# The adoption and diffusion of strategic investments: The case of land leveling in central Arizona

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Anderson, David Philip, M.S.

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U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

# THE ADOPTION AND DIFFUSION OF STRATEGIC INVESTMENTS: THE CASE OF LAND LEVELING IN CENTRAL ARIZONA

by

David Philip Anderson

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STATEMENT BY AUTHOR

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This thesis has been approved on the date shown below:

Paul N. Wilson 12/29/89

Dr. Paul N. Wilson
Associate Professor
of Agricultural Economics

Date

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## ABSTRACT

Previous adoption and diffusion literature had only studied innovations oriented towards operating inputs. This thesis examines the adoption and diffusion of a strategic investment - land leveling. Logit analysis is used to identify the characteristics of adopters of dead level fields. The diffusion of dead level fields is fitted to a logistic function. The data revealed three intra-period diffusion curves that seem to be responses to non-relative price stimuli. The diffusion of the strategic investment - dead level fields - seems to be increased only by government action.

# CHAPTER ONE

## Historical Background

Irrigated agriculture began in Arizona around the year 300 B.C. when the Hohokam Indians of Central Arizona began to develop an intricate canal system in the Salt and Gila River valleys (Hadingham, 1982). By 1100 A.D. there were an estimated 200,000 Hohokam living in Central Arizona. Fields of beans, grains, melons, squash, maize, and cotton, were irrigated by more than 200 miles of canals (Johnson, 1977).

Sometime around the 14th century the Hohokam disappeared. The reason for their disappearance is unclear but some theories suggest a severe drought, alkali buildup in their fields due to the overuse of water, canals silting up, or a combination of these factors (Johnson, 1977, Powell, 1976). Whatever the reason, it appears that water played a large role in the rise and the fall of their civilization.

In the 16th century Spanish conquistadors and missionaries explored Arizona. When Father Eusebio Kino entered Arizona in the late 1600s he found Pima Indians irrigating small fields of maize, beans, and peas in central

Arizona (Peplow, 1958). Spanish settlers started large cattle and sheep ranches but did nothing to develop the remains of the Hohokam canals.

Until the end of the Civil War agriculture in Arizona consisted of cattle and sheep ranches and small irrigated plots of land. In the late 1860s the Swilling Ditch Company began to build canals and brush diversion dams along the Salt River to irrigate hay fields. Swilling used the same canals that the Hohokam had built hundreds of years earlier. At about the same time large scale irrigation began in the Yuma Valley using Colorado River water.

By the 1890s 120,000 acres of citrus, cotton, alfalfa, and assorted grains and vegetables were being irrigated in the Salt River Valley. Large acreage was also being irrigated in the Yuma Valley and along the Gila River. Severe floods on the Salt River in 1890 and 1891 destroyed many of the brush dams and canals. The floods, combined with an extreme drought from 1897 to 1899, made clear the need for upstream dams to provide flood control and water storage. The National Reclamation Act of 1902 provided the means for the construction of six dams along the Salt and Verde Rivers between 1911 and 1945 to provide a reliable source of water for irrigation for Central Arizona. These dams, along with dams built along the Gila and Colorado Rivers, also provide electrical power for Central Arizona. The power is sold at a subsidized rate by the Federal Government. This electricity is used by farmers to pump groundwater for irrigation uses.

The Gila, Salt/Verde rivers, and the Colorado River are the only major natural sources of surface water in Arizona. Reservoirs, created by dams, along these rivers provide water for low rain years. Essentially all surface waters are stored or diverted for use.

Groundwater pumping to augment surface water supplies began around 1900 in Arizona. About 200,000 acre feet of ground water was pumped in 1920. By 1945 annual groundwater use had risen to 1.5 million acre feet. Public concern about the overdraft issue began in the 1930s. This concern prompted several government studies on the problem. Due to this pressure the state legislature passed the Critical Groundwater Act of 1948.

The 1948 Act allowed for the declaration of critical groundwater areas where new wells would be prohibited. The law did not limit the amount of water that could be pumped from existing wells. It also did not apply to domestic, industrial, or stock watering uses of water. These shortcomings allowed the overdraft to continue to grow. Four and a half million acre feet were pumped in 1953. Ground water pumping in excess of recharge grew at an increasing rate during this period reaching an estimated 2.2 million acre feet annually by the 1980s.

The Central Arizona Project (CAP), a manmade aqueduct, supplies surface water from the Colorado River to Maricopa, Pinal, and Pima counties. The idea to pump Colorado River water to serve agricultural and urban water users in central Arizona was first proposed in the 1920s. In 1944 when Arizona signed the Colorado River Compact it contracted for 2.8 million acre feet of Colorado River water annually. Lobbying by Arizona's congressional delegation over the next twenty years resulted in construction approval for the CAP in 1968. Farmers in central Arizona began taking delivery of CAP water in the last half of the 1980s.

Encouraged by abundant supplies of surface and groundwater, Arizona's agricultural and urban areas expanded. Table 1.1 shows the growth of farming and population in Arizona during the 20th century. By 1980 1.2 million acres of cotton, small grains, alfalfa, citrus, and vegetables were being grown up from about 600,000 acres in 1930. Over this same period the state's population grew from 435,000 to 2.7 million people.

Table 1.1 Arizona Population and Acreage Planted to Major Crops.

| YEAR | POPULATION | ACREAGE |
|---|---|---|
| 1900 | 122,931 | NA |
| 1910 | 204,354 | NA |
| 1920 | 334,162 | 500,000 |
| 1930 | 435,573 | 600,000 |
| 1940 | 499,261 | 800,000 |
| 1950 | 749,587 | 1,150,000 |
| 1960 | 1,302,161 | 1,400,000 |
| 1970 | 1,775,399 | 1,219,030 |
| 1980 | 2,718,215 | 1,267,300 |

Sources: 1980 Census of Population, US Dept. of Commerce. Arizona Agricultural Statistics

In 1980 the Bureau of Reclamation required that something be done to control the groundwater overdraft or the CAP would not get further funding for construction. It was clear that a plan to manage the state's groundwater resources would have to be implemented if Arizona were to continue to grow and prosper, or even maintain itself at its current levels. This realization led to the creation of the Groundwater Management Act (GMA) of 1980.

## 1980 Groundwater Management Act

The 1980 GMA was negotiated by a commission made up of representatives from the State Legislature, cities, mining, agriculture, Indian tribes, utilities, and the general public. The purpose of the Act is to provide a comprehensive plan for groundwater conservation and management.

The Act designated four water basins as Active Management Areas (AMAs) (figure 1.1). These four areas, Phoenix, Tucson, Pinal, and Prescott, comprise 80 percent of the state's population and 69 percent of the state's groundwater overdraft. Additional AMAs may be created by the Director of the Department of Water Resources (DWR) or by the people of the area if necessary to protect and preserve the water supply. In addition to the four AMAs, the Douglas and Joseph City Irrigation Non-Expansion Areas (INAs) were created in 1980. A third INA, the Harquahala, was designated by the Director in 1982. INAs are designated when there is insufficient groundwater to provide a reasonably safe supply for irrigation of cultivated lands in the area at the current rate of withdrawal. In these areas cultivation is limited to acreage that was irrigated in the five years prior to the designation of the area as an INA. Most provisions of the 1980 GMA apply only to AMAs.

