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The Adaptations of Farmers in an Era of Declining Groundwater Supplies

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ABSTRACT In recent years it has become increasingly apparent that modern agricultural practices are resulting in a wide array of environmental problems, and in particular resource depletion problems. As of yet, however, there has been a relative lack of research on the adaptations made by farmers when faced with the depletion of an important resource. This paper helps address this void by exploring the adaptations of farmers (N = 700) in the Texas High Plains to the depletion of their primary source of irrigation water—the Ogallala Aquifer. It was found that the proportion of farm operators who had adopted each of the various water conservation techniques varied significantly. Over half of the farmers had reduced the number of times that crops are irrigated each year in response to declining groundwater supplies, while only 13 percent had adopted bench terraces or moisture sensing instruments. Farmers adopting the water conserving technologies that were relatively cheap to implement, but that could reduce the amount of groundwater needed, tended to come from smaller farms and areas where groundwater supplies were not as extensive. On the other hand, farmers adopting more expensive irrigation technologies, such as the center-pivot sprinkler, tended to come from larger farms with a more extensive groundwater supply. Such farms were in a better position to economically justify a major investment into irrigation.

Introduction

Although farming is often depicted as a bucolic and environmentally pristine enterprise, it is becoming increasingly apparent that modern agricultural practices are resulting in a wide array of severe environmental resource problems in the United States (Buttel *et al.*, 1981). The average farm in the midwestern United States loses about 12 tons of topsoil per acre each year, and it is estimated that two bushels of topsoil are lost for each bushel of corn produced. In addition, agricultural herbicides, pesticides, and fertilizers are contaminating both underground and surface water supplies, and extensive irrigation is depleting numerous underground aquifers (Albrecht and Murdock 1990; Rogers *et al.* 1988). While rural sociologists and others are increasingly likely to recognize the presence of severe agriculturally related environmental problems in general and resource depletion problems in particular, there remains only a very limited body of sociological research on

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such issues. The primary exception is an impressive and growing body of research on soil erosion (e.g., Heffernan and Green, 1986).

The depletion of important resources in a modern agricultural setting results in at least two types of sociological research becoming critically important. The first type of research utilizes macro-level data to determine the overall farm structure, demographic, economic, and other changes occurring as a result of the resource depletion (Albrecht, 1988). The second type of sociological research that is needed involves an examination of how individual farm operators react and attempt to cope with an increasingly restrictive environment. As of yet, there is a general lack of individual level research on how farmers adapt when faced with a severe resource depletion problem. Thus, we are unsure of the adaptations that farmers make to forestall the negative effects of resource depletion, and if the types of adaptations made vary by the farm or personal characteristics of the individual farm operators. This paper attempts to partially fill this void by examining the actions taken by a sample of farm operators in the High Plains of Texas to the continuing depletion of their primary source of irrigation water—the Ogallala Aquifer.

The depletion of the Ogallala Aquifer

Historically, the major deterrent to successful agricultural production in the Great Plains has been a lack of water (Webb 1936; Kraenzel 1955). Annual rainfall in much of the Great Plains averages less than 20 inches a year, which is well below the levels received in the East and generally insufficient for dependable crop production. Further, the region is nearly devoid of surface water that can be used for irrigation purposes (Lawson and Baker 1981). This lack of water severely retarded early settlement in the Great Plains, and the Great Plains became one of the last areas in the continental United States to be settled.

However, from early in the settlement period, it was well known that much of the Great Plains was underlain by the extensive groundwater resources of the Ogallala Aquifer. Eventually, the technology was developed which made it economically possible to lift large amounts of groundwater to the surface for irrigation purposes (Hughes and Magee 1960; Hughes and Motheral 1950). Soon, thousands of wells were drilled, millions of acres were placed under irrigation and the Ogallala Aquifer became one of the most intensely developed groundwater resources in the country. Between 1940 and 1978, the number of acres irrigated in the Great Plains increased from 2.5 million to 16.5 million, an increase of 547 percent.

