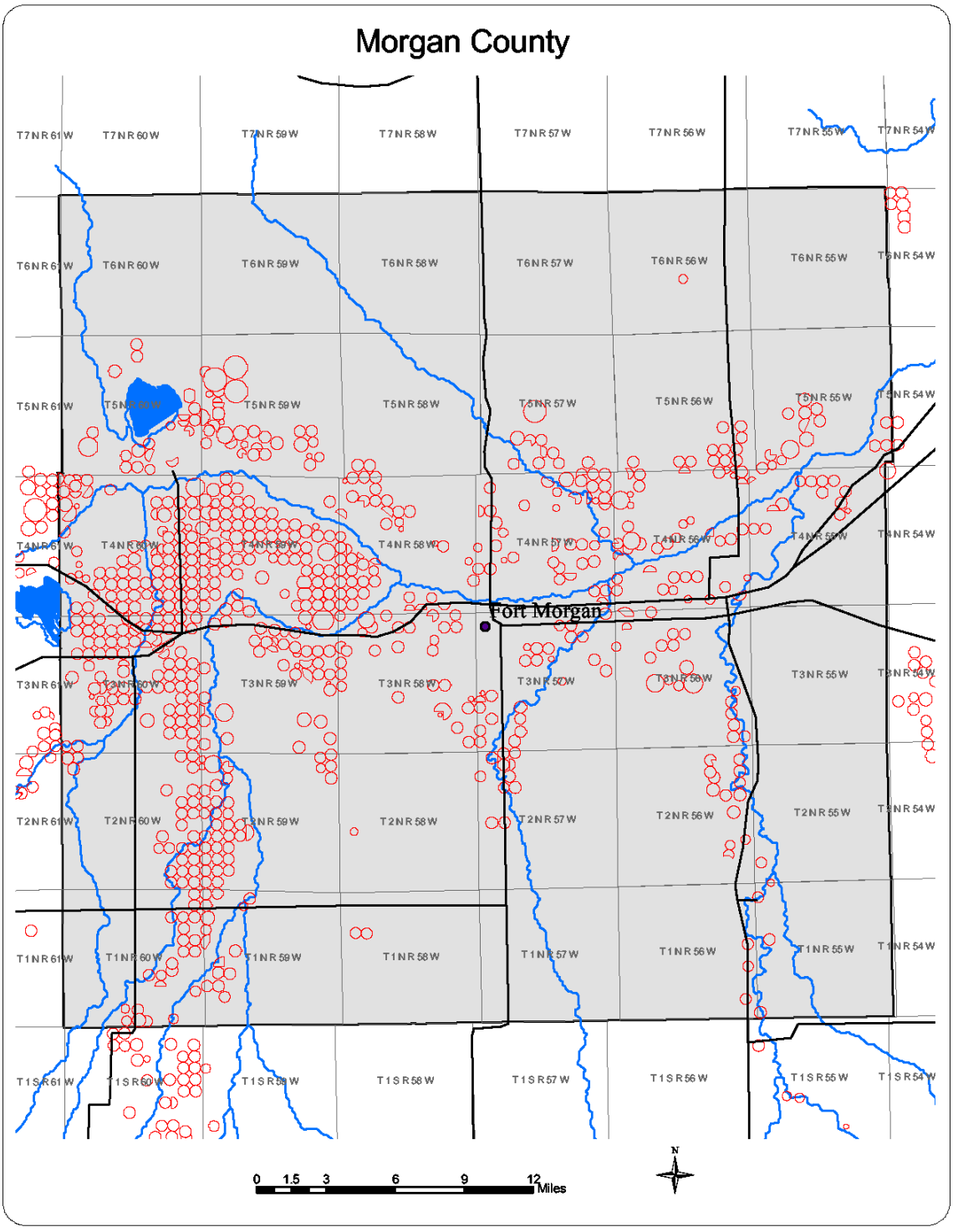

Figure 40. Center pivot irrigation in Morgan County.