The goal of the Phoenix, Tucson, and Prescott AMAs is safe yield by January 1, 2025. Safe yield is the "long term balance between groundwater withdrawals and natural and artificial groundwater recharge" (Johnson, 1981). The Pinal

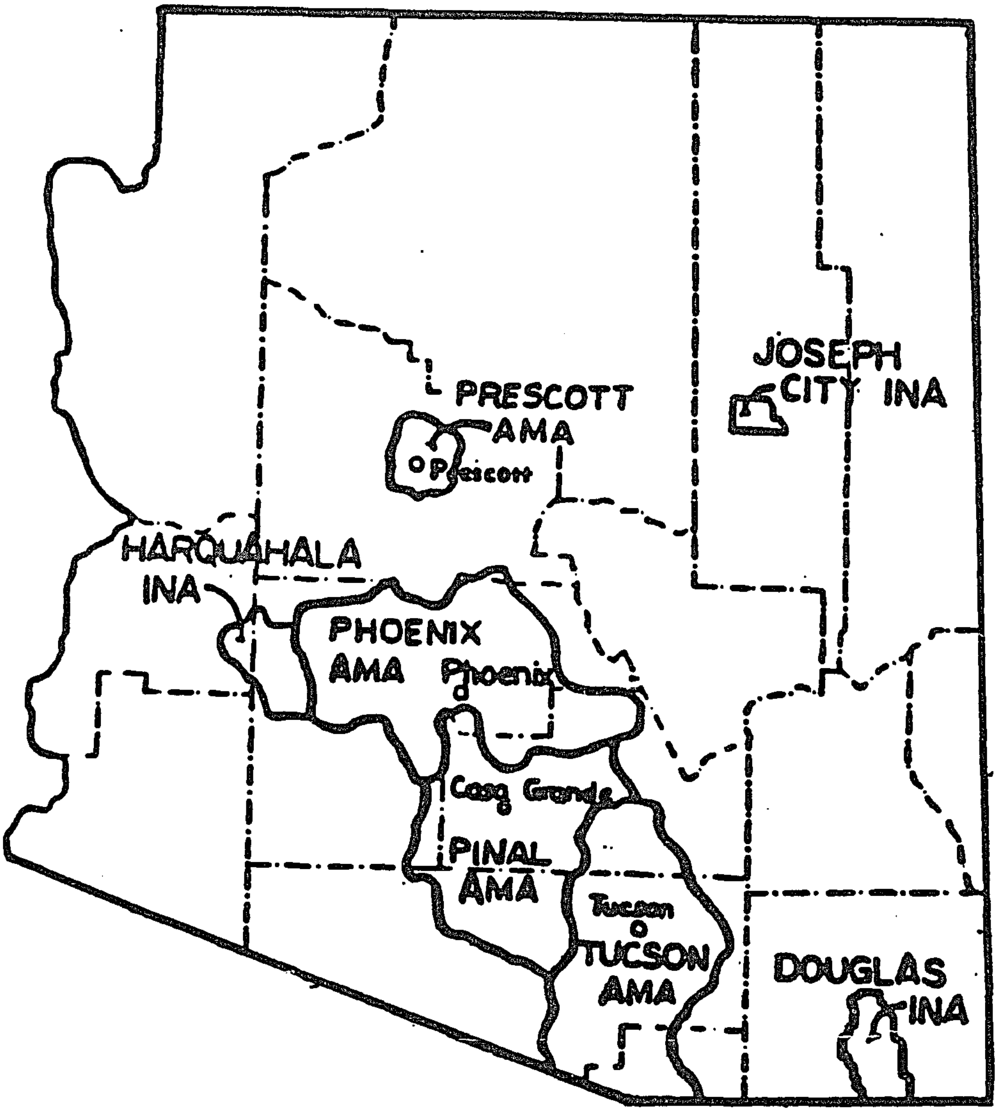
AMAs goal is "to allow the development of non-irrigation uses, extend the life of the agricultural economy for as long as possible, and preserve water supplies for future non-irrigation uses" (Water Planning News, 1988).

There are five management periods for each AMA covering the years 1980 to 2025. The management plan for each period will impose tougher conservation measures on all groundwater users in the area. If the plans do not meet conservation goals sufficiently by 2006, then the Director of the Department of Water Resources (DWR) is authorized to buy and retire irrigation water rights.

When the Act was passed, all legal uses of groundwater in the AMAs became "grandfathered" and could be continued. There are tree types of grandfathered rights designated by the 1980 GMA. The first is an Irrigation Grandfathered Right. This right applies to land that was irrigated during the five years prior to January 1, 1980. Only the land previously irrigated has an irrigation right. This right can be transferred to others for farming or non-irrigation uses. However, once the right is transferred to a non-irrigation use it can never be used for irrigation again.

The second type of right is the Type I Non-Irrigation Right. When an irrigation right is purchased and retired

Figure 1.1 AMAs and INAs in Arizona




source: Arizona Department of Water Resources, Pinal AMA Second Management Plan, 1988.

from the land it becomes a Type I right and can not be converted back to an irrigation right. The right will usually be three acre feet of water annually which can be used for any purpose other than for irrigation. Possible uses include industrial uses, water for housing developments, and commercial enterprises.

The third type of grandfathered right is the Type II Non-Irrigation Right. These are based on uses of water other than irrigation before the AMA was formed. The maximum amount of water held by the right is the highest amount of groundwater used in any of the five years prior to the creation of the AMA. These rights can be used for any purpose other than irrigation and can be transferred freely.

Additional permits for the pumping of groundwater may be granted by the Director of the DWR. These can be issued to mines, industrial complexes, or any other special use where extra water is deemed necessary. Permits are issued for a limited time only and are therefore not a permanent right.

To fund the implementation of the GMA a water withdrawal fee was levied. The tax will be collected form each person pumping groundwater in the AMA. By law the tax can not exceed five dollars per acre foot pumped.

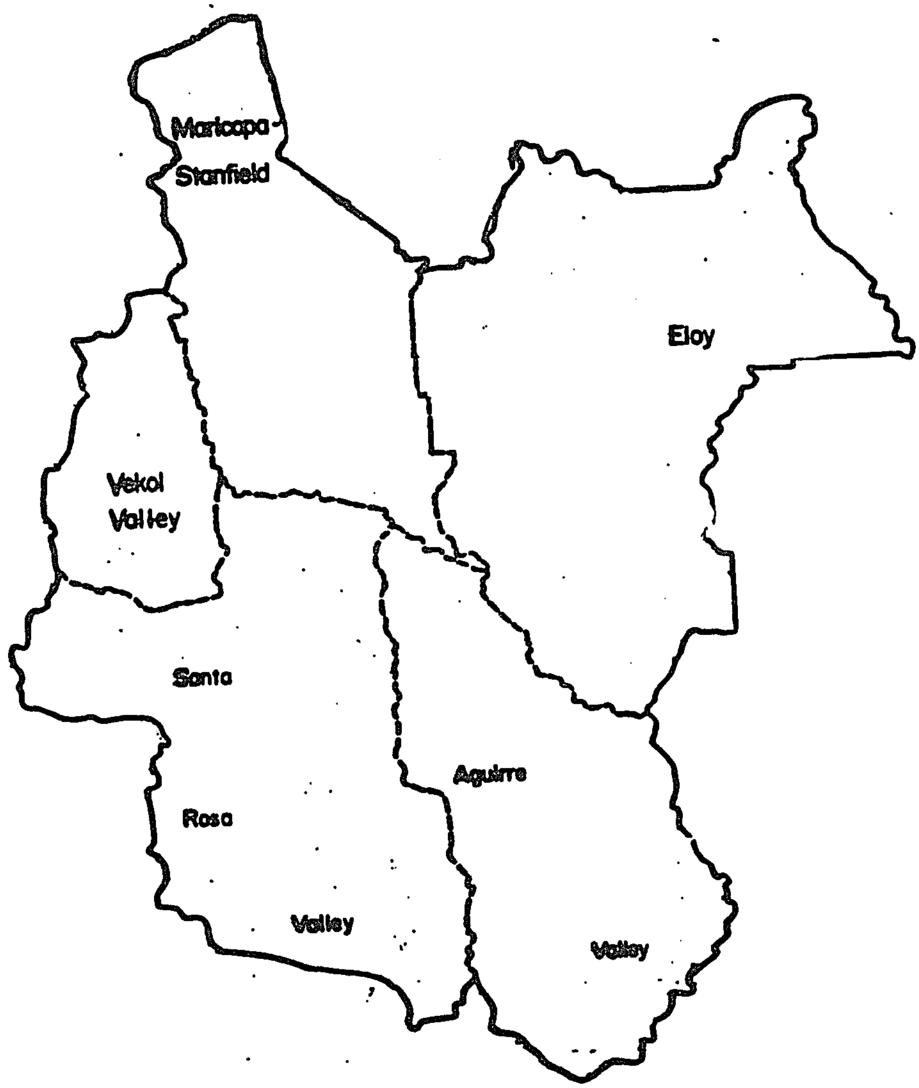
Pinal AMA

The Pinal AMA covers about 4000 square miles in Central Arizona (figure 1.2). Figure 1.1 shows the proximity of the Pinal AMA to the rest of the state. This area includes all of the major agricultural area of Pinal County and small parts of Pima and Maricopa Counties. Cotton, wheat, barley, and alfalfa are the major crops grown. In addition to these crops some vegetables, melons, grapes, pecans, and citrus are produced.