Having the water resources available for irrigation provided the impetus for extensive changes in the economic, demographic, and social structure of the Great Plains (Bittinger and Green 1980; Green 1973). The pumpage of groundwater effectively removed a critical ecological constraint (water) and

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helped the Great Plains to become one of the most productive farming regions in the nation. Research has shown that this increased farm productivity resulting from irrigation has allowed incomes, lifestyles and populations to increase to higher levels than would otherwise have been possible (Albrecht and Murdock 1985; 1986a; 1986b; Gulhati and Smith 1967; Steward *et al.* 1955).

Today, two major factors are combining to threaten the feasibility of continued irrigation in the Great Plains. These include increased energy costs and declining groundwater supplies. In the decade following the Arab oil embargo, the price of energy used to fuel irrigation pumps increased by an average of 400 percent (Ellis *et al.* 1985). Such increases greatly reduced the profitability of irrigated agriculture. Much of the irrigation development that has occurred in the past in the Great Plains was a direct consequence of the very low energy prices that prevailed in the United States until the 1970s. These low energy prices permitted Great Plains irrigation farmers to competitively produce the same crops that were being grown elsewhere in the country without irrigation, despite the fact that a substantial amount of energy was required to pump groundwater to the surface. The greater production that occurs on irrigated farms compared to dryland farms was able to offset the costs associated with irrigation. In fact, energy prices were so low that many farmers utilized irrigation techniques that were extremely inefficient where much of the water that was pumped was never utilized by the crops. When energy prices increased during the 1970s, it greatly increased the irrigation farmers' cost of production, making crop production less profitable for them. In addition, in many areas there is virtually no recharge to the Ogallala Aquifer, and consequently as water is removed it is essentially being mined. Thus, areas where there has been extensive irrigation for an extended period of time have also experienced substantial declines in their groundwater supply. For example, in parts of Texas, the water table has already declined by more than 100 feet (Matthews *et al.* 1984).

As a result of increased energy costs and declining water resources, the number of acres irrigated in the Great Plains region has begun to decline. In Texas, where groundwater resources are relatively limited and have been extensively depleted, the number of acres irrigated declined by more than 1 million between 1978 and 1982. In contrast, in Nebraska where groundwater supplies are more extensive and have not been depleted by years of extensive irrigation, the number of acres irrigated continued to increase during this time period. In parts of Texas, the declines in the number of acres irrigated have been dramatic. For example, the number of acres irrigated in Hockley County, Texas declined from 201,000 in 1969 to 99,000 in 1982, and in Crosby County, Texas, the number of acres irrigated declined from 154,000 to 83,000 in just four years from 1978 to 1982.

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Adaptations to a resource depletion

During the era when technological developments made it possible for the waters of the Ogallala Aquifer to be used by Great Plains farmers, the adaptations occurred quickly. In a relatively short period of time, most of the acreage that could potentially be irrigated was being irrigated (Albrecht and Murdock 1985). When other technological developments occurred that made it possible to irrigate areas that could not previously have been irrigated, the adoption of the technology and the expansion of irrigation occurred rapidly. When given the opportunity, incomes and lifestyles expanded quickly.

However, since most humans tend to live their lives to the fullest extent possible, it is not likely that incomes and lifestyles will decline as sharply when the resource that their livelihoods are based on begins to diminish. Rather, farmers will make changes and adaptations with the goal of maintaining their incomes and lifestyles as long as possible. Given this goal of maintaining incomes and lifestyles, understanding the reactions of farmers to resource depletion is made more complex by the fact that adjusting to a declining groundwater resource is only one of the many factors that influence farmers. Farmers are also influenced by changing prices, government programs and many other factors.

In this paper, seven potential adaptations to groundwater depletion will be explored. These include not irrigating at all, reducing the number of acres irrigated, reducing the number of times that crops are irrigated each year, and the adoption of four different irrigation techniques that reduce the amount of irrigation water needed. The most drastic form of adaptation for farmers to take is to stop irrigating altogether. If the farmer chooses this approach, he can revert his previously irrigated cropland to dryland crops or to rangeland for the grazing of livestock.

