FARM SIZE, IRRIGATION PRACTICES, & ON-FARM IRRIGATION EFFICIENCY IN NEW MEXICO'S ELEPHANT BUTTE IRRIGATION DISTRICT

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ABSTRACT

Relationships between farm size, irrigation practices, and on-farm irrigation efficiency in the Elephant Butte Irrigation District, New Mexico, U.S.A. are explored using water delivery data supplied by the District. The study area is experiencing rapid population growth, development, and competition for existing water supplies. Analysis of pecan and alfalfa water delivery data, fieldwork, and interviews with irrigators found extremely long irrigation durations, inefficient irrigation practices, inadequate on-farm infrastructure, and little interest in making improvements to the current irrigation system or methods on the smallest farms. These findings are attributed to the nature of residential, lifestyle, or retirement agriculture. Irrigation practices on large farms are notably different from small farms: irrigation durations are shorter, less water is applied, producers are commercially oriented, and have high levels of on-farm efficiency. Many small producers appear to view irrigation as a consumptive, recreational, social, or lifestyle activity, rather than an income generating pursuit. Small farm operators are likely to show limited interest in improving on-farm irrigation infrastructure, adopting management intensive irrigation technologies or practices, or making significant irrigation investments. Easement and common property disputes over ditch maintenance between owners of small parcels also create disincentives for infrastructure improvements.

INTRODUCTION

New Mexico's Lower Rio Grande Valley is experiencing rapid population growth, development of the rural countryside, and decreasing municipal groundwater supplies. Plans are underway to transfer some of the surface water from agriculture to municipal and industrial use in Doña Ana County, where most of the Elephant Butte Irrigation District (EBID) is located. Lifestyle agriculture is widespread in the county, where the total number of irrigated farms increased by 70% between 1974 and 1997 (U.S. Dept. of Commerce, 1981; U.S. Dept. of Agriculture, 1999). EBID irrigated acreage has been stable over that period of time (~75,000 acres), while numbers of farms in the smallest acreage categories

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grew dramatically as a result of land splits. For instance, there were 150 farms between one and nine acres in 1974 and 691 of these farms in 1997.

EBID currently delivers water to almost 8,300 parcels of land. Thirty-eight percent of the irrigated parcels are less than two acres in size, while another 28% are between two and five acres, with both these parcel categories accounting for 12% of the District's irrigated lands. In comparison, irrigated parcels of more than 100 acres comprise less than 2% of irrigated parcels, but account for almost 28% of irrigated land. Larger, commercially-oriented farms often operate on numerous non-contiguous parcels. Alfalfa, pecans, cotton, chile peppers, and onions are the primary crops produced in the District.

EBID conveyance efficiency (e.g., diversion / farm delivery) is estimated to be 54%, while district-wide on-farm irrigation efficiency (e.g., consumptive irrigation requirement / farm delivery) is estimated to be 83% (Magallanez and Samani, 2001). Although most of the District is irrigated by traditional basin or basin-furrow methods (with no runoff from the end of the field), on-farm efficiency is high as a result of deficit irrigation practices on much of the crop acreage.[3] The efficiency studies that support EBID's aggregate assessments have been conducted on a small number of relatively large, commercial farming operations; thus while they represent a large percentage of irrigated lands, they reflect the irrigation practices of a small percentage of total irrigators and farms.

The objective of the research reported here was to examine irrigation practices and efficiency across a broad cross-section of farms. Water delivery data for 864 EBID accounts were analyzed using Excel™ and SAS™, with the objective of identifying patterns in on-farm irrigation efficiencies and water use in pecans and alfalfa. The data presented in this report are for the 2001 irrigation season. Field visits were conducted in 2002 and 2003 in order to ground-truth findings of the data analysis, observe actual irrigations, and meet the irrigators.