The AMA also includes the Ak Chin Indian Reservation and parts of the Gila River and Tohono O'odom Indian Reservations. These Native American communities are not bound by the 1980 GMA. However they have begun to implement water conserving irrigation practices. In 1980 about 65,000 acre feet of water were used to irrigate approximately 18,000 acres of reservation farmland. By 2025 the number is expected to increase to 200,000 acre feet of water and 42,000 acres of farmland due to CAP water allocations.

The AMA is characterized by declining water tables. Water tables have declined as little as 50 feet in some areas and as much as 550 feet in other areas between 1900 and 1983 (DWR, 1988). Much of this water table decline has occurred since the early 1950s when pumping began in

Figure 1.2 THE PINAL AMA




source: Arizona Department of Water Resources, Pinal AMA Second Management Plan, 1988.

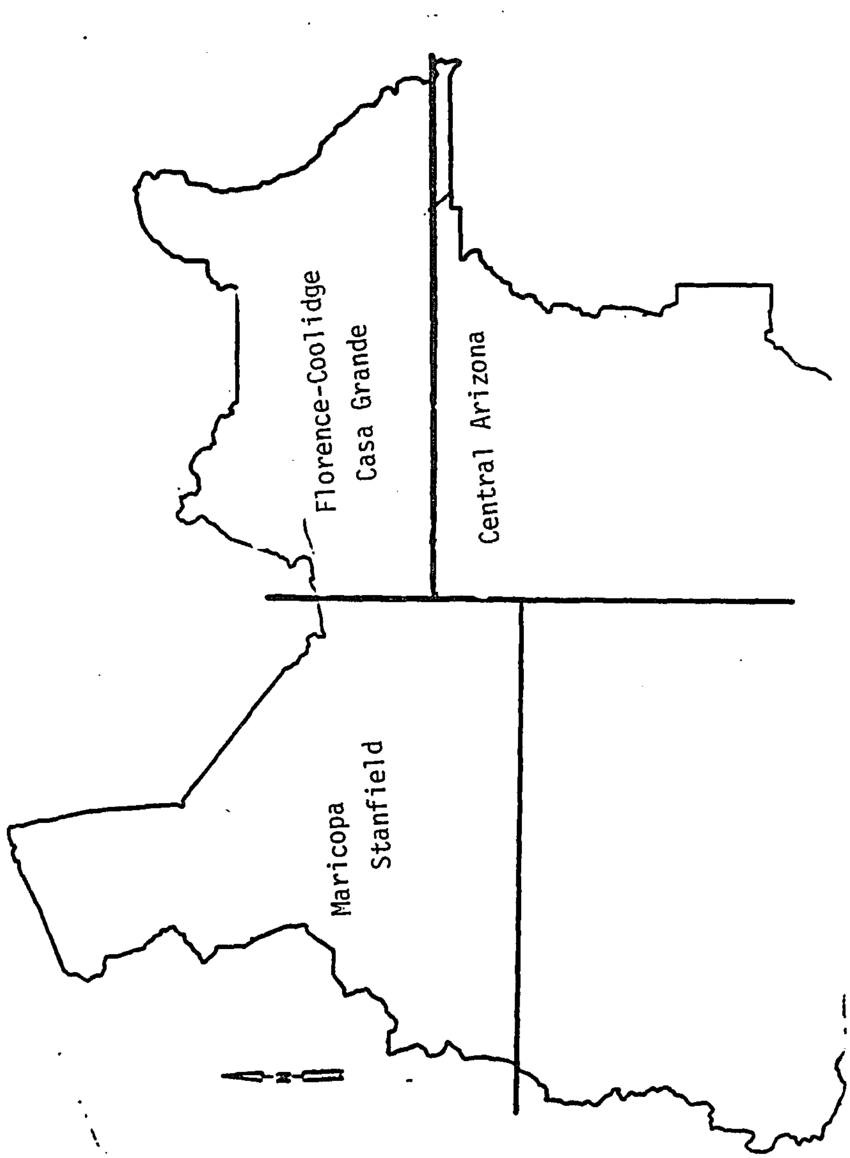
earnest. Figure 1.3 shows the pumping lift decline in the AMA. The pumping lift has declined about 150 feet in the Florence-Coolidge-Casa Grande area. A large portion of the irrigation water in this area is surface water from the Gila River supplied by the San Carlos Irrigation District. Water tables have declined 200 to 300 feet in the Central Arizona area and from 250 feet to more than 450 feet in the Maricopa-Stanfield area. These two areas have relied almost exclusively on groundwater for their irrigation needs.

The major towns in the area are Casa Grande, Coolidge, Eloy, Florence, Maricopa, and Stanfield. The AMA had a population of 56,000 in 1985 and is expected to reach 137,000 people by the year 2025.

The stated goal of the Pinal AMA is "to allow the development of non-irrigation water uses, extend the life of the agricultural economy for as long as feasible, and preserve water for future non-agricultural uses" (DWR, 1988). To accomplish the goal, plans for water conservation and management have been established for all agricultural, urban, and industrial users of water.

The foundation of the water conservation program for agriculture is the assignment of irrigation water duties and irrigation efficiencies. The irrigation water duty is the

Figure 1.3 Water Table Decline in the Pinal AMA.




source: Arizona Department of Water Resources, Pinal AMA Second Management Plan, 1988.

"quantity of water reasonably required to irrigate the crops historically grown on the farm unit" (DWR, 1988). The DWR uses the following formula to calculate the irrigation water duty:

$$\text{Irrigation Water Duty} = \frac{\text{Total Irrigation Requirement} \,/\, \text{Total Planted Acres}}{\text{Assigned Irrigation Efficiency}}$$

The numerator is the average annual irrigation requirement per acre for the crops grown from 1975 to 1979. The irrigation efficiency measures the effectiveness of the water application practice. It is calculated by dividing the total amount water required by the plant by the total volume of water applied.

To calculate the maximum annual groundwater allotment the irrigation water duty is multiplied by the water duty acres. The water duty acres are the largest number of acres irrigated in one year between 1975 and 1979.

The assigned irrigation efficiency is determined by "the maximum conservation consistent with prudent long-term farm management practices within an area of similar farming conditions (A.R.S., 45-565.A.1)." The Department of Water Resources defines prudent long-term management practices to be those that are commonly used on Central Arizona farms and are economically feasible.

The 1980 Pinal AMA management plan, covering the years 1980-1990, concluded that concrete lined ditches, land leveled to grade with quarter mile runs and efficient water application practices were reasonable minimum conservation methods for all farms in the AMA. These methods provide an estimated 60 percent irrigation efficiency. Therefore, the minimum assigned irrigation efficiency in the AMA was 60 percent. The average water use in the AMA at the time the first management plan was written was 5.8 acre feet per acre. The average water duty assigned during the first management plan was 5.0 acre feet per acre.

The second management plan covers the period 1990 - 1999. The DWR studied eleven designated Areas of Similar Farming Conditions and determined that it is feasible for most farms to install level basin irrigation systems by the end of the second management plan in 1999. By using good management practices this type of system can provide an irrigation efficiency of 85 percent. Allowances can be made for soils and orchards that prohibit the use of basin level systems. In these later cases irrigation efficiencies of 75 percent and 65 percent have been assigned. The average irrigation water duty was lowered from 5.0 acre feet per acre during the first management plan to 3.75 acre feet per acre during the second management plan.

The GMA allows for a "flexibility account" to be set up for each farm. This account permits the farmer to use more or less water than is allotted to the farm. Water used in excess of the maximum amount is debited to the account. When an amount of water less than the maximum allotment is used a credit is applied to the account. The farmer is not allowed to borrow more than 50 percent of their maximum annual groundwater allotment. The amount of water credited to their account may be used at any time. The purpose of this account is to allow the farmer the flexibility to adjust to changing environmental and economic conditions.

Irrigators are required to report the amount of water withdrawn annually. This information is used by the DWR to monitor compliance of farmers with the management plan. Civil penalties of up to $10,000 per day may be levied against persons found in violation of the code.

The Department of Water Resources also applied appropriate and efficient conservation measures to the providers of water for use in cities and towns. Each water provider was assigned a gallons per capita per day (GPCD) amount that was based on the average water used of existing residential and industrial used plus the expected average water use of new residential and industrial users.