A second form of adaptation to a declining groundwater supply that farmers may take is to reduce the number of acres irrigated. For some farmers this may occur naturally because as the aquifer declines, the yields from the irrigation wells will decrease and the number of acres that can be irrigated per well will become smaller. Under these circumstances of diminishing groundwater supply, the farmer is not likely to go to the expense of drilling new wells. Other farmers may choose to close some wells and withhold irrigation from some of their more marginal land and thereby conserve the limited water supply for the better cropland. A third form of adaptation to be explored is the reduction in the number of times that crops are irrigated each year, which in turn reduces the total amount of irrigation water that is used. Farmers can accomplish this by planting crops that require less moisture, or by planting the same crops as before and accepting a lower yield.

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Finally, farmers can adopt a variety of irrigation techniques that allow them to conserve irrigation water. As the threats associated with the depletion of the Ogallala Aquifer have become apparent, researchers have developed a number of more efficient irrigation techniques. By more efficiently utilizing the groundwater that is pumped, these techniques allow farmers to get the same amount of water to the root zone of the plants at the time it is most needed while reducing the total amount of groundwater that is pumped. Two of these techniques diminish the amount of water that is necessary to pump by reducing run-off and keeping more water on the fields. The construction of bench terraces of furrow dikes greatly reduces the run-off of both rainfall and irrigation water, and thus reduces the amount of groundwater that is necessary to pump. Furrow dikes are small earth dams that are placed in the furrow about 4 to 10 feet apart and hold moisture on the field where it can be utilized by the crops, while bench terraces are larger constructs that accomplish the same purpose.

A third water conserving irrigation technique is the adoption of center-pivot sprinkler systems. In the early years of irrigation, the water was pumped to the surface where it was then placed in ditches to run to the field and then in furrows where it reached the plants. When using such an irrigation system, a substantial amount of water is lost to evaporation, run-off, and percolation. Percolation is water that is lost because the top of the field becomes thoroughly soaked before water reaches the bottom of the field at all. Irrigation water is used much more efficiently if farmers convert from furrow to sprinkler irrigation systems. Sprinkler systems allow water to be placed evenly all over the field and greatly reduce water losses from evaporation, percolation and run-off. This is especially true of the more recent center-pivot sprinkler systems where the water is sprayed down upon the crops rather than thrown in the air where the amount lost to evaporation increases.

A final way of irrigating more efficiently to be explored in this paper is to utilize automated timers or sensors that detect the level of soil moisture. By knowing the level of soil moisture farmers can assure that crops are irrigated when they need it the most (Lyle *et al.* 1982; Lacewell and Lee 1986).

Factors influencing the adaptations of farmers

Four sets of independent variables will be explored in an attempt to determine if farmers with different characteristics are responding differently to groundwater depletion, and which of these characteristics are most important in determining the form of adaptation that is taken. The first such set of independent variables are the ecological factors. Two ecological variables are used in this paper including the saturated thickness and the

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location of the farm. The saturated thickness is the depth or thickness of the water table under the individual farm. The amount of irrigation occurring in the Great Plains is generally less in areas having a smaller saturated thickness. Further, those areas where the groundwater supply has been depleted most extensively are most likely to be forced to stop or reduce irrigation.

In addition to determining whether or not irrigation can occur, the amount of groundwater available is likely to influence which forms of adaptation are used in response to declining groundwater resources. Albrecht and Ladewig (1985) found that farmers with the most extensive groundwater resources were the most likely to adopt water conserving irrigation techniques. Farmers with a limited groundwater supply could not economically justify the expense of purchasing irrigation conservation equipment that is often very expensive.

For this study, it is hypothesized that farmers with a greater saturated thickness will be the least likely to discontinue irrigating and the least likely to reduce both the number of acres irrigated and the number of times that crops are irrigated each year. It is also hypothesized that those farmers with the greatest saturated thickness will be the most likely to adopt each of the four water conserving irrigation techniques. Farmers with greater water resources are expected to have the water resources to continue irrigating at past levels and also have a sufficient resource to economically justify investing in new irrigation technology.