FINDINGS

Total Irrigation Water Applied

Descriptive statistics and quantile analysis for acre-feet/acre of water applied for the 340 pecan farms are presented in table 1. Analysis of variance confirmed that the water applied means were not significantly different by farm size; however, the range of water applied does vary greatly by farm size. The range of water

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[3] Samani and Al-Katheeri (2001) used on-site flow measurement and chloride tracing and found basin and basin-furrow irrigation efficiency to be as high as 95% for pecans. Deras (1999) found efficiencies ranging from 88% to 98% in alfalfa, 88% to 97% in cotton, 79% to 94% in pecans, and 83% to 94% in chile peppers (Salameh Al-Jamal et al., 1997).

applied across all quantiles is 5.30 acre-feet/acre for the smallest farm size, which is more than three times larger than the second highest range (≥ 20 acres). The irrigation district data included no information about supplemental groundwater, and parcels which received surface water less than five times during the irrigation season were not included in the analysis in an effort to eliminate farms which apply primarily groundwater. Nevertheless, it is curious to see the low levels of surface water applications in the 25% of the pecan farms using the least amount of water in each farm size category. It may thus be more appropriate to compare the ranges of water applied to pecans for the highest 25% of water users in each farm size category, to reduce the likelihood of supplemental groundwater use. Examination of the ranges of water applied for the highest 25% of water users again shows the largest range of acre-feet/acre in the smallest farm size group.

Table 1. Quantile analysis and descriptive statistics for pecan water applied (acre-feet/acre) relative to farm size (2001, n = 340).

		Farm Size Category			
		2 ≤ acres< 5	*5 ≤ acres < 10*	*10 ≤ acres < 20*	*≥ 20 acres*
Quantiles					
0%	Minimum ac-ft/ac water applied	1.85	2.18	2.47	2.27
25%		3.04	3.11	3.37	3.28
50%	Median ac-ft/ac water applied	3.78	3.67	4.01	4.49
75%		4.53	4.37	4.95	4.98
80%		4.72	4.51	5.35	5.09
85%		4.97	4.61	5.61	5.20
90%		5.44	5.09	5.63	5.79
95%		6.09	5.59	5.64	5.95
99%		6.45	5.99	5.70	6.23
100%	Maximum ac-ft/ac water applied	7.15	5.99	5.70	6.23
Descriptive Information					
	Number of farms	223	65	24	28
	Percent farms	65.6	19.1	7.1	8.2
	Mean ac-ft/ac[1]	3.91	3.79	4.12	4.23
	Grand mean – all farm size groups	3.93 acre-feet/acre (47.16 inches/acre)			
	Standard deviation (ac-ft/ac)	1.05	0.94	0.99	1.09
	Range (all quantiles) (ac-ft/ac)	5.30	1.26	1.58	1.70
	Range (75% - 100%) (ac-ft/ac)	2.62	1.62	0.75	1.25
	Number of acres	648	396	303	1,368
	Percent acres	23.9	14.6	11.2	50.4
	Total water applied (ac-ft)	2,567	1,483	1,224	5,748
	Percent total water applied	23.4	13.4	11.1	52.2

[1] Means were not significantly different.

Acre-feet/acre of water applied to alfalfa parcels relative to farm size is presented in table 2. Analysis of variance found significant differences in means of water applied for alfalfa. Specifically, the mean acre-feet/acre for the smallest farm size was significantly lower than the means for farms in the 10 ≤ acres < 20 and ≥ 20 acres groups. As presented in table 3, differences in the ranges of water applied for the highest 25% of water users are very large, with an almost 10-fold difference between the smallest and largest farm size groups. Examination of differences in mean water applied by farm size indicates that larger parcels have a higher average level of water applied. However, the data for ranges of water applied complicate that conclusion, and show that even when the highest 1% of extreme observations is excluded, the range of water applied is greatest for the smallest farm size.

Table 2. Quantile analysis and descriptive statistics for alfalfa water applied (acre-feet/acre) relative to farm size (2001, n = 524).

		Farm Size Category			
		2 ≤ acres< 5	*5 ≤ acres < 10*	*10 ≤ acres < 20*	*≥ 20 acres*
Quantiles					
0%	Minimum ac-ft/ac water applied	2.00	2.19	2.29	2.21
25%		3.03	3.39	3.76	3.90
50%	Median ac-ft/ac water applied	3.86	4.17	4.45	4.62
75%		4.75	4.98	5.37	5.14
80%		5.08	5.17	5.50	5.75
85%		5.34	5.31	5.76	6.00
90%		5.61	5.59	5.99	6.13
95%		6.13	6.59	6.59	6.54
99%		8.55	7.19	7.25	6.59
100%	Maximum ac-ft/ac water applied	19.18	10.91	7.25	6.59
Descriptive Information					
	Number of farms	290	116	73	45
	Percent farms	55.3	22.1	13.9	8.6
	Mean ac-ft/ac[1]	4.06[ab]	4.29	4.52[a]	4.60[b]
	Number of acres	884	727	946	1,479
	Grand mean – all farm size groups	4.22 acre-feet/acre (50.64 inches/acre)			
	Standard deviation (ac-ft/ac)	1.53	1.24	1.11	1.11
	Range (all quantiles) (ac-ft/ac)	17.18	8.72	4.96	4.38
	Range (75% - 100%) (ac-ft/ac)	14.43	5.93	1.88	1.45
	Number of acres	884	727	946	1,479
	Percent acres	21.9	18.0	23.4	36.7
	Total water applied (ac-ft)	3,605	3,117	4,363	6,734
	Percent total water applied	20.2	17.5	24.5	37.8