The 1980 GMA required that all land to be sold for subdivision have an assured water supply. An assured supply is the amount of water sufficient and continuously available to satisfy the water needs of the project for at least 100 years. The proposed water use must also be consistent with the management plan and achievement of the management plan's goals. To prove an assured supply the developer must either arrange for service by a designated municipal water provider, one that already has an assured supply, or get a certificate verifying an assured supply. Having a contract for Central Arizona Project water was deemed to be verification of an assured supply. In the year 2001 all developers must again prove an assured supply in addition to meeting the requirements of the second management plan. CAP contracts will no longer be proof of an assured supply after this date.

Industrial users are those who don't receive water from cities or private water companies. These types of industries are turf related businesses, dairies, feedlots, and gravel operations, metal mining, electrical power generation and other industrial users. In 1985 these users accounted for one percent of the water used in the Pinal AMA. Turf facilities have been assigned an average application of 4.6 acre feet per acre. Dairies have been instructed to cut water use by using more efficient means of udder washing and by recycling waste water. They are allowed 120 gallons per day per lactating cow and 20 gallons per day per dry or replacement cow. Cattle feedlots use water for livestock drinking, dust control, feed mixing, environmental control, health control, and fire protection. They are required to pave all roads in the feedlots and are given an allotment of 30 gallons per day per animal. Sand and gravel operations, mines, electric power generators, and other industries all must submit conservation plans to the Department of Water Resources for approval.

The Pinal Management Plan promotes the development of water supply augmentation and reuse to support water conservation plans. The goal of augmentation and reuse is to develop additional water supplies and maximize renewable water. The plan suggests three augmentation methods. One is the importation of water, which is performed by the CAP. The second method is water storage. Building storage facilities for flood waters or unused CAP water can help provide for future needs. The third is artificial groundwater recharge. This involves using basins to enhance natural recharge. The water to recharge could be effluent, CAP water, or captured flood waters.

Effluent constitutes the only source of water in the AMA whose supply is increasing. It is a major source of water for reuse. About 4,000 acre feet of effluent is generated in the Pinal AMA, and 2,000 more acre feet are expected by the year 2000 (DWR, 1988). Approximately 1680 acre feet of effluent was used for agriculture in 1988 (Lieuwen, Anderson, and Wilson, 1988). Another 952 acre feet were included in a proposed effluent recharge project in the AMA.

The Pinal management plan also includes provisions for protecting groundwater quality. Its goal is to maximize the quantity of water available for beneficial use. To achieve this goal the DWR will implement strategies to: 1) prevent the introduction of contaminants into the aquifer, 2) prevent the migration of poor quality groundwater, 3) encourage beneficial use of poor quality groundwater, and 4) conduct programs to correct groundwater quality problems (DWR, 1988). Future plans will be implemented as needed.

The Pinal AMA plan is estimated to reduce the groundwater overdraft in the AMA by 55 percent, but not eliminate it. More conservation will be needed after the end of this management period in the year 2000.

Water Saving Technologies

The irrigation method most commonly used in Central Arizona has been the flood irrigation of furrowed or bordered fields. The fields are leveled to slope and the water is transferred from a ditch on one side of the field. An irrigation efficiency of 50% - 65% can be expected from such a system.

Each new irrigation system to be discussed -laser leveled fields, linear move sprinklers, and drip irrigation- has several things in common. Each can reduce the amount of water applied thereby increasing irrigation efficiencies and reducing the cost of production, and increasing crop yields by distributing water more uniformly. Each system is also characterized by a large initial investment per acre. All of these systems require more intensive management skills to maximize the benefits from them. Studies also show that these new irrigation technologies must produce higher yields to be profitable (Wilson, Ayer, and Snider 1984; Wilson, Coupal, and Hart 1987).

Laser Leveling

Prior to the advent of laser leveling equipment fields were leveled in the conventional way. This involved surveying and staking the fields to show where cuts and fills were to be made. Achieving the desired grade (non-grade) depended, to a large degree, on the skill of the equipment operator. Fields could be dead leveled but high and low spots could occur. Lasers enabled fields to be leveled to 0 percent slope much more efficiently and without uneven spots. A dead level field, or a field having a 0 percent slope is defined by the Soil Conservation Service as a field that has a slope of less than .2 feet over a one quarter mile irrigation run. The terms "dead level field" and "0 percent slope" will be used throughout this thesis and will be considered defined as above.

The use of lasers in land leveling is a relatively new innovation. It originated in the Midwest as a means of controlling the installation of land drainage systems. Lasers were first used in Arizona for land leveling in 1975 in the Wellton Mohawk Irrigation and Drainage District (IDD). The IDD was mandated by the Federal Government to reduce water use and decrease water drainage of lower quality water back into the Colorado River. This was implemented because of a treaty with Mexico to increase the quality of water flowing into that country from the United

States. Federal subsidies ( up to 75% of the cost ) induced growers to laser level their fields to 0 percent slope (dead level). Approximately 40,000 to 50,000 acres in the IDD were dead leveled by 1979 (USDA, 1979).

Leveling to a grade with lasers can improve irrigation efficiencies from 50-60% to 60-70% (Daubert and Ayer, 1982). Leveling to 0 percent slope can achieve the 85% irrigation efficiency required by the DWR.

Dead level fields provide many advantages over fields leveled to grade. Deep percolation losses are minimized because the most efficient amount of water can be applied. Large streams of water can be used thus reducing irrigation set time. Increased yields result from the more exact amount of water being distributed uniformly across the field.

There are some limitations to a dead level system. One is that more soil movement may be necessary than for leveling to slope. This is limited by soil depth. If the topsoil is sufficient then the amount of topsoil movement will be constrained by leveling costs. The amount of water available and the soil intake characteristics are generally limiting conditions. Dead leveling is best suited to soils with low intake rates (Jensen, 1983). If much soil must be moved then topography (original slope of the land) may become a limiting factor (USDA, 1979).

The cost of laser leveling (and all leveling) depends on the amount of soil, measured in cubic yards, that must be moved. The cost to level is generally around 43 cents per yard of earth moved (DWR, 1986). Replacing ditches and changing fields can increase the cost of leveling. Daubert and Ayer (1982) found that dead leveling can cost between $400 and $600 per acre.

The installation of a dead level system requires different cultural and management practices to achieve the highest irrigation efficiency. The intake rate of the soil will determine how fast the water seeps into the soil. Care must be taken not to overwater as it will damage some crops. Large water turnouts from the canal will shorten the water application time and allow for faster irrigation. If managed properly a dead level system can provide the required irrigation efficiency.

Linear Move Systems

Linear move irrigation systems are sprinkler systems that move laterally across a field. The systems are made up of a distribution manifold and a pump-and-prime-mover system. The distribution manifold consists of a lateral pipe which sprays the water. The pump-and-prime-mover system consists of a wheeled platform, a piping system, a booster pump, and internal combustion or electric motor to move the system, and a generator to guide the system (Wilson, Coupal, and Hart, 1987).

Water is generally pumped into the distribution manifold from a ditch. The water is pumped through the system and is released by either socks dragging in the furrow or spray emitters pointing downwards. While more complicated than furrow systems, linear move systems can increase irrigation efficiencies to 70 - 99 percent. The highest percentages are reached when microbasins are used. The initial capital investment for a system like the one described above is $300 to $700 per acre.

Linear move systems require much better management, when compared to traditional furrow irrigation management, to derive the most benefits. Because less water is applied during each irrigation, water application timing is more critical. Many more water applications will be needed during the growing season. Repairs will probably have to be made by the manager to save time and expense.

Drip Irrigation

Drip Irrigation systems slowly apply water to the crop through above or below ground delivery lines. Drip systems have been found to reduce water use by 30 to 50 percent and increase crop yields by up to 29 percent when compared to conventional furrow systems.

Each system is made up of a control station and a distribution system. The control station includes a booster pump, fertilizer injection system, filters, valves, and the controls. It is located near the well and pump. Microcomputers or electric times can be used to activate and control the system. The distribution system is made up of the main lines, submains, and the drip lines in the field. Water from the well passes through filters in the control station. These filters are to prevent the emitters in the drip lines from plugging. Emitters are placed anywhere from 12 inches to 36 inches apart.