A second ecological variable used is the location of the farm. In addition to the amount of groundwater under the farm, there are a number of other factors that influence the amount and type of irrigation that occurs. Among these factors are the soil type, contour of the land, and the distance from the ground surface to the water table. One rough measure that takes into account many of these factors is the county in which the farm is located. In the Texas High Plains where this study was conducted, the distance from the ground surface to the water table generally increases as one moves from south to north. Also, however, the saturated thickness of the aquifer tends to increase as one travels from south to north. As for soil type and terrain, the southern High Plains of Texas is among the flattest places in the country. Moving north, one becomes more likely to encounter rolling terrain and sandy soils. The flat terrain and shallow water of the southern High Plains of Texas made it ideal for early irrigators, and this section of the country was extensively irrigated with Ogallala water long before other parts of Texas or other parts of the Great Plains in other states. As a consequence of years of extensive irrigation, the water depletion problem in this part of the state is much more severe than in the northern Texas High Plains. Given these various considerations related to location, it is hypothesized that farmers residing in the southern Texas High Plains will be most likely to quit irrigating altogether,

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to reduce the number of acres irrigated, to reduce the number of times that crops are irrigated, and will be the least likely to adopt each of the four water conserving irrigation techniques.

A second variable that could influence the form of adaptation taken to a declining groundwater resource is to measure the financial condition of the farm. A commonly used measure of the financial condition of the farm is the debt-to-asset ratio (Bultena *et al.* 1986). This measure is derived by dividing total liabilities by total assets. This measure taps the relative indebtedness, and consequently the solvency and risk-bearing ability of the farm enterprise. In a region such as the Great Plains, some of the high debt levels incurred by some farmers may be a consequence of their making very expensive investments into irrigation such as drilling wells and purchasing irrigation technology. However, once this irrigation technology is in place, the farmer will most likely use it in an attempt to recoup some of the investment. Thus, in this study it is hypothesized that farmers with the highest debt-to-asset ratio will be the least likely to not irrigate, the least likely to reduce the number of acres irrigated, the least likely to reduce the number of times that crops are irrigated each year, and the most likely to adopt each of the water conserving irrigation techniques.

The structure of the farm operation may be a third set of factors that influence the form of adaptation taken in response to a declining groundwater resource. The size of the farm (determined here by gross farm sales) and whether or not the farm operator has off-farm employment may influence the reactions of farmers to groundwater depletion. Since larger farms generally have more financial resources and bargaining power with financial institutions, it is hypothesized that larger farmers will most likely adopt each of the water conserving irrigating techniques and also be the least likely to not irrigate, reduce the number of acres irrigated, and reduce the number of times that crops are irrigated each year. In contrast, because part-time farms are smaller, have fewer financial resources, and have less time to devote to the farm, it is expected that they will be the most likely to not irrigate, reduce the number of acres irrigated, and reduce the number of times that crops are irrigated. It is also expected that part-time farms will be the least likely to adopt each of the water conserving irrigation techniques.

Finally, the forms of adaptation utilized by farmers may be influenced by the social and demographic characteristics of the farm operators. The farmers' level of education may enhance their capacity to understand and utilize complex technologies. Also, the number of years in farming may affect the type of adaptations that are made. As farmers near retirement, they may be less concerned about conserving resources for the future. Further, older farmers may also be less able to provide the extensive amount of labor required on an irrigated farm. Thus, it is hypothesized that as the farmers level of education increases, they will be less likely to not irrigate, reduce the

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number of acres irrigated, reduce the number of times that crops are irrigated, and will be more likely to adopt each of the water conserving irrigation techniques. Further, it is expected that farmers with the most experience in farming will be most likely to not irrigate, reduce the number of acres irrigated and the number of times that crops are irrigated each year, and will be the least likely to adopt each of the four water conserving irrigation techniques.

Methods

Data

The data for this study were obtained from a 1987 survey of farm operators in the Texas High Plains. Seven counties were selected for analysis that represented the diversity of the Texas High Plains region. These seven counties are in areas that are heavily irrigated and range from the southern plains south of Lubbock to the northern plains near the Oklahoma border. The seven counties represent areas that are very flat to those with rolling terrain, and include areas with a relatively limited and heavily depleted groundwater supply to those with a much more extensive resource where the amount of depletion has been relatively minimal.

After the seven counties had been selected, a list of all of the farmers in each county was obtained from the county ASCS office. Farmers to be interviewed by telephone were randomly selected from these lists. One hundred farmers were interviewed in each of the seven counties, and in each county successful interviews were completed with more than 80 percent of those contacted. Thus, the following analysis is based on 700 completed interviews.