[1] Means with the same letter are significantly different at $p < 0.05$.

Pecan consumptive use is ~5.0 acre-feet/acre for mature trees. Based on analysis of the District's 2001 records, approximately 18% of the pecan farms analyzed applied water in excess of the consumptive use requirement. By comparison, 70% of the 524 alfalfa farms analyzed were applying water in excess of consumptive use (i.e., ~3.5 acre-feet/acre).

Irrigation Duration

The District's 2001 accounting of water delivered does not reflect actual measurements. The water delivery data analyzed are based on engineering estimates of canal deliveries, and the similarities in tables 1 and 2 between percent total acreage and percent total water applied by farm size group illustrate this situation. During examination of the 2001 water delivery data provided by EBID, differences in irrigation durations between farms became very obvious. The data included start and stop times for water deliveries, and spreadsheet functions were used to estimate total irrigation durations and irrigation durations per acre. Field measurements conducted for this research showed that for alfalfa irrigators EBID's accounting is about 30-35% lower than actual applied water. For pecans, actual water applied was found to be more consistent with EBID's records for the farms where field measurements were taken. Given these field observations, the irrigation duration data were analyzed extensively. Irrigation duration (i.e., hours/acre/irrigation) is an indicator of field level irrigation efficiency, and is particularly useful when measurements of actual water applied are unreliable.

Descriptive statistics and quantile analysis for irrigation durations are presented in tables 3 and 4 for the two crops.

Table 3. Quantile analysis and descriptive statistics for pecan irrigation durations (hours/acre/irrigation) relative to farm size (2001, n = 340).

		Farm Size Category			
		2 ≤ acres< 5	*5 ≤ acres < 10*	*10 ≤ acres < 20*	*≥ 20 acres*
Quantiles					
0%	Min. hours/acre/irrigation	0.35	0.46	0.28	0.91
25%		0.98	0.70	0.52	0.28
50%	Median hours/acre/irrigation	1.25	0.82	0.65	0.38
75%		1.71	1.17	0.92	0.46
80%		1.80	1.24	0.97	0.53
85%		1.95	1.48	1.01	0.53
90%		2.14	1.65	1.40	0.81
95%		2.73	1.74	1.44	0.83
99%		7.54	2.05	2.01	1.09
100%	Max. hours/acre/irrigation	25.6	2.05	2.01	1.09
Descriptive Information					
	Number of farms	223	65	24	28
	Mean hours/acre/irrigation[1]	1.57^{abc}	0.97^{a}	0.76^{b}	0.42^{c}
	Grand mean – all size groups		1.30 hours/acre/irrigation		
	Standard deviation (hours/acre/irrigation)	1.93	0.40	0.40	0.21
	Range (all quantiles) (hours/acre/irrigation)	25.25	1.59	1.73	0.90
	Range (75% - 100%) (hours/acre/irrigation)	23.89	0.71	0.64	0.63
	Total irrigation hours	10,288	4,165	1,473	2,004
	Percent total irrigation hours	57.4	23.2	8.2	11.2

[1] Means with the same letter are significantly different at $p < 0.05$.

Table 4. Quantile analysis and descriptive statistics for alfalfa irrigation durations (hours/acre/irrigation) relative to farm size (2001, n = 524).