The management of a drip system is much more intense than that for a furrow system. Less water is applied with each application so there is less margin for error. Timing of irrigations is critical to prevent stress to the plant. No plowing is done and less cultivation is used to reduce possible damage to the underground system. Herbicides are relied on more to reduce weeds. Fertilizer can be injected into the drip lines and applied when needed. Drip lines must be monitored closely so that breaks in the lines can be repaired quickly.

Drip irrigation systems may not be suited to all farms. Each system must be designed to fit each unique farm. Water quality, quantity, location, and soil type greatly affect the design and efficiency of the system. Because of these problems a drip system will cost $900 to $1200 per acre.

Objectives

The major objective of this thesis is to analyze the rate of, and factors influencing, the adoption and diffusion of strategic investments, primarily dead leveling, by Pinal AMA farmers. The changing legal environment, as described earlier, and a changing economic environment have provided incentives to farmers to adopt strategic water conserving technologies. Higher production costs caused by rising energy costs, greater depths to water, and higher water costs have made new technologies profitable in some cases.

This study will attempt to answer several questions about the spread of dead leveling and laser leveling in the Pinal AMA. Some of these questions are:

(1) What socio-economic characteristics are significant in the decision to adopt these capital intensive innovations?

(2) Are farm characteristics significant in the decision to adopt?

(3) Have government policies such as the 1980 GMA significantly increased the diffusion of dead level systems?

(4) Have other variables like energy prices or crop prices been significant for the diffusion of this technology?

The remainder of this study will proceed as follows. Chapter two surveys the adoption and diffusion literature. It identifies the major research thrusts in both areas. Chapter three discusses the economic theory behind the adoption of new technologies, methods of adoption and diffusion estimation, and data acquisition. The results of the analysis are detailed in chapter four. The final chapter discusses the implications of the results, their uses, and some unanswered questions.

# CHAPTER TWO

The research tradition of the adoption and diffusion of innovations began in the early years of the twentieth century. Sociologists in the 1920s and '30s began to trace the diffusion of an innovation through geographical areas. Research by rural sociologists began in the 1920s with attempts by the USDA agricultural extension service to evaluate their programs. Their work focused on the adoption of innovations by individual farmers, and the diffusion of agricultural innovations through farming areas. Anthropologists also researched the spread of ideas through groups and the social consequences of these innovations (Rogers, 1962; Jones, 1967).

This review summarizes the literature on the adoption and diffusion of agricultural innovations. The two topics are closely related and are discussed together in much of the previous work. They are presented here in chronological order.

## Seminal Adoption and Diffusion Literature

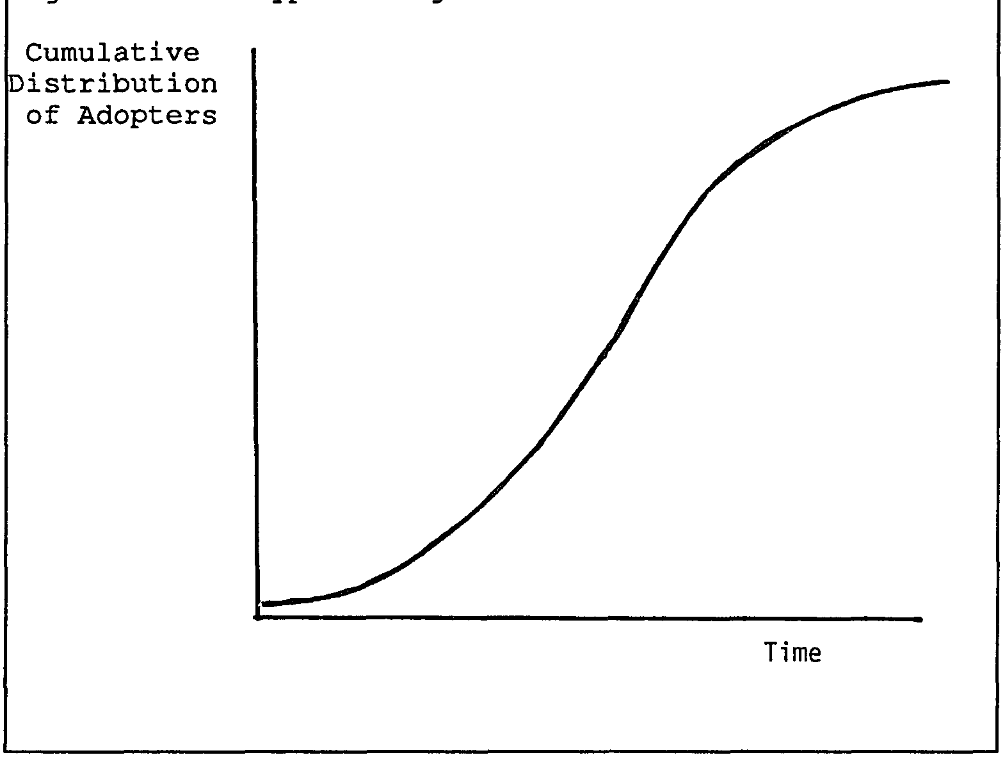
Ryan and Gross (1943) examined the adoption and diffusion of hybrid seed corn through two Iowa farming communities. They defined adoption as the first use of an innovation, an operational definition that will be used throughout this thesis. They discussed farmers' sources of information and their effects on the diffusion path. Evidence showed that few farmers used hybrid seed on all their acreage the first time they tried it. Later adopters planted a larger percentage of land to hybrid corn in the first year they tried it. It appeared that the earlier adopters provided a laboratory where the rest of the community could gain experience and information. This information was believed to contribute to the observed s-shaped diffusion pattern of hybrid seed corn and other innovations.

Ryan and Gross found that there appeared to be differences in the influence of different sources of information. Salesmen were most often cited by the farmers surveyed as the most influential initial source of information. Neighbors were considered to be the most influential when adoption was considered. The authors concluded that the decision to adopt the new practice was affected by the decision maker's particular situation and various influences brought to bear upon him.

Neal Gross (1949) conducted a later survey of the characteristics that differentiate adopters and non-adopters of new agricultural practices. This study surveyed Iowa farmers to determine if early adopters of hybrid seed corn and hog sanitation practices had similar characteristics. The evidence showed that the adopters of both hybrid seed corn and new hog sanitation practices were significantly better educated, had higher social participation rates, were better informed, had larger farms, and had higher incomes than non-adopters. Non-adopters of hog sanitation practices were found to be on average 6.4 years younger than the adopters, whereas adopters of hybrid seed corn were found to be younger than non-adopters. Gross found that farm tenure status, nationality background, and interfarm mobility were not significant in determining the adoption of either innovation. The study suggested that there was a type of person more likely to adopt an innovation.

Griliches (1957) introduced economic variables to explain the differences in the past and current rates of use (diffusion) of hybrid seed corn in the United States. He estimated the percentage of land using hybrid seed corn as a logistic function of time. The logistic curve is an S-shaped function that allows for the estimation of the origin with respect to time of the first use of the innovation, the rate of diffusion of the innovation, and the ceiling level of aggregate adoption. Figure 2.1 illustrates a typical logistic curve. Notice that the number of adopters increases at an increasing rate, then at a decreasing rate, then flattens out at the ceiling level.

Figure 2.1 A Typical Logistic Curve.




Griliches broke up each state in the United States into nine growing districts and the logistic growth function was estimated for each. It was shown that the diffusion curve parameters varied among each district. The author showed that a large part of this variation was caused by differences in the profitability of the hybrid corn in different districts. Diffusion of hybrid corn in different areas was faster where the seed was better suited to the area. The author concluded that the lags in development of adaptable hybrids for each area could be explained on the basis of the profitability of entry. Where the profits of innovation were large, adoption was rapid. Iowa farmers' plantings of hybrid corn went from 10 percent to 90 percent of their acreage in four years. Where profitability was lower, particularly in the Southeast, adoption was much slower.

Everett Rogers, in his classic work Diffusion of Innovations (1962), summarized the literature and defined adoption as "a decision to continue full use of an innovation." He defined the adoption process as "the mental process through which an individual passes from first hearing about an innovation to final adoption." Rogers summarized this process into five stages: awareness, interest, evaluation, trial, and adoption. The awareness stage begins when the farmer first learns that an innovation exists. The interest stage is characterized by the farmer actively seeking more information about the innovation. The farmer analyzes the information he has gathered during the evaluation stage. During the trial stage the farmer uses the innovation on a small scale. The author characterized the final adoption stage as 100% use of the innovation by the farmers.