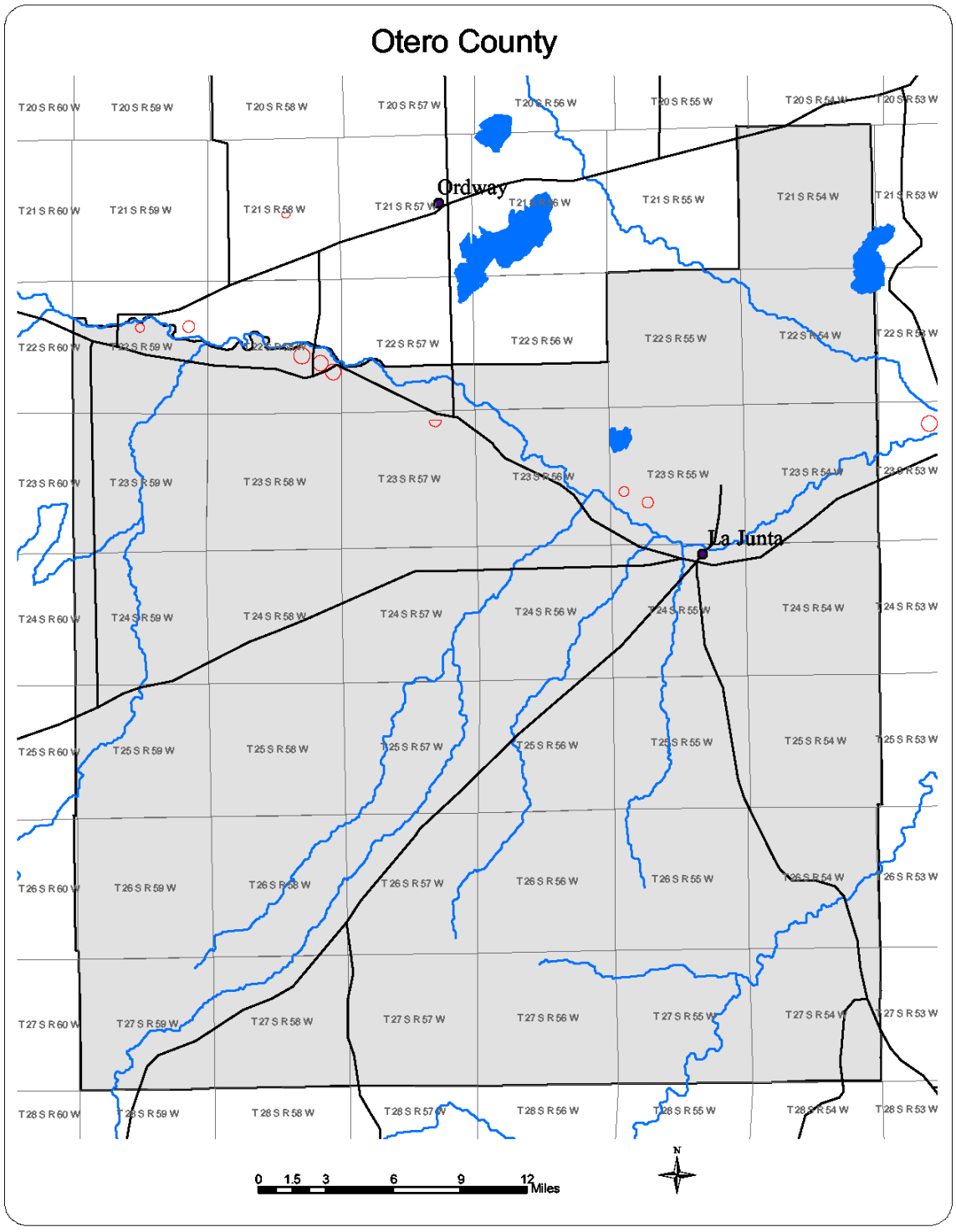

Figure 41. Center pivot irrigation in Otero County.

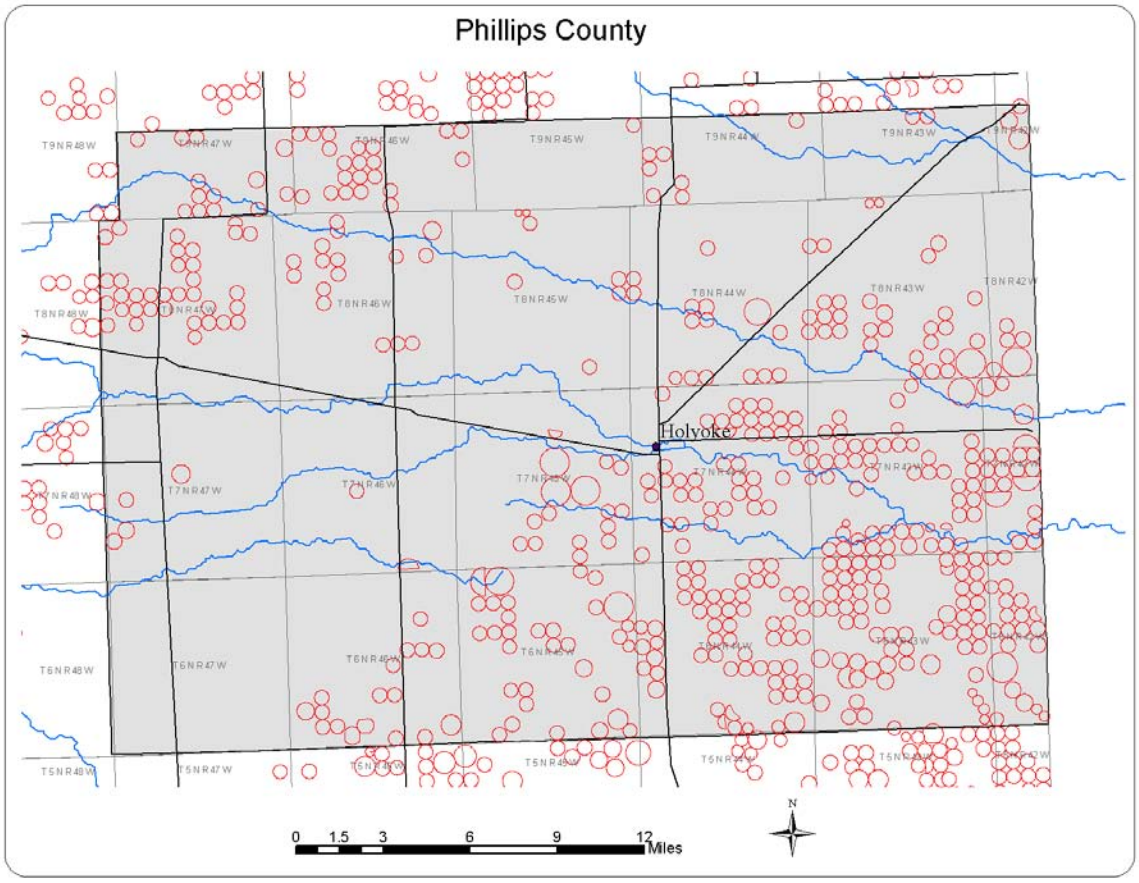

Figure 42. Center pivot irrigation in Phillips County.