		Farm Size Category			
		2 ≤ acres< 5	*5 ≤ acres < 10*	*10 ≤ acres < 20*	*≥ 20 acres*
Quantiles					
0%	Min. hours/acre/irrigation	0.59	0.44	0.33	0.24
25%		1.10	0.72	0.56	0.46
50%	Median hours/acre/irrigation	1.38	1.00	0.74	0.55
75%		1.86	1.33	1.12	0.67
80%		2.06	1.39	1.19	0.70
85%		2.29	1.52	1.29	0.74
90%		2.73	1.76	1.50	0.90
95%		3.92	2.25	2.27	0.99
99%		7.20	2.55	2.83	1.09
100%	Max. hours/acre/irrigation	9.90	2.76	2.83	1.09
Descriptive Information					
	Number of farms	290	116	73	45
	Mean hours/acre/irrigation[1]	1.73^{abc}	1.10^{ad}	0.92^{be}	0.57^{cde}
	Grand mean – all size groups		1.38 hours/acre/irrigation		
	Standard deviation (hours/acre/irrigation)	1.19	0.50	0.53	0.20
	Range (all quantiles) (hours/acre/irrigation)	9.31	2.32	2.50	0.85
	Range (75% - 100%) (hours/acre/irrigation)	8.04	1.43	1.71	1.02
	Total irrigation hours	11,836	6,870	8,077	8,070
	Percent irrigation hours	33.9	19.7	23.2	23.2

[1] Means with the same letter are significantly different at $p < 0.05$,

Prior field work and recent observations throughout the district by the authors have resulted in the empirical guideline of 0.5 hours/acre/irrigation. Regardless of soil type (e.g., sand, loam, clay), it has been found that irrigations on large, commercially-oriented farms typically require about 30 minutes of water flow per acre through the farm turnout onto the field. This guideline reflects typical lengths of run for the water in the fields, normal water flows at the farm turnouts, and adequately-sized on-farm turnouts. On heavy, clay soils, 0.2 hrs/ac/irrigation has been observed. Very long irrigations usually indicate that on-farm irrigation efficiency will be reduced due to deep percolation losses at the front of the field.

Differences in irrigation durations and ranges between the $2 \leq$ acres < 5 group and all other farm size groups are very striking. There is a clear distinction in irrigation duration on parcels of less than 5 acres relative to all other parcel sizes. The pecan and alfalfa data sets also were each divided into four equal quartiles by hours/acre/irrigation, and chi-square tests of differences in proportions were conducted. The chi-square analyses found that for both crops, there were significantly more small farms with the longest irrigation durations, and significantly more large farms with the shortest irrigation durations.

Several fields with long irrigation durations were visited during the 2002 and 2003 irrigation seasons to gain a better understanding of the conditions which led to the lengthy irrigation periods and confirm whether the extreme observations found in the EBID data were accurate representations of on-farm conditions. These fields were visited while irrigations were underway. Fields with average and below average irrigation durations were also visited while irrigations were occurring in order to compare those conditions with long duration conditions.

Common reasons identified for long durations were the condition of the farm delivery ditches and the size of the on-farm turnouts. In several cases, the water was moving so slowly through the farm delivery ditches toward the on-farm turnouts that flow measurements could not be taken with a digital propeller meter. The water was released from the district's larger canal via partially open 24-inch gates into the farm delivery ditch, and then through very small on-farm turnouts onto the fields. These small turnouts were usually round four-inch pipes. In other cases, the on-farm turnouts were not really structures; instead, they were more like controlled breaks in the farm delivery ditch. When asked about the length of time spent irrigating their fields, several individuals complained about the bad condition of the on-farm delivery ditch from which they take their water. The irrigation district has no responsibility or authority for maintaining these ditches, and the irrigators noted that weeds, trash, rodents, and breaks were factors that resulted in long irrigation durations. In the case of one of the long-duration fields, a fallow lot approximately 100 feet wide and 100 feet long was being used as a channel through which the water flowed uncontrolled before it reached the small pecan orchard actually being irrigated. Complaints about neighbors' unwillingness to grant easements for improving irrigation water delivery, or allow modifications to easements for the purpose of increasing the size of the on-farm delivery infrastructure were often heard. Conversations with the irrigators conducted during the field visits revealed some common themes. One theme can be summarized by one older man's comment regarding the fact that it took him almost two days to irrigate his ~3 acre pecan orchard. He said, "I'm retired, what else have I got to do?" Other comments revolved around the view that irrigation was a family tradition, that irrigating often meant the involvement of members of extended families, that irrigation was a social undertaking, that irrigation was a peaceful, meditative, enjoyable task.