Rogers defined diffusion as the process by which an innovation spreads. He discussed types of adopters as contributing to the S-shaped diffusion pattern observed by others. He identified five categories of adopters: innovators, early adopters, early majority adopters, late majority adopters, and laggards. The time period from awareness to adoption of an innovation is shorter for earlier adopters.

Rogers defined an innovation as "an idea perceived of as new by the individual." There are many possible aspects of innovations that make them more likely to be adopted and diffused through an area. Rogers combined these various aspects into five general characteristics that effect the adoption of innovations. These five are 1) relative advantage, 2) compatibility, 3) complexity, 4) divisibility, and 5) communicability.

Relative advantage can be expressed as how an innovation is superior to current practices. This superiority is often expressed as profitability, which Griliches (1960) considers to be the main determinant of the adoption and diffusion of an innovation. Relative advantage can also represent labor or time savings. The suitability of an innovation to its intended environment can be part of its relative advantage as well. In many cases, relative advantages may not be realized until a crises develops.

Compatibility represents the consistency of an innovation with well established values and experiences of the potential adopters. Innovations that are culturally compatible or compatible with previously adopted ideas may be adopted at a faster rate. Adoption of one innovation may lead to the adoption of related innovations.

Complexity is how hard an innovation is to understand and use. The easier an innovation is to use the faster it may be adopted.

Divisibility allows the farmer to try the new technology on a small scale. The farmer can then better estimate the benefits of the innovation. This may be more important for early adopters because they don't have any examples to observe other than their own experience. For example, new seed varieties may be tried on a very small scale.

Communicability is the ease with which results can be reported to others. Results that can be seen or easily demonstrated may diffuse more readily through an area. A was from the innovation source, the longer the adoption lag. This lag was offset somewhat by education and farm size.

There may be cases where the adoption decision involves two or more complementary innovations that can be adopted at the same time. Feder (1982) suggested a model for a case like this where one innovation is neutral to scale and the other is a lumpy innovation. The lumpy innovation is characterized as one that has declining per unit costs as it is used on more acres (an implement or tractor). The two are complementary in that average yield is larger when both innovations are employed. The model indicated that the scale neutral innovation will be adopted by all and that the lumpy one will only be adopted by farmers larger than some critical size.

Feder suggested that policies to encourage adoption may affect complementary innovations differently. It is possible for the adoption of one to be encouraged and the other discouraged. He demonstrated that when credit is scarce subsidies will encourage the adoption of scale neutral innovations and discourage lumpy innovations. Variable input cost subsidies can increase both types of innovations. Output price subsidies can decrease the use of variable inputs when a credit constraint is imposed on the new herbicide may diffuse rapidly because other farmers passing by can see its effectiveness.

The term "cosmopoliteness" was coined by Rogers to represent the degree to which a person is involved externally to a particular social system. Early adopters have access to more outside information. More cosmopolitan individuals will travel more, belong to more organizations, and may subscribe to more journals and magazines that other more "localite" individuals. This cosmopoliteness translates into more information being available to the individual and perhaps more opportunity to adopt new innovations.

Education and experience enhance one's ability to receive, decode, and understand information (Nelson and Phelps, 1966). They hypothesized that in a technologically advanced economy a manager must quickly adapt to change. The more educated the manager is the quicker he will adopt new technologies. Educated people make good innovators, so education speeds the adoption of innovations. Nelson and Phelps suggested a theoretical model where the rate at which the latest theoretical technology implemented depends on the level of feasible technology and its level of use throughout the industry. The model indicates that more technologically progressive society has a greater payoff to education.

Adoption and Diffusion Literature of the 1970s

Schultz (1975) informally discussed how education and experience affects the efficiency of people to perceive, interpret, and take action to reallocate their resources in response to changes in economic conditions. He hypothesized that the ability to deal with economic changes is enhanced by education and that this ability is one of the major benefits of education. Based on his past research he suggested that education greatly increased the adoption of beneficial innovations.

Kislev and Shchori-Bachrach (1973) proposed a theory of innovation diffusion by suggesting the presence of an innovation cycle. This theory holds that early adopters are more skilled and have a higher opportunity cost for their resources, and are better at getting and using information. When an innovation is introduced the higher skilled producers are the first to adopt. Lower skilled producers wait until they have more information and experience. As output expands because of the new technology the price for output falls. The higher skilled producers switch to new technologies or opportunities because of their higher opportunity costs. This implies the "innovation cycle".

The innovation cycle in Kislev and Shchori-Bachrach's research is illustrated by the diffusion of plastic covers to aid growing winter vegetables in Israel. Israeli agriculture from 1958-67 was divided into four sections: kibbutzim, moshavim, private farms, and Arab farmers. Kibbutzim have the highest education and capital-labor ratios of the four sectors. Moshavim have lower education and capital levels. Private farms rely on hired labor to a large extent. Arab agriculture is traditional farming and has the lowest education and capital-labor ratio. The first adopters were a few private farmers and kibbutzim. By fitting the data to a logistic function, the latest adopters, the Arabs, were found to have a faster rate of adoption than the earlier adopting groups. This supported earlier research that indicated that late adopters adopted faster than early adopters. Put another way, late adopters first adopt on a larger percentage of their land than early adopters. Over the period 1961-67 the percentage of covered vegetables grown by the kibbutzim and private growers had fallen from half of the production to less than one third of the total production. This is hypothesized to be due, in part, to the more skilled producers moving to other activities or technologies with a greater return.

Hiebert (1974) proposed that the adoption decision is made under uncertainty. The adopter gets new information during the adoption process which reduces the uncertainty involved in the decision. He proposed a model of new seed adoption which assumed the need for a modern input (fertilizer) and land.

The farmer is assumed to choose input levels to maximize the expected utility of net income given output price and fertilizer price. The model indicated that the risk preferring producer will use more fertilizer and more land in modern production than the risk neutral producer.

Hiebert considered learning to mean gaining more information about unknown parameters which reduces the chance of allocating the inputs incorrectly. As producers gain information they adjust input levels so that the probability of higher payoffs is increased. The effects of learning are represented by a rightward shift of the net income distribution function.

Recent Adoption and Diffusion Literature

Feder (1980) introduced a formal model of production to address the role of risk aversion and credit constraints in the adoption of high yielding seed varieties. The farmer is assumed to allocate his land between two crops. The first is a low yield traditional crop that has no uncertainty in yield. The second is a "modern" high yielding crop that requires the use of fertilizer and is of uncertain yield. The author assumed that the farmer was risk averse and would maximize his expected utility of income.

Feder derived several implications from his model regarding the optimal use of fertilizer. One was that the optimal level of fertilizer use per acre is independent of the degree of risk aversion. Another was that the optimal level of fertilizer per acre is independent of farm size. With regards to the optimal allocation of land to the modern crop, Feder found that it declined with degrees of risk aversion. As risk aversion declined the acreage allotted to the modern crop increased.

Feder and O'Mara (1981) studied the affect of farm size on the adoption and diffusion of a scale-neutral green revolution innovation. These innovations consist of hybrid seeds, chemical inputs, and new cultural practices. An innovation that is divisible and scale neutral such as seed or fertilizer should not be affected by farm size, however, empirical evidence shows that it is. To model the affects of farm size they assume that all farmers are the same except for land holding. As assumed by Feder there are two crops available, one traditional (no uncertainty of yield), and the other modern (uncertain yield, requiring special inputs). While per acre input costs are scale neutral some fixed costs are introduced. Possible sources of these fixed costs are the time and cost involved in gathering the information relating to the new technologies, the time it takes to secure the additional capital, and the time needed to obtain the necessary inputs. The farmer maximizes expected utility by selecting the optimal level of land allocated to the modern crop and the optimal level of variable input per acre.

The Feder and O'Mara model implies that the per acre variable input is independent of farm size and fixed cost. It also implies that there is a critical level of farm size. Farms smaller than a critical level will not adopt the new technology. This is due to the uncertainty of the crop and the presence of fixed information costs. Smaller farmers benefit from accumulating information as larger farmers around them adopt the new technology. Finally, over time, uncertainty falls and thus the fixed costs of adoption are low enough for small farms to adopt. In the absence of fixed costs, if the new technology is more profitable than the traditional technology, nonadoption is not the optimal decision by the small farmer.