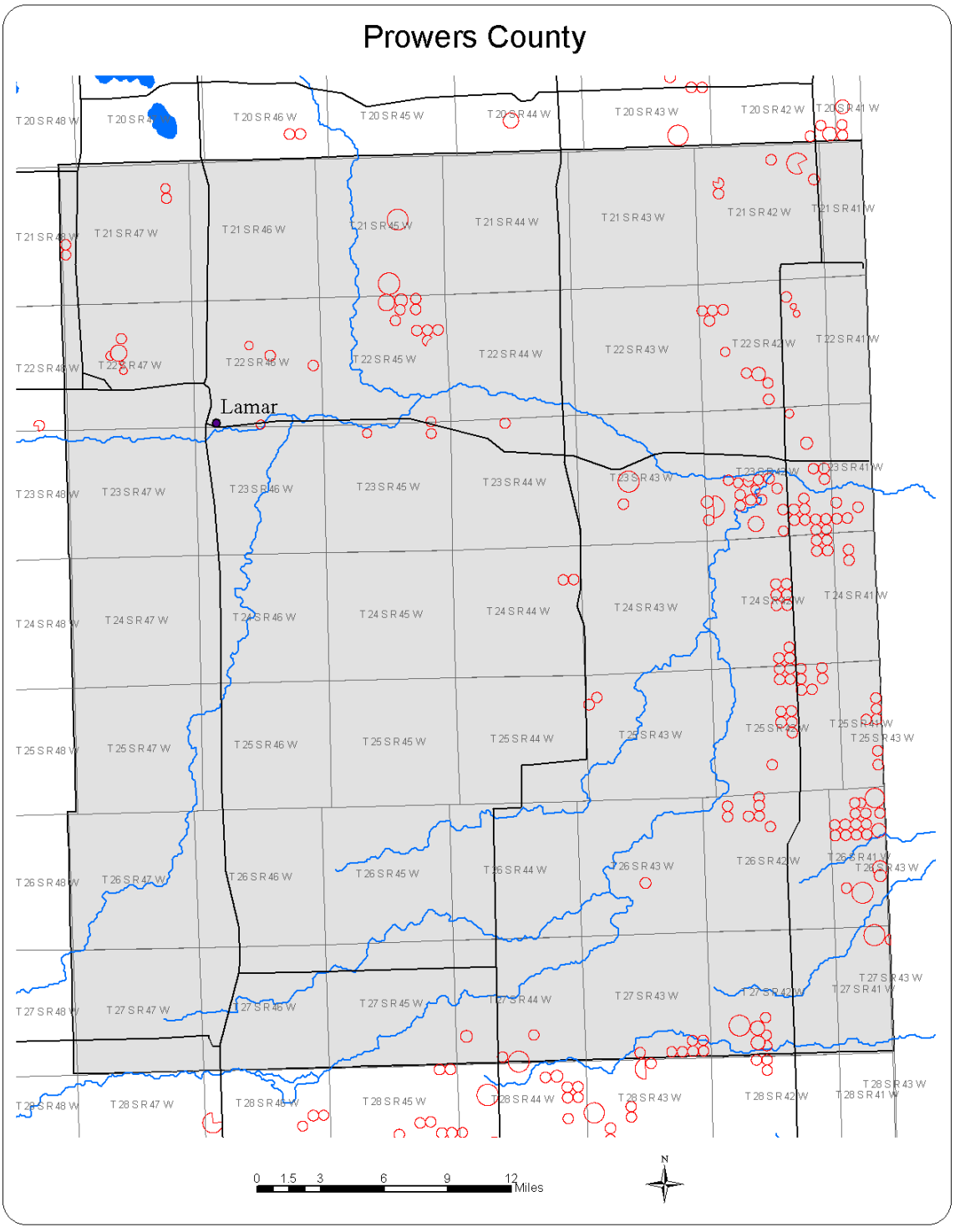

Figure 43. Center pivot irrigation in Prowers County.

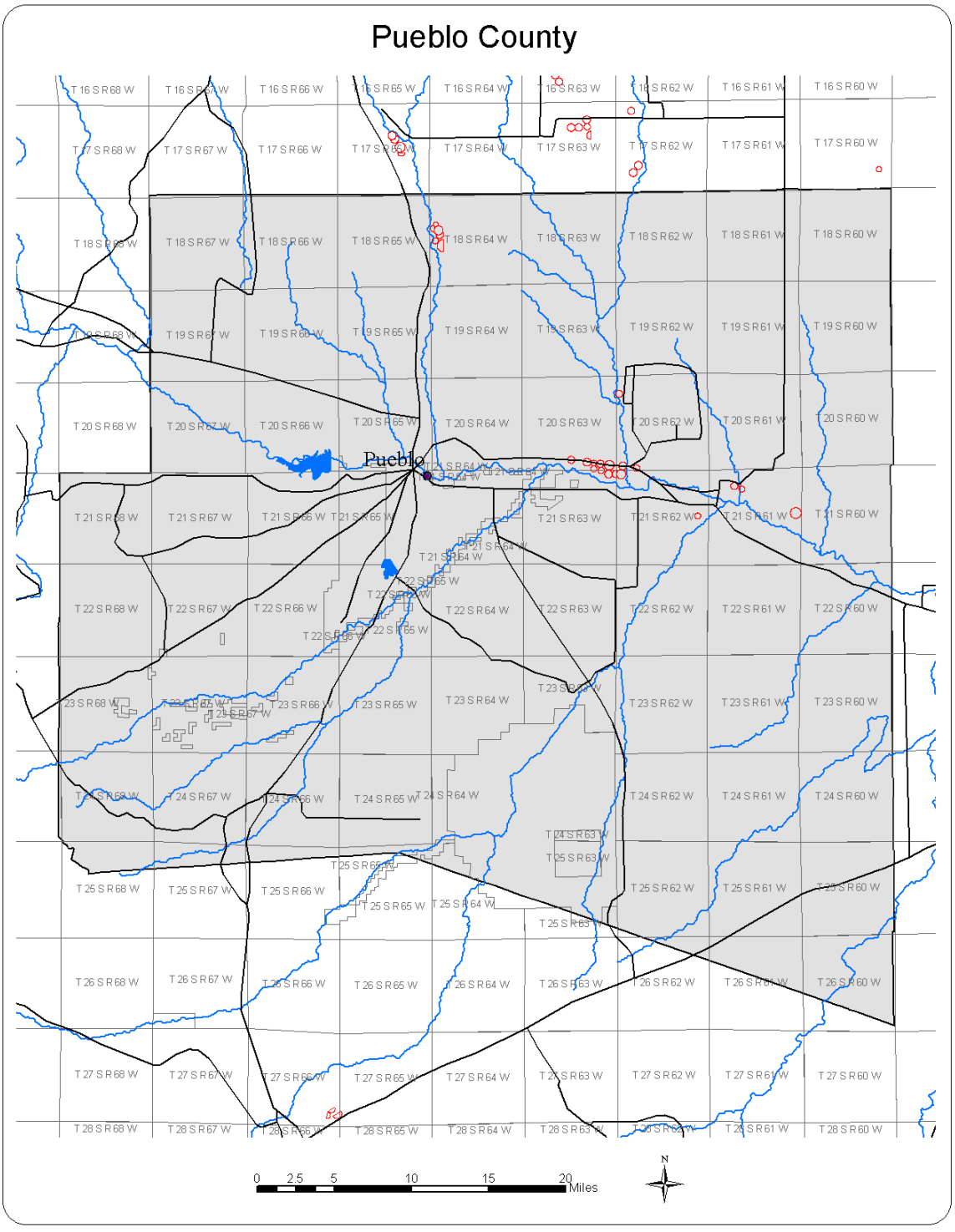

Figure 44. Center pivot irrigation in Pueblo County.