Measurement of variables

The seven different forms of adaptation to a declining groundwater supply were measured by asking farm operators if during the last five years they 1) had quit irrigating 2) had reduced the number of acres irrigated, and 3) had reduced the number of times that crops are irrigated each year. Farmers were then asked if they used each of the four water conserving irrigation techniques. Thus, all of the dependent variables are in a dichotomous yes/no form.

The saturated thickness was determined by simply asking the farmers. This is something that nearly all High Plains farmers are aware of since it is so important to the operation of their farm. The location of the farm variable was determined by placing the seven study counties into one of three categories. The first category of counties is labeled the shallow-water counties, which includes the three southern-most counties in the study. For

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the most part, these counties are extremely flat and have a relatively limited groundwater supply that has been extensively depleted. As a result, the number of acres irrigated in these shallow-water counties has declined considerably in recent years.

The two counties in the central part of the region are labeled the medium-water counties. These counties have a deeper but more extensive groundwater supply than the previous set of counties. The deeper water resulted in irrigation development coming later, but the more extensive water supply has allowed the total amount of irrigation to surpass that occurring in the shallow-water counties. The remaining two study counties are located in the Northern High Plains of Texas near the Oklahoma border. A relatively deep but extensive water supply was tapped for widespread irrigation years later than in the other study regions. Consequently, the amount of groundwater depletion in these counties is much less than in other parts of the study region.

In measuring the remaining variables, the debt-to-asset ratio was determined by asking farmers their total assets and their total liabilities, and then dividing the total debts by the total assets. Gross farm sales were self-reported by the farm operator for 1986. Off-farm employment was determined by asking producers if they had an off-farm job in 1986. Number of years in farming was self-reported by the farm operator, and level of education was assessed by asking producers the highest level of formal education that they had achieved. For the education variable, eight categories were used which ranged from less than a grade school education to a graduate or professional degree.

Data analysis

The data are reported in three sections. First, frequencies are presented showing the proportion of the farmers in the study utilizing each of the seven forms of adaptation. Following this, a bivariate analysis is made comparing the characteristics of farmers using and not using each form of adaptation studied in this paper. Finally, logistic regression is used to provide a multivariate analysis of the characteristics of farms most and least likely to use each form of adaptation to a declining groundwater resource. Logistic regression is used because the dependent variables are dichotomous.

Findings

In Table 1, data are presented which show the proportion of farm operators in the study that have adopted each of the seven ways of dealing with a declining groundwater supply. This table shows that only one of the forms of adaptation is being utilized by a majority of the farm operators in

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Table 1. Percentages of Texas High Plains farmers (N = 700) using various forms of adaptation to declining groundwater supplies

ADAPTATION	PERCENT USING
No Longer Irrigate*	29
Reduced Number of Acres Irrigated	41
Reduced Number of times Crops are Irrigated Each Year	56
Use Center-Pivot Sprinklers	32
Use Furrow Dikes	34
Use Bench Terraces	13
Use Moisture Sensing Instruments	13

*Those who no longer irrigate are eliminated from further analysis.

the study. Fifty-six percent of the farm operators have reduced the number of times that crops are irrigated each year. At the other extreme, only 13 percent of farm operators are using bench terraces or moisture sensing instruments. It was found that nearly one-third (29 percent) of the farm operators were no longer irrigating. Persons no longer irrigating were not questioned about their use of the other water conserving techniques. While most of the conservation techniques have not been adopted by a majority of the farmers, only four percent of the farmers had not adopted any of the conservation techniques. Thus, it appears that nearly all of the farmers have made some efforts to conserve the limited groundwater supply, but the approach taken varies greatly from farmer to farmer.

Table 2 presents data which compare the characteristics of the persons who have adopted each of the approaches for dealing with a declining water supply with those who have not adopted. This table allows a direct bivariate test of the study hypotheses. The first column in Table 2 compares the average saturated thickness of those who have adopted each of the approaches with those who have not adopted them. It was found that there are significant differences between adopters and nonadopters on four of the seven forms of adaptation. As expected, persons not irrigating in 1986 had a substantially smaller saturated thickness (62.2 feet) than those who irrigated in 1986 (102.5 feet). Also as expected, persons adopting center-pivot sprinklers had a substantially greater groundwater supply than those not adopting this technique. Contrary to expectations, however, farmers adopting both furrow dikes and bench terraces had a significantly smaller saturated thickness than those who have not adopted these technologies. The differences in saturated thickness between the adopters and nonadopters for the other three forms of adaptation are not statistically significant.