Feder and O'Mara indicated that policies which reduce the fixed costs of adoption will speed the adoption rate. Improving the distribution of information about inputs can reduce adoption time. Speeding up the credit loan process, it is suggested, can also reduce the fixed cost component. Finally, transaction cost subsidies of loan guarantees for small farmers can increase the rate of adoption.

Jarvis (1981) used a modified logistic function to estimate and predict the diffusion rate, and ceilings of improved pasture in Uruguay. He tested the hypothesis that technology diffusion in later years can be predicted from the first years following its introduction and that the rate and ceiling of diffusion are positively related to changes in the technology's profitability. Since the diffusion of improved pasture technology was still occurring, the rate and ceiling of diffusion were estimated simultaneously. When the rate of diffusion and the diffusion ceiling of new pastures were specified as a function of beef prices neither the rate or the ceiling were significant in determining the diffusion of adopting ranchers. Both the rate and the ceiling were significant for hectares planted to improved pasture with the ceiling being positive and the rate being negative. This indicates a longer diffusion period. Jarvis also tested the effect of fertilizer prices, the inflation rate, and the Central Bank's index for adjusting principal and interest payments. None were found to be significant in explaining the diffusion of improved pasture.

Ceiling estimates of 56 percent for adopting ranchers and 11.5 percent for hectares planted were estimated by Jarvis. The price elasticity of the ceiling number of adopters divided by the total potential adopters for ranchers was estimated to be 0.05, and for planted hectares about 0.3. Increasing the price of beef ten percent would only increase the ceiling of planted hectares to 11.8 percent. Jarvis predicted the effect of beef price cycles on future diffusion of improved pastures with this information.

To reconcile shortcomings in earlier definitions of adoption Feder, Just and Zilberman (1982) offered a new definition of adoption in their survey of adoption literature. They defined adoption as " the degree of use of a new technology in long run equilibrium when the farmer has full information about the new technology and its potential." This definition allows for a period of disequilibrium while the farmer moves to a new more efficient use of resources. They assumed aggregate adoption (diffusion) to be the spread of a new technology in an area. Diffusion was measured by the cumulative level of use of the innovation within a region.

The literature recognizes that there is a time lag between the availability of an innovation for use and the adoption of the innovation by a farmer. Lindner, Pardey, and Jarrett (1982) examined the factors affecting the adoption time lag, especially the effect of the distance from the information source to the potential adopter. They use data from the early adopters of trace element fertilizers in Australia from 1939-52. The explanatory variables used were farm size, education, distance to the original innovation source, distance to the nearest known adopter, distance-by-education, birth date of the adopter, years of experience, and a scale for the level of debt. Their regression results showed that the distance to the innovation source was positive and significant in determining the adoption lag. Farm size and distance-by-education were significant and negative. The other variables were insignificant in determining the length of the time lag. This indicated that the farther the farmer was from the innovation source, the longer the adoption lag. This lag was offset somewhat by education and farm size.

There may be cases where the adoption decision involves two or more complementary innovations that can be adopted at the same time. Feder (1982) suggested a model for a case like this where one innovation is neutral to scale and the other is a lumpy innovation. The lumpy innovation is characterized as one that has declining per unit costs as it is used on more acres (an implement or tractor). The two are complementary in that average yield is larger when both innovations are employed. The model indicated that the scale neutral innovation will be adopted by all and that the lumpy one will only be adopted by farmers larger than some critical size.

Feder suggested that policies to encourage adoption may affect complementary innovations differently. It is possible for the adoption of one to be encouraged and the other discouraged. He demonstrated that when credit is scarce subsidies will encourage the adoption of scale neutral innovations and discourage lumpy innovations. Variable input cost subsidies can increase both types of innovations. Output price subsidies can decrease the use of variable inputs when a credit constraint is imposed on the farm.

Feder and O'Mara (1982) used a Bayesian learning model to explain the effect of the accumulation of information over time on innovation adoption. In their model, each farmer has an initial distribution of beliefs about an innovation that affect his decision to adopt. The distribution of beliefs changes as more information is gained over time. Adoption occurs when the farmer believes that the expected value of profit from the new technology is at least as large as the return from the old technology. This can result in the characteristic s-shaped diffusion pattern.

Jensen (1982) viewed adoption as "a problem of decision making under uncertainty when learning can occur." When a new technology becomes available the firm does not know if it is profitable or not, but by waiting and gathering information this uncertainty can be reduced. The firm adjusts its original beliefs in a Bayesian fashion as it gathers information. Firms original beliefs differ due to the decision makers attitudes and expertise about innovations. Firms that don't adopt immediately revise their beliefs upward as they learn the innovation is good. They eventually have enough information to adopt. The s-shaped pattern of diffusion is then explained by the differences among firms' original beliefs that the innovation will be good.

Farm size and the adoption of a more uncertain modern crop is discussed by Just and Zilberman (1983). The results indicated that the role of farm size in technology adoption is largely determined by the relationship between the returns per acre from the traditional and modern crops and risk attitudes. The intensity of input use depends on whether the input is risk reducing or not and if risk aversion is increasing or decreasing. The marginal risk effects of adopting the modern variable inputs are important in determining the intensity of adoption by farm size.

Land tenure has been hypothesized as a factor which influences the planning horizon of the farmer, thus the farmer's willingness to adopt long term conservation practices. Lee and Stewart (1983) assessed the relationship between landownership and the adoption of minimum tillage methods. Their results indicated that farm owner-operators had lower minimum tillage adoption rates than did part owner-operators and nonoperator landlords. They suggest that this may be due in part to owner-operators being older and having a shorter planning horizon than younger farmers who are more likely not to own the land they farm outright. Landowners with small holdings were also shown to have a lower adoption rate. They also found that non-family corporate structure did not significantly influence the adoption decision.

The Bayesian framework is used again by Feder and Slade (1984) to incorporate the decision to gather information about an innovation. Farmers are assumed to actively gather information when they expect to receive an economic return on it. The model assumes that the production function should include the level of knowledge as an input. As knowledge increases the farmer should be able to increase output for a given bundle of resources. The process of seeking information is costly in terms of time and money. The model implies that farmers larger than a critical size will adopt, smaller farmers will not adopt but will actively seek information, and the smaller farmers will not adopt nor will they actively seek information. This is related to Hiebert's study where the farmer collects information and revises his actions based on it. Once the innovation is adopted information will continue to be sought as long as the marginal product of that information is greater than or equal to its marginal cost.

The adoption of an innovation may be influenced by expectations about the true path of future technological changes (Balcer and Lippman, 1984). They analyzed the role of technological expectations on the demand for new technologies. They presented three theorems derived from their model. One was that there is a threshold where a firm will adopt the current best practice if its technological lag exceeds that threshold: otherwise it postpones adoption. The second theorem was that as time passes without new innovations it may become profitable to purchase a superior innovation that was not profitable in the past. The third was that the adoption threshold increases and adoption postponement becomes more attractive when the firm believes that the pace of innovation has increased. These results suggest that firms will avoid adoption, as the speed of technological change increases, to prevent being locked into obsolescence.

When farmers become aware of a new technology they often have inaccurate beliefs about the costs and benefits associated with the innovation. Feder and Slade (1985) discussed public sector involvement in the dissemination of information to affect the adoption of a new innovation. This is particularly relevant to the issue of laser leveling where the government has a long history of encouraging adoption. They assumed that insufficient information causes the perceived characteristics of an innovation to be different from its true characteristics. This divergence slows the adoption process. Public sponsored diffusion of information, taxes, and subsidies can speed the adoption of a desirable innovation. Subsidies present a problem because those who have already adopted know the true characteristics of the technology and do not need the subsidies to behave efficiently. They suggested that policies to speed technology diffusion may only be justified in the early years of the diffusion process. Early adopters produce information and experience positive externalities that aid later adopters, eliminating the need for aid later in the diffusion process. Government sponsored expansion of credit markets may speed the adoption of innovations requiring large cash outlays.

Epplin and Tice (1986) investigated the influence of crop and farm size on the adoption of conservation tillage. They suggested that adoption rates of conservation tillage may differ because of differences in investment costs. A mixed integer mathematical programming model was used to determine the least cost machinery complements for different farm sizes. Their results indicated that adoption of conservation tillage will lag on small farms if adoption depends on a change in the farms machinery complement. Epplin and Tice also suggested that lower adoption rates on small farms more likely relates to investment requirements in management education and machinery than on differences in land ownership patterns.