Overall, the levels of irrigation technology and water management found on field visits to small farms were extremely low, and often a consequence of inadequate irrigation design. The principal design problem found was narrow diameter farm turnouts which cannot physically deliver to the field the minimum flow necessary to rapidly push the water across the field, thus reducing both the time spent irrigating and infiltration losses during the irrigation process. The level of involvement by other small-scale water users in the practice of irrigation also appeared to be quite low, and a relatively high degree of resentment toward other users of the same farm delivery ditches was noted among some interviewees (e.g., "Nobody else does anything to maintain the ditch, why should I?"). Many of the long-duration irrigators complained about their neighbors' unwillingness to improve the mutual on-farm delivery ditch (i.e., that part of the delivery system not maintained by the district).

The EBID water delivery data were collected for the objective of billing irrigators; and were not the result of actual measurements of on-farm deliveries. Results of the field measurements have been intriguing, and usually at odds with the district's water delivery data, which record six acre-inch deliveries for most irrigation events. Field analysis on selected farms consistently found that the amount of water applied to a field is strongly and positively related to irrigation duration per acre. Irrigation depths per event ranging from 2.2 acre-inches to 14.7 acre-inches were measured in fields. Furthermore, the excessively high water applications (including the 14.7 acre-inch case cited above) are an *average* across the entire parcel, and do not account for what may be 20+ acre-inch applications at the top of the fields. These high top-end applications occur during the process of the irrigation water's extremely slow advance.

Results of field measurements taken in 2002 and 2003 indicated a large range of actual water deliveries to farms, and some patterns have emerged. Results tend to show underdelivery (i.e., less than six acre-inches) and subsequent overcharges to larger fields, while smaller fields (i.e., less than 10 acres) tend to receive more than six acre-inches per irrigation. Smaller farms are thus undercharged for their irrigation water. Overdelivery of water is related to the excessively long irrigation durations discussed above, with reasons for overdelivery including long fields (i.e., irrigation runs >1,200 feet), rough field surfaces, low flows, and small turnouts to the farm. During field work many water deliveries ranging from 8-12 acre-inches were measured. The fields receiving the water were generally smaller, although not exclusively so. Many deliveries in the range of two to four acre-inches on larger fields were also measured. These fields tended to be intensively managed (evidenced by surface smoothness and absence of weeds), and were part of large, commercial farms. These fields also tended to be located near the larger delivery canals, irrigated through large turnouts, and received high flows of water during the observed irrigation events. The water rapidly moved over the fields, and due to the common practice of shutting off the water when it reaches the end of the field, underdelivery occurred.

Monthly Irrigations and Evapotranspiration

Both field work and examination of the irrigation district's data also lead to the conclusion that there is little relationship between seasonal water demand and applied water for the fields studied. Traditional irrigation timing practices (i.e., every 7-14 days throughout the irrigation season) contribute to overwatering at the beginning and end of the irrigation season, plant stress at peak crop water use periods, and can result in reductions in both crop yields and quality. Figures 1 and 2 show average water applied by month for each farm size group on the left vertical axes and maximum monthly evapotranspiration on the right vertical axes.

The pattern of water application to pecans and alfalfa is similar across the different farm size groups. Average acre-feet/acre/month applied to pecans is very stable throughout the irrigation season, while alfalfa generally shows decreasing applications from the beginning to the end of the irrigation season. Both figures 1 and 2 illustrate over irrigation at the beginning of the season, and less than optimal applications during the peak growing months of June and July. For the two smallest size pecan farm groups and all the alfalfa farm sizes, irrigation at the end of the season is higher than maximum evapotranspiration.

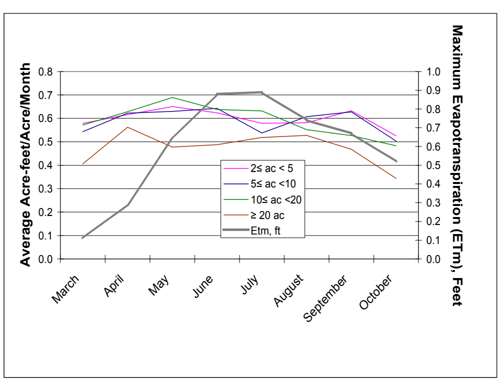

Figure 1. Pecan average acre-feet/acre/month water applied by farm size (by month, 2001, n = 340) and maximum Et.