In looking at the adoption of the water conserving irrigation techniques in retrospect, it may be that the difference in the technologies have influenced the variations in who adopts them. A center-pivot sprinkler irrigation system

Table 2. A comparison of the characteristics of persons using and not using each form of adaptation to declining groundwater supplies (N = 700)

ADAPTATION	AVERAGE SATURATED THICKNESS	LOCATION OF FARM (PERCENT)			AVERAGE DEBT-TO-ASSET RATIO	AVERAGE GROSS FARM SALES	PERCENT WITH OFF-FARM EMPLOYMENT	AVERAGE NUMBER OF YEARS FARMED	LEVEL OF EDUCATION
		SHALLOW WATER	MEDIUM WATER	DEEP WATER					
Irrigated in 1986** (N = 700)									
Yes (N = 497)	102.5*	62*	89	65	43.2*	\$159,377*	19*	24.5	5.6
No (N = 203)	62.2	38	11	35	32.8	\$59,942	43	24.8	5.5
Reduced Number of Acres Irrigated (N = 497)									
Yes (N = 204)	103.4	40	36	49	43.8	\$153,515	17	25.2	5.7
No (N = 293)	99.8	60	64	51	43.4	\$161,645	19	24.0	5.5
Reduced Number of Times Crops Are Irrigated Each Year (N = 497)									
Yes (N = 278)	108.5	43*	36	57	45.0	\$154,682	21	25.2	5.7
No (N = 219)	97.0	57	64	43	40.9	\$165,342	17	24.0	5.5
Use Center-Pivot Sprinklers (N = 497)									
Yes (N = 159)	133.2*	17*	37	47	49.5*	\$210,570*	17	24.2	5.7
No (N = 338)	85.7	83	63	53	41.1	\$137,557	19	24.4	5.5
Use Furrow Dikes (N = 497)									
Yes (N = 169)	73.3*	55*	28	13	48.0*	\$130,053*	22	23.1	5.6
No (N = 328)	117.3	45	72	87	40.4	\$175,120	17	25.3	5.6
Use Bench Terraces (N = 497)									
Yes (N = 65)	54.4*	27*	5	4	51.6*	\$190,165	15	23.6	5.6
No (N = 432)	109.4	73	95	96	41.9	\$154,255	19	24.7	5.6
Use Moisture Sensing Instruments (N = 497)									
Yes (N = 64)	110.7	10	16	15	39.1	\$205,040	12	25.4	5.7
No (N = 433)	100.9	90	84	85	44.0	\$151,267	20	24.4	5.6

*Differences are statistically significant at the .05 level.

**Persons not irrigating in 1986 are eliminated from the remainder of the analysis.

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is extremely expensive and farmers are not likely to make such a large investment unless they have a sufficient water resource to enable them to irrigate enough to justify the expense. In contrast, bench terraces and especially furrow dikes are substantially cheaper to implement and may be appealing to farmers who wish to conserve a limited resource.

The second variable shown in Table 2 is the location of the farm. Differences in the location of the farm between those using and those not using the various forms of adaptation were statistically significant on five of the seven adaptations studies. It was found that people in the medium water areas were the least likely to quit irrigating. Only 11 percent of the farmers in the medium water areas had quit irrigating, compared to 38 percent in the shallow water areas and 35 percent in the deep water areas. Apparently, a depleted resource is causing farmers to quit irrigating in the shallow water areas, while the high costs of pumping the deep water areas are having the same consequence. Table 2 also shows that farmers in the medium water areas are the least likely to reduce the number of times that crops are irrigated each year. The differences were not significant on reducing the number of acres irrigated.