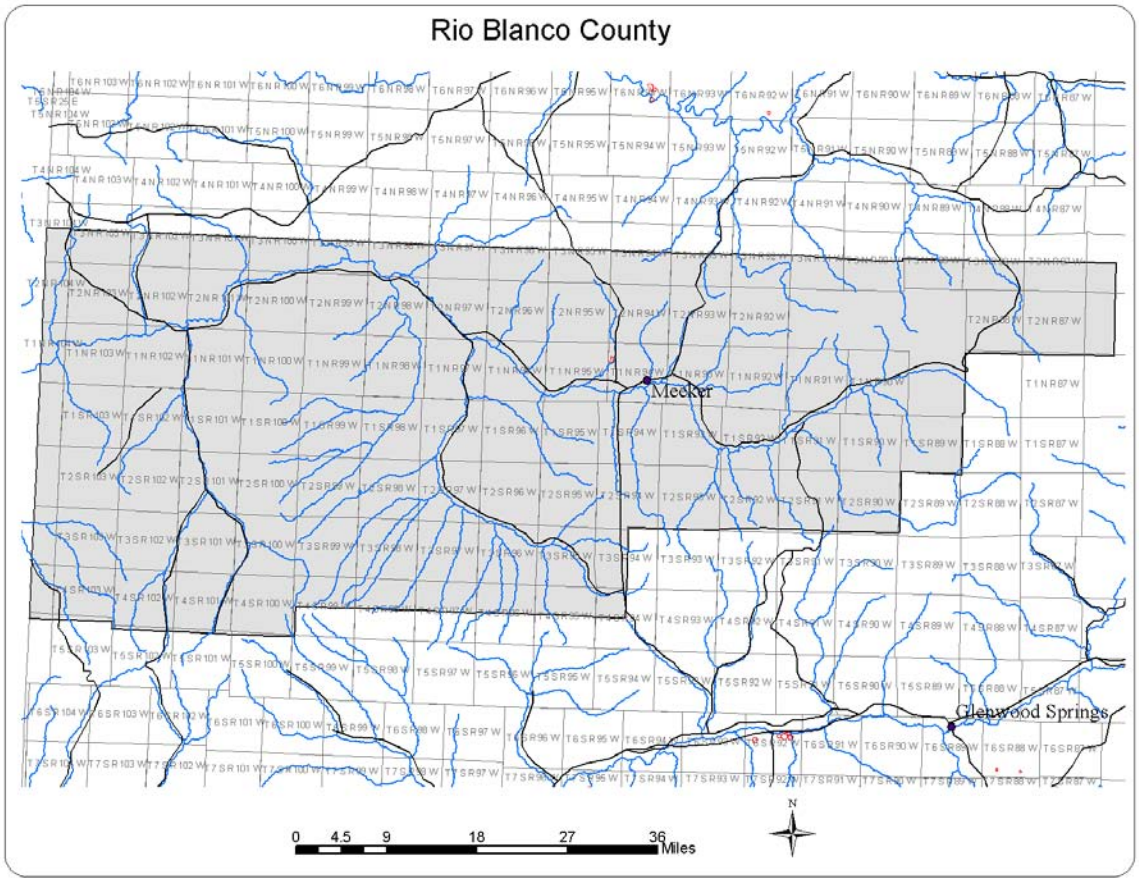

Figure 45. Center pivot irrigation in Rio Blanco County.

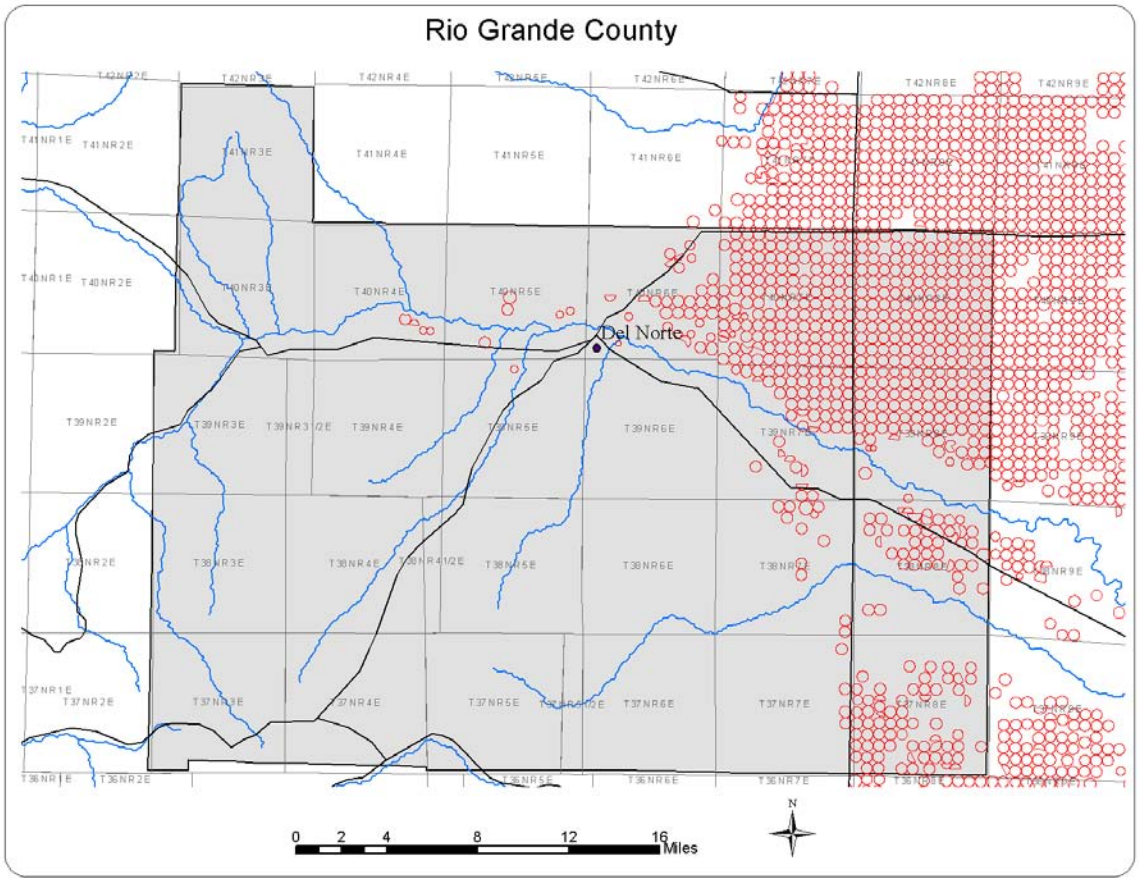

Figure 46. Center pivot irrigation in Rio Grande County.