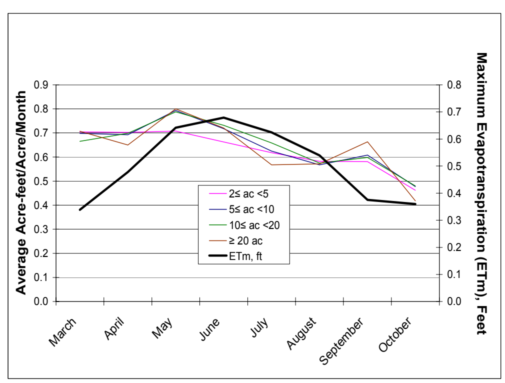

Figure 2. Alfalfa average acre-feet/acre/month water applied by farm size (by month, 2001, n = 524) and maximum Et.

Differences in farm size should be considered a proxy for other characteristics of the irrigator population (for which data are currently unavailable), and it should be clear that the irrigator population is not homogeneous. As discussed above, irrigation duration may be a better indicator of actual water deliveries than the district-recorded data. And, interviews with irrigators leads to the conclusion that a portion of the irrigator population does not view long durations as problematic, and that dealing with the "problem" of long irrigation durations is very complicated (i.e., common property issues, easement disputes, etc). Potential water savings from increased on-farm efficiency and irrigation infrastructure investments, or responses to incentives created by water marketing thus will vary by farm and throughout the irrigator population.

The loss of 46% of EBID's diverted water before deliveries to the farm turnouts is often cited by critics as an example of extreme inefficiency. However, the research described here has led to skepticism about the 54% diversion-to-delivery efficiency estimates. It is likely that at least part of the loss claimed to occur from diversion into EBID canals to delivery on farms is water actually applied to fields and not accounted for at the farm level. The district's water accounting procedures do not document this. It is also likely that carriage water requirements are larger for the smaller water deliveries to the smaller fields. Irrigation infrastructure on the smaller fields limits the rate at which water can be diverted to farms, resulting in deep percolation, runoff, and excess carriage water losses. Many necessary infrastructure improvements are unlikely to occur as a result of limited financial resources, easement disputes, disagreements between local irrigators, and lack of urgency or interest on the part of many irrigators.

It is commonly assumed by many observers and critics of EBID that the irrigation practices of the large, commercial farms must be improved in order to release water for other uses. However, the results of this and earlier research, the prevalence of deficit irrigation practices and other techniques or technologies currently used on large farms to increase the physical efficiency of irrigation water indicate that marginal increases in efficiencies on many large farms are likely to be small and come at a high cost. And the price at which many small farm operators will be inclined to change their irrigation practices may be extremely high, because for them, irrigation is a recreational, social, or lifestyle activity, and not an income generating pursuit. The common property nature of those segments of the water delivery system not owned by EBID also creates a disincentive for investment and improvements by individual water users.

We currently hypothesize that many smaller EBID water users have minimization of the costs or risks of operating their small farms (regardless of the impacts on irrigation water productivity, yields, or total production) as their primary objective. Some smaller water users seem to have maximizing their utility or satisfaction from the small farm generally (and irrigation activities in particular) as a key objective. Again, these objective functions do not seem very compatible with the notion that water users generally will be interested in increasing irrigation efficiency through changes in technology, increases in management intensity, and responding to financial incentives to release surface water from agriculture for other competing uses.

The number of irrigated farms in the EBID has increased over the last several decades, due to splitting larger farms into smaller parcels. The ramifications of this for on-farm irrigation, delivery efficiencies, irrigation infrastructure, and irrigation system management are serious and underappreciated. One final conclusion of this research concerns the relationships between engineering and socio-economics. The conclusion is that the irrigation structures (e.g., ditches, gates, turnouts, etc.) designed for the agricultural structure (i.e., numbers and distribution of farms by size) which characterized the EBID in the early 20th century are currently a source of significant inefficiencies. The degree of reinvestment or disinvestments necessary to make irrigation structure compatible with current agricultural structure is surely very large. Furthermore, agricultural structure in Doña Ana County will continue to evolve with urbanization, population growth, and economic development. As a result, compatibility between irrigation infrastructure and agricultural structure is not a static target, given the dynamic nature of urban fringe agriculture in Doña Ana County.

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