When examining the adoption of each of the four water conserving irrigation techniques, it was found that farmers living in the deep water areas were the most likely to adopt the center-pivot sprinkler because they have a resource sufficient to justify it. In contrast, farms in the shallow water areas were significantly more likely to adopt furrow dikes and bench terraces in an attempt to conserve their limited resource. The differences on the use of moisture sensing instruments were not statistically significant.

The third variable shown in Table 2 is debt-to-asset ratio where differences were significant for four of the adaptations. As expected, farmers who irrigated in 1986 had a significantly higher debt-to-asset ratio than those who did not. Also, as hypothesized, farmers with higher debt-to-asset ratios were the most likely to adopt center-pivot sprinklers, furrow dikes, and bench terraces.

The data in Table 2 reveal that farmers who irrigated in 1986 had substantially higher gross farm sales (\$159,377) than those who did not irrigate (\$59,942). It was also found that those using center-pivot sprinklers had substantially greater gross farm sales than the nonadopters, while the adopters of furrow dikes had significantly lower gross farm sales than the nonadopters.

It was hypothesized that persons who irrigated would be less likely to have an off-farm job than those who did not irrigate. The data in Table 2 provide strong support for this hypothesis. Only 19 percent of the farmers who irrigated in 1986 had an off-farm job, compared to 43 percent of those who did not irrigate. The differences in off-farm employment between adopters and nonadopters of the other water conserving irrigation techniques

were not statistically significant. Further, when examining the two social and demographic variables (number of years in farming and level of education), none of the differences between adopters and nonadopters were statistically significant.

In Table 3, data are presented which show the results of the logistic regression analysis. For this analysis, the seven forms of adaptation to groundwater depletion were used one at a time as the dependent variables, while the personal and farm characteristics were used as independent variables. This multivariate analysis allows a determination of the effects of the various independent variables while controlling for the effects of the other independent variables. The table presents the odds ratio of answering "yes" for each of the dependent variables. The first variable shown deals with whether or not the farmers irrigated in 1986. Consistent with the bivariate analysis, it was found that those most likely to be irrigating in 1986 included farmers living in medium water areas, those with a high debt-to-asset ratio, with high gross farm sales, and those with no off-farm employment.

On each of the next two dependent variables, reducing the number of acres irrigated and reducing the number of times crops are irrigated, only one variable had a statistically significant relationship. In both cases, this variable was level of education. It was found that persons with more formal education were the most likely to both reduce the number of acres irrigated and the number of times that crops are irrigated. At the bivariate level, none of the independent variables were significantly related to reducing the number of acres irrigated, while only the location of the farm was related to reducing the number of times that crops are irrigated.

In the logistic regression analysis, three of the independent variables were significantly related to the use of center-pivot sprinklers. These three variables included the location of the farm, the debt-to-asset ratio, and gross farm sales. Saturated thickness was significant in the bivariate analysis but became insignificant at the multivariate level. As was the case with the bivariate analysis, those most likely to adopt center-pivot sprinklers included farmers in deep and medium water areas, farmers with high debt levels, and farmers with larger gross farm sales.

An examination of the multivariate analysis for the use of furrow dikes shows that two of the independent variables had a significant relationship including the location of the farm and gross farm sales. The saturated thickness of the aquifer under the farm and debt-to-asset ratio were significantly related to the use of furrow diking at the bivariate level but became insignificant when the effects of the other independent variables were controlled for. As was found in the bivariate analysis, those most likely to use furrow diking included those living in shallow water areas and those with lower gross farm sales.

Table 2. Logistic regression of various forms of adaptation to declining groundwater supplies (N = 700)