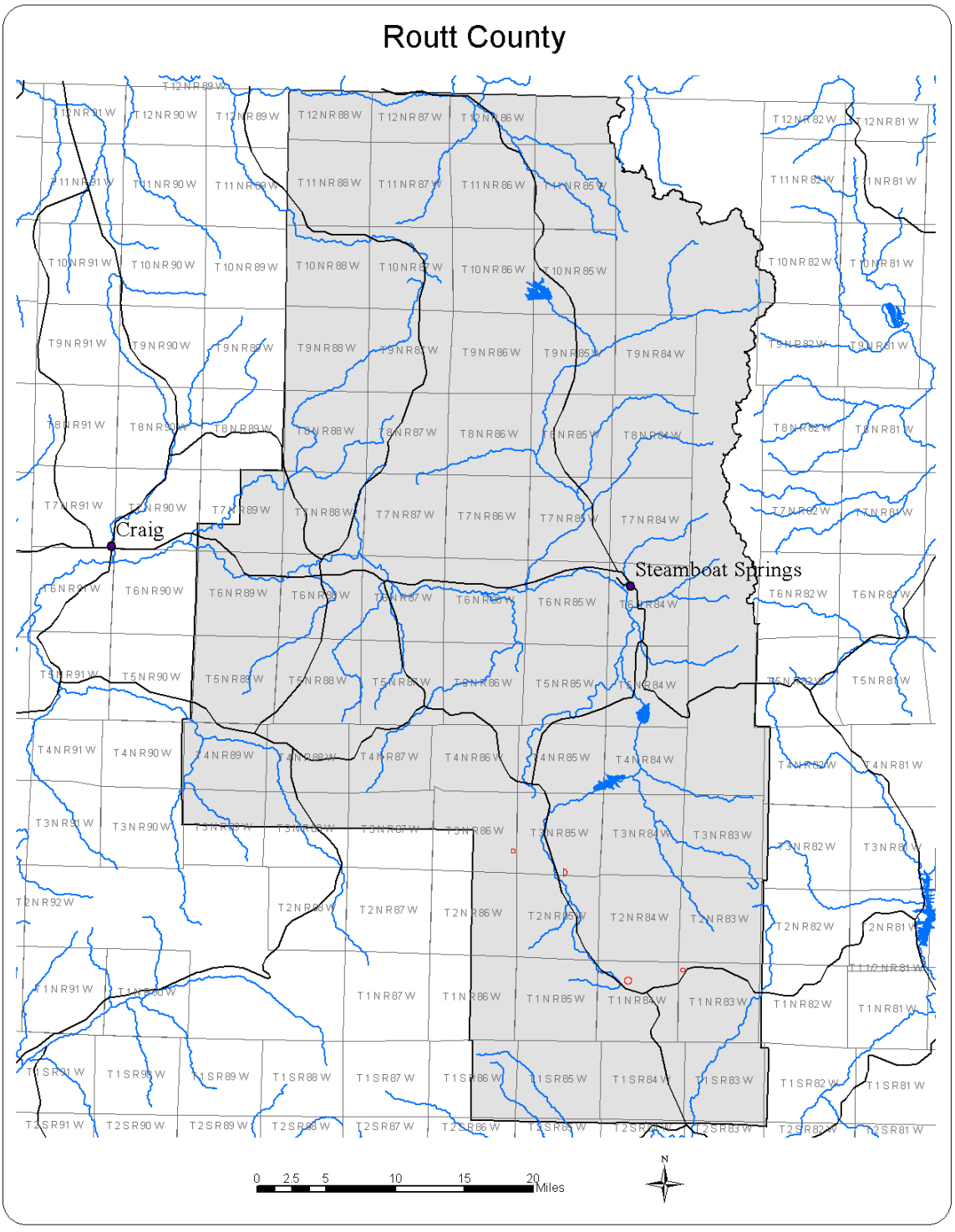

Figure 47. Center pivot irrigation in Routt County.

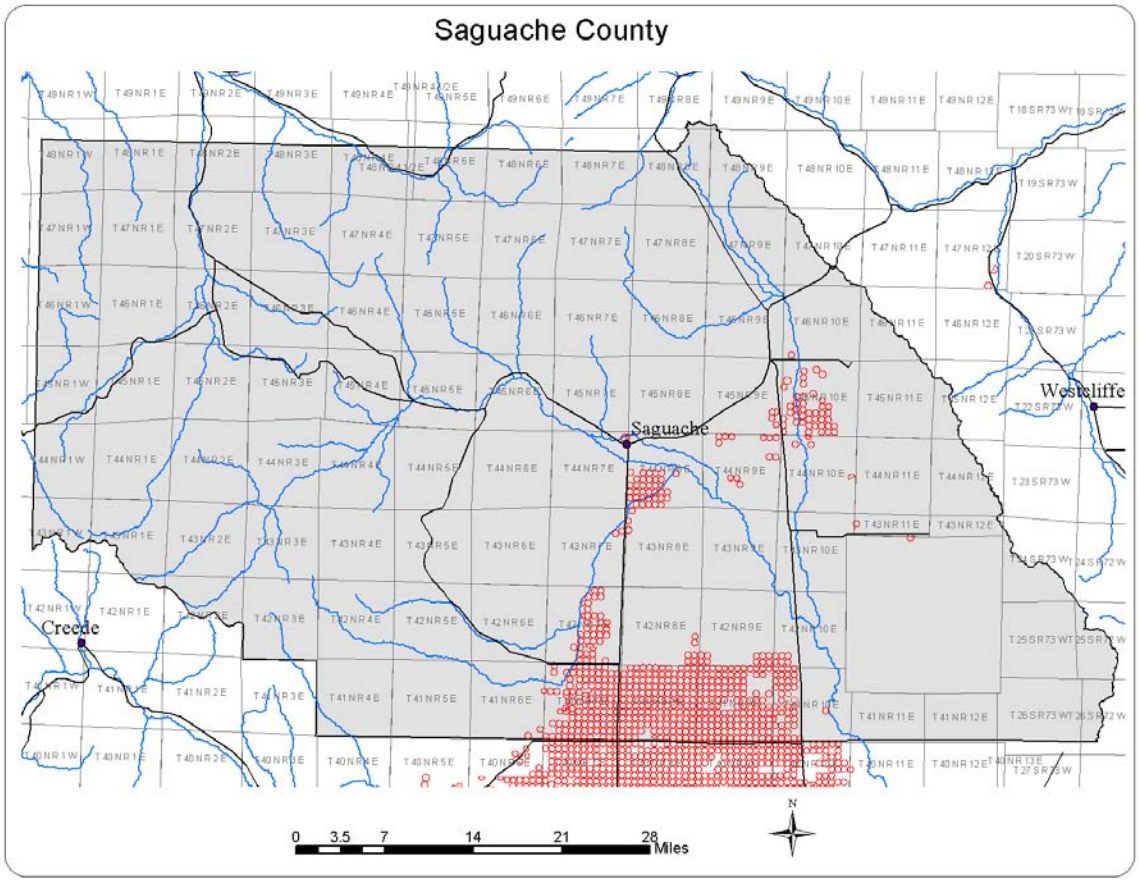

Figure 48. Center pivot irrigation in Saguache County.