INDEPENDENT VARIABLE	IRRIGATED* IN 1986		REDUCED NUMBER OF ACRES IRRIGATED		REDUCED NUMBER OF TIMES CROPS ARE IRRIGATED		USE CENTER-PIVOT SPRINKLERS		USE FURROW DIKES		USE BENCH TERRACES		USE MOISTURE SENSING INSTRUMENT	
	ESTIMATE	X ²	ESTIMATE	X ²	ESTIMATE	X ²	ESTIMATE	X ²	ESTIMATE	X ²	ESTIMATE	X ²	ESTIMATE	X ²
Intercept	.42	NS	-1.93	5.06	-2.40	7.68	-1.99	4.40	-1.83	3.80	-3.46	5.56	-1.81	NS
Saturated Thickness	.00	5.62	-.00	NS	.00	NS	.00	NS	-.00	NS	-.00	NS	.00	NS
Location of Farm														
-Shallow water	-.38	24.73	-.00	NS	-.01	NS	-.54	6.61	.98	23.66	1.54	21.90	-.31	NS
-Medium water	1.23	24.73	-.21	NS	-.29	NS	.30	6.61	-.41	23.66	-1.16	21.90	.23	NS
-Deep water**	.85	24.73	.21	NS	.30	NS	.24	6.61	-.57	23.66	-.38	21.90	.08	NS
Debt-to-Asset Ratio	.89	7.65	-.06	NS	.10	NS	.61	6.50	-.08	NS	.14	NS	-.07	NS
Gross Farm Sales	.00	15.86	-.00	NS	-.00	NS	.00	4.14	-.00	4.00	.00	NS	.00	NS
Have Off-Farm Employment	-.51	12.41	-.02	NS	.21	NS	-.03	NS	.15	NS	.28	NS	-.38	NS
No Off-Farm Employment**	.51	12.41	.02	NS	-.21	NS	.03	NS	-.15	NS	.28	NS	.38	NS
Years in Farming	-.01	NS	.00	NS	.01	NS	.01	NS	.01	NS	.18	NS	-.00	NS
Level of Education	-.13	NS	.31	5.25	.38	7.50	-.00	NS	.25	NS	.08	NS	-.06	NS
LR X ²	378.43		388.18		379.40		328.93		339.90		190.89		250.99	
DF	404		286		278		283		287		287		287	
Probability	0.81		0.0001		0.0001		0.03		0.02		1.00		0.94	

*Persons who did not irrigate in 1986 are eliminated from further analysis.
 **Values were suppressed during the analysis and have been calculated.
 NS - Not Significant

With respect to the logistic regression for the use of bench terraces, it was found that only the location of the farm had a significant relationship. Here it was found that persons living in the shallow water areas were the most likely to use this form of adaptation to a declining groundwater supply. Finally, as was the case with the bivariate analysis, none of the independent variables were significantly related to the use of moisture sensing instruments.

Conclusions

In recent years, American agriculture has been beset by a host of resource depletion problems. As of yet, however, researchers have not extensively examined the forms of adaptation that individual farm operators make in response to resource depletion, and if the adaptations that are made vary with the farm or personal characteristics of the farm operator. This paper attempts to partially fill this void and provide a preliminary examination of the responses of farm operators in the Texas High Plains to the problem of a declining groundwater supply.

It was found that the proportion of farm operators who had adopted each type of adaptation varied significantly, but most of the approaches are not being extensively utilized. It was also found that there were significant differences in the characteristics of the adopters and nonadopters of these various forms of adaptation. Generally, the economic and environmental factors were critical in determining which technologies were adopted.

The findings of this research raise a number of important questions about resource depletion issues in general and the Ogallala Aquifer in particular. To begin with, the results of this study show that many farmers are continuing to irrigate using less efficient irrigation techniques. This becomes problematic when it is considered that in many parts of the Great Plains, the Ogallala Aquifer is the only source of water for both agricultural and nonagricultural needs. To what extent should farmers be allowed to exhaust a resource that is virtually nonrenewable, given the negative effects that this may have for the rest of the communities? Further, researchers should explore the relative effectiveness of various approaches of conserving groundwater in the Great Plains such as economic incentives, educational programs, and government regulations. Also, additional research is needed to determine the relationship between government farm programs and the amount of irrigation in the Great Plains.

Obviously, a great deal of additional research is needed on this topic. Researchers should attempt to better understand the adaptations that farmers make in response to the depletion of other resources in other areas and determine which farm and personal characteristics are most important in determining which forms of adaptation are made. Improved theoretical models are needed which allow the generalization of empirical findings. A longitudi-

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nal research design may be especially useful in understanding the reactions of farmers and the factors influencing these reactions. As modern agricultural practices continue to result in a variety of resource depletion problems, rural sociologists need better insight concerning the consequences of these problems than they currently have. It is toward this goal that additional research is encouraged.

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