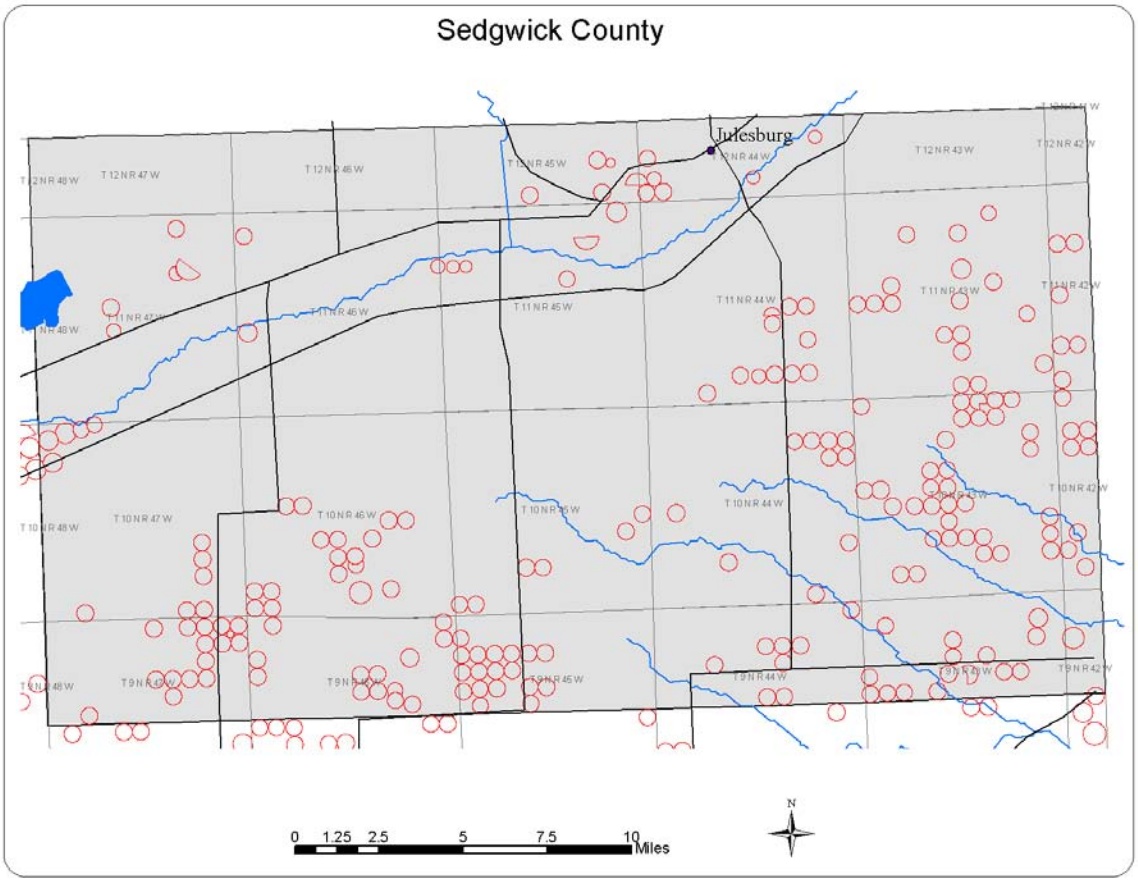

Figure 49. Center pivot irrigation in Sedgwick County.

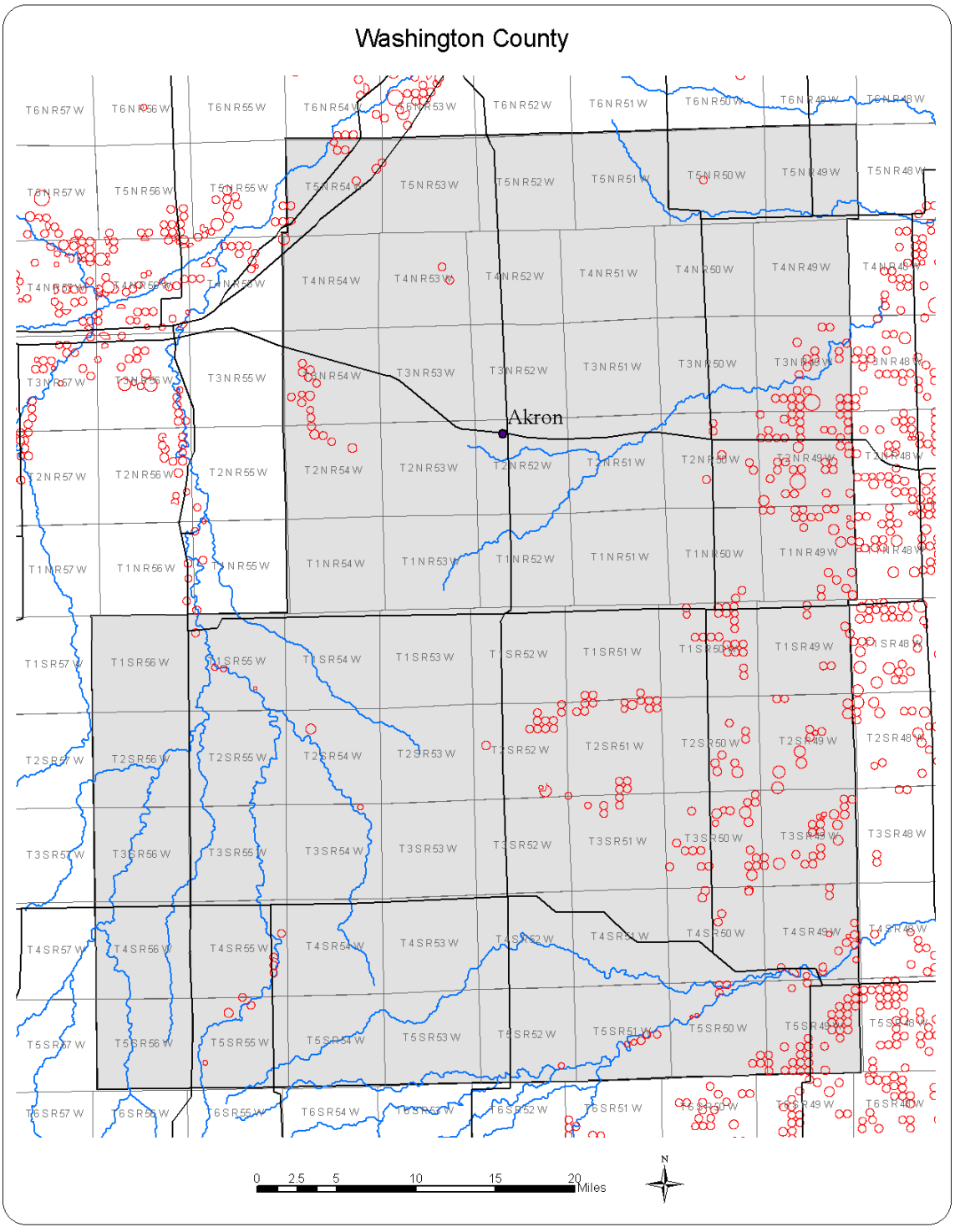

Figure 50. Center pivot irrigation in Washington County.

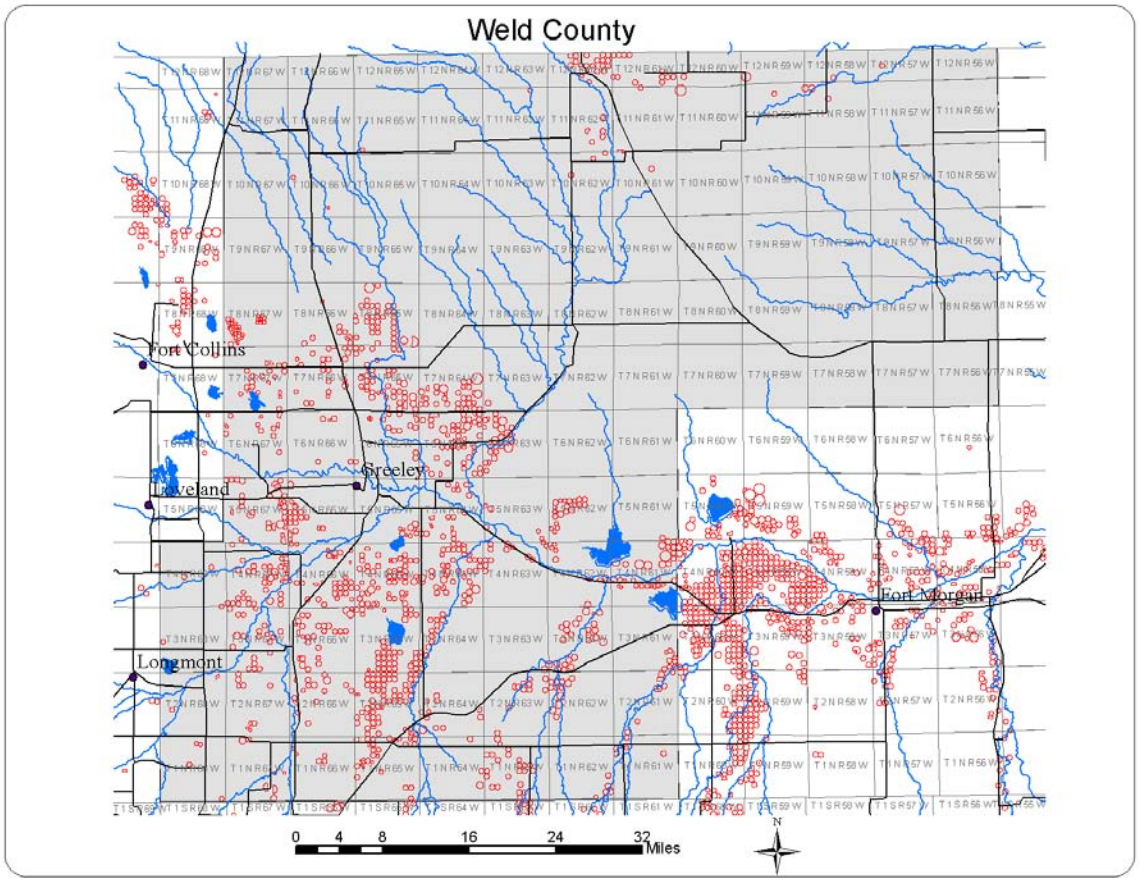

Figure 51. Center pivot irrigation in Weld County.

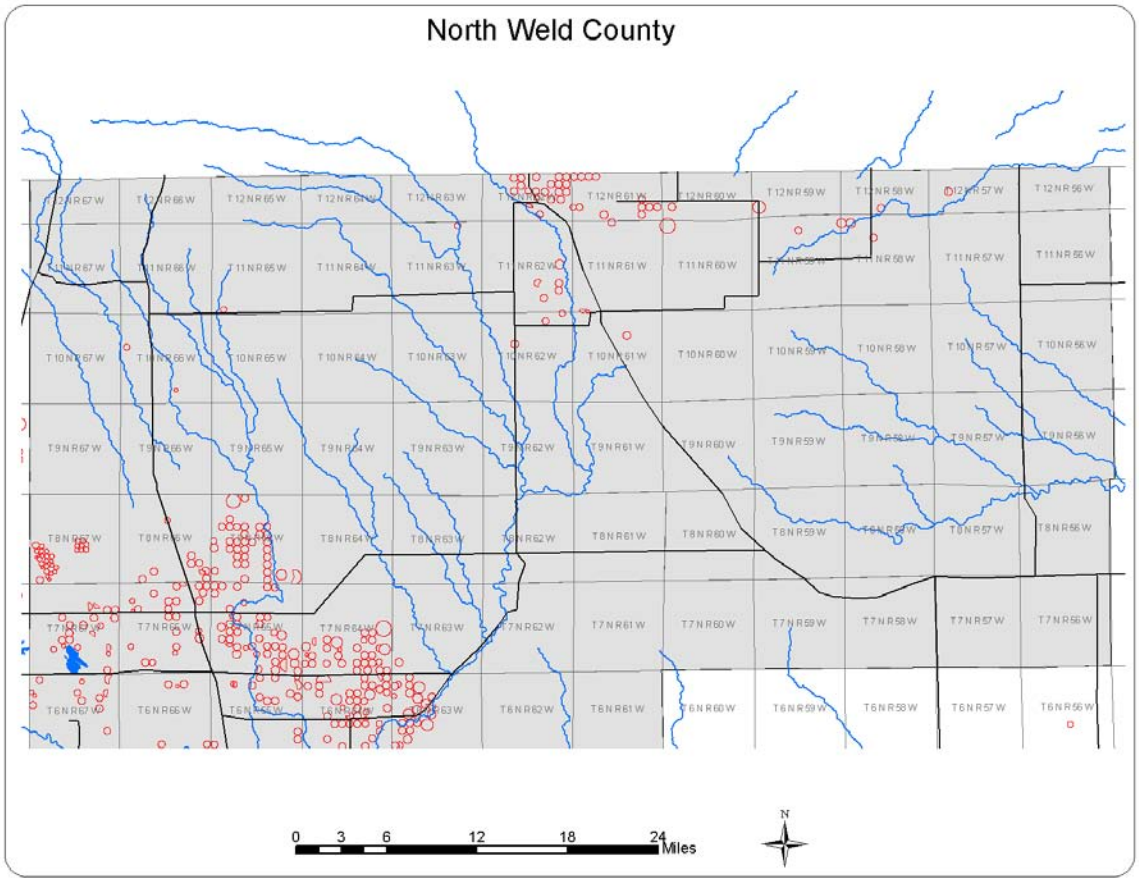

Figure 52. Center pivot irrigation in North Weld County.

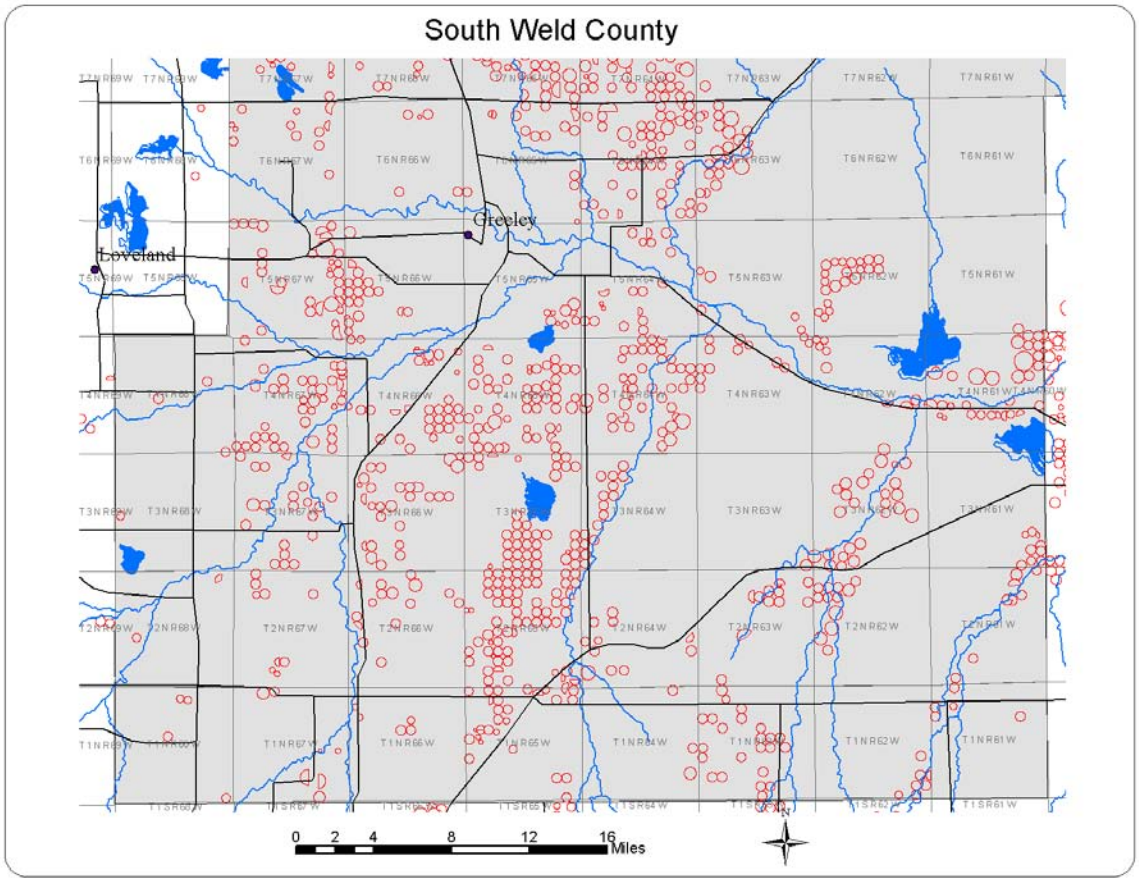

Figure 53. Center pivot irrigation in South Weld County.

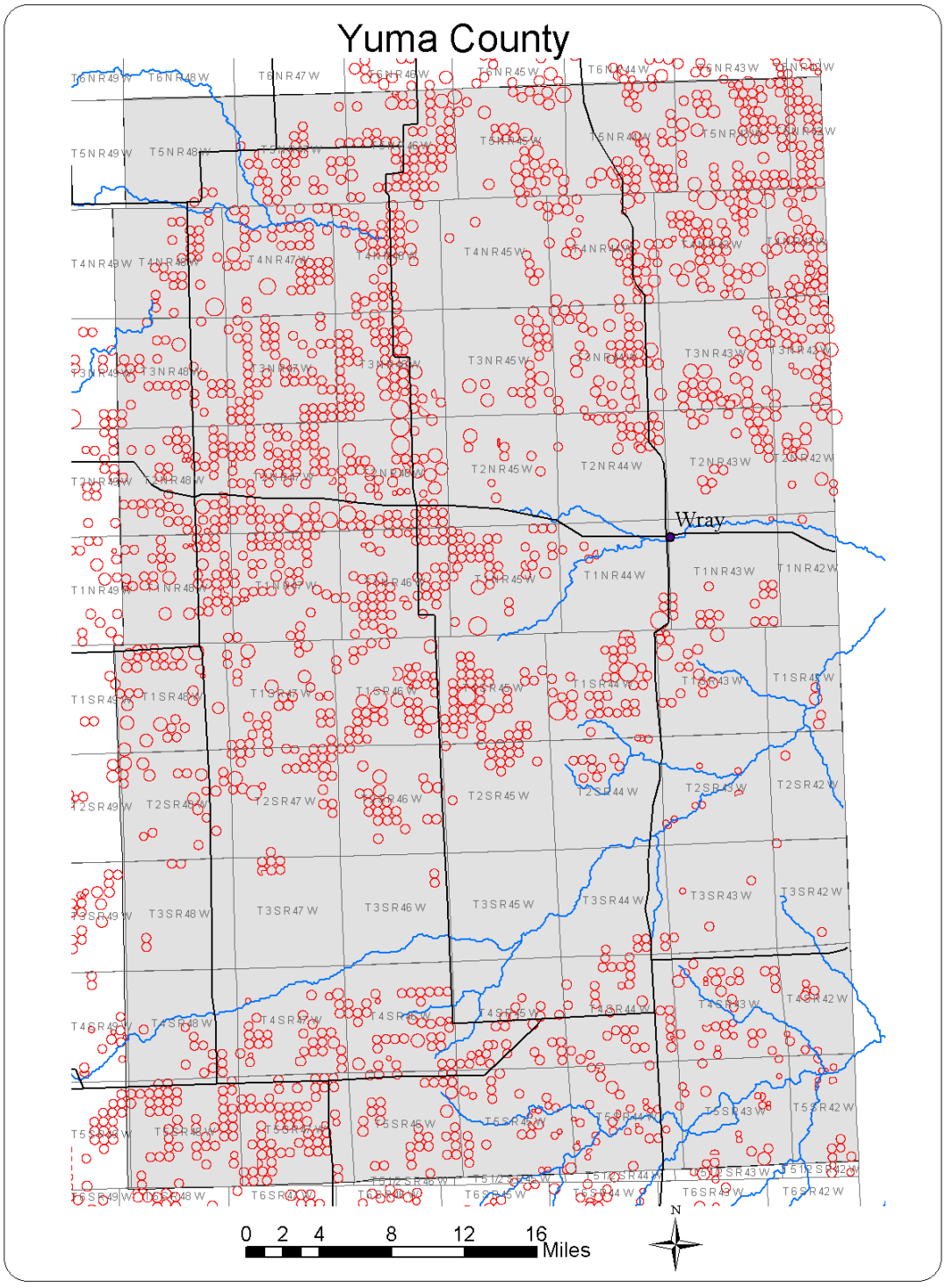

Figure 54. Center pivot irrigation in Yuma County.