A more relevant example of adoption research is the work of Caswell and Zilberman (1986). They proposed a model incorporating the effects of soil quality and well depth on the decision to adopt new irrigation technologies.

The Caswell and Zilberman model yields several important conclusions. First, the new irrigation technology (drip or sprinkler systems) will not be adopted where it doesn't increase yields. This supports the work in Arizona by Wilson, Ayer and Snider, and Wilson, Coupal and Hart. Second, the model indicates that these technologies tend to save water except where water is very expensive. Third, there may be instances when adoption saves water but increases the use of energy. Therefore, water and energy conservation may not be compatible.

Low land quality and expensive water were found to encourage the adoption of drip and sprinkler systems.

Heavy, leveled soils and cheap water were more likely to encourage the continued use of traditional irrigation systems. Land quality augmenting technologies increased the value of low quality land but reduced the value of high value lands.

Helms, Bailey, and Glover (1987) investigated farmer participation in government price support programs and the decision to adopt conservation tillage practices. Using whole farm computer simulation analysis they examined the impacts of the 1981 and 1985 farm bills on dryland wheat farmers' adoption decisions. They hypothesized that because government programs reduce price uncertainty they may aid adoption of minimum tillage practices. Their results showed that the 1981 plan had larger impacts than the 1985 plan. Due to lower wheat prices in 1985 it was more essential to participate in the government program. Lower net returns in 1985, caused by lower wheat pries and loan rates than in 1981, gave less incentive to adopt conservation tillage in 1985. They hypothesized that this was due to the decreased ability of the farmer to spread the cost of new tillage equipment over more acres by non-participation in government programs. The cost of leveling can not be spread over more acres. That may encourage farmers to stay in the government program to keep up their base and keep their profits up.

Belknap and Saupe (1988) used a probit model to identify variables related to the probability that a farm operator used a conservation tillage practice. They used data gathered from a survey of 529 randomly selected Wisconsin farmers. Their results indicated that the number of acres farmed, the percent of cropland owned, the number of farm-related programs the farmer has been involved in, and the amount of community involvement by the farmer are significant and positively related to the probability of no-plow adoption. A measure of average farm slope, the amount of precipitation, cooler temperature, and a factor measuring erosion awareness were negative and significant determinants of the probability of adoption. Several attitudinal questions to provide a measure of risk averseness indicated that adopters were more likely to be less risk averse than nonadopters.

Finally, Putler and Zilberman (1988) estimated the probability of computer adoption and software ownership among Tulare County, California farmers. The decision to adopt was considered a dichotomous choice, the farmer adopts or does not adopt. The maximum likelihood logit estimation technique was used.

The model indicated that the likelihood of adoption increased with farm size but at a decreasing rate. Increases in farm size significantly increased the likelihood of adopting most types of applications. The production of different farm products and the number of farm enterprises had no significant effect of adoption choice. Age had a significant effect on computer adoption. The data suggested that adoption increases with age up to the 36-40 year age group then decreases with age. Farmers with a bachelors degree or post graduate degree were significantly more likely to adopt computers than those with less than a bachelors degree. Owners of sales related businesses were more likely to adopt computers than farmers without a farm related business. Farmers with service oriented businesses were no more likely to adopt a computer than farmers without these businesses. The type of operation was found to affect the kind of software owned. Livestock producers were more likely to use decision support systems. Sales related business owners were more likely than crop producers to use transaction processing applications.

Lessons Learned

The s-shaped logistic curve seems to estimate the diffusion of innovations very well. The curve begins with few adopters early in the diffusion period. The number of adopters increases at an increasing rate, then increases at a decreasing rate. Eventually, fewer people adopt in each period. This is partly because there are fewer people left to adopt. The ceiling level does not have to be 100%. There may always be some nonadopters of any innovation.

The use of the logistic s-shaped curve goes back to the seminal adoption and diffusion work by Ryan and Gross, and Griliches. Since these articles were published the s-shaped logistic curve has become the accepted model for the diffusion of innovations.

The literature suggested many variables that affect the adoption and hence the diffusion of innovations. Several studies found that education was positively related to adoption. People who are more educated are more likely to realize the benefits of new technologies and adopt. Experience is related to education. More experience may help a farmer evaluate an innovation's worth. Farmers with larger farms were generally found to be more likely to adopt. Farm size is then hypothesized to be positively related to adoption. Income has also been found to be positively related to adoption. A larger income may make a farmer more able to pay for an innovation. Older farmers are less likely to adopt. Higher age may shorten the farmer's planning horizon which may reduce the benefits to be gained by adoption. Farm ownership has been found to be both positively and negatively related to adoption. Ownership may be positive because the owner has more control over the decision making process. It may be negative because ownership and age could be related. Older farmers are more likely to own their land. Risk and uncertainty are hypothesized to have a negative effect on adoption. A farmer will not adopt until he is certain that the innovation will be beneficial. Government policies can have a mixed affect on adoption. Policies to encourage adoption of one innovation may retard the diffusion of another innovation. Credit that is more available is hypothsized to lower the cost of adoption thus speed the diffusion of the innovation.

The literature is lacking in several areas. Many of the innovations discussed dealt with variable costs. Fixed costs were mainly discussed as they relate to time costs associated with information gathering. These time costs may delay the adoption of some innovations but adoption will occur eventually if the innovation is a beneficial one.

The innovations discussed in the literature are generally variable inputs which affect operating costs; the literature has neglected the adoption of strategic investments which are lumpy and require the farmers to incur fixed or sunk costs. New seed varieties, chemicals, and fertilizers all affect operating costs. When they are used the payoff is received quickly, generally through increased yields. The minimum tillage literature did discuss the use of a lumpy investment such as new equipment. While it is not an operating cost, the cost of buying equipment can be spread over many acres.

There has been no empirical work on the adoption and diffusion of strategic investments. Strategic investments can be defined as lumpy, capital intensive, long term oriented investments that are oriented to position the firm to survive and prosper over the long haul. Their costs can not be spread over more acres. They are generally sunk costs because once the are adopted it is not cheap or easy to dis-adopt.

This thesis will attempt to fill the strategic investment gap in the adoption and diffusion literature by providing an empirical study of the adoption and diffusion of a strategic investment, namely dead level fields.

# CHAPTER THREE

## Analytical Framework and Data Acquisition

The purpose of this chapter is to explain the conceptual models underlying this research. The first section applies firm theory to a firm considering the adoption of a new irrigation technology. The second section relates strategic management theory to the adoption of new irrigation technologies as strategic investments. The third section explains the use of the logistic curve to map and predict the diffusion of an innovation through an area. Section four outlines the use of logit analysis to identify characteristics of farmers more likely to adopt a new technology and predicts potential adopters. The fifth part explains the data acquisition and survey design.

## Economic Framework

Barry and Robison (1987) detail a model of adoption of a new production process that is easily applied to the adoption of dead level fields. The farm has a fixed amount of land, L, to be divided between the sloped fields and the dead level fields. s is the amount of land allocated to the dead level fields. $R_0$ is the net return per unit of L using the sloped fields that are assumed to be risk free. $R_1$+e is the net return per unit of L using the new risky level fields. The variability of the term is represented by the error term, e, having a mean of zero and a variance of $\sigma^2$. The average risk attitude of the farmer is measured by $\lambda$. The farm must allocate its resources between the safe and risky technologies. Expected income is:

$$E(\pi) = R_1 s + R_2(L - s) \tag{3.1}$$

The variance of income is:

$$\sigma^2(\pi) = s^2\sigma_\varepsilon^2 \tag{3.2}$$

The certainty equivalent income model is:

$$\max \quad \pi_{CE} = R_1 s + R_2(L - s) - \lambda/2\, s\sigma_\varepsilon^2 \tag{3.3}$$

The first derivative with respect to s yields the optimal amount of land allocated to the new technology. This is:

$$s = (R_1 - R_2)/\lambda\sigma_\varepsilon^2 \quad \text{for} \quad 0 \leq s \leq L \tag{3.4}$$

This shows that the expected return from the dead level fields must be greater than the safe return from the sloped fields for it to be adopted. An increase in risk aversion or an increase in the perceived riskiness of the new technology reduces the rate of adoption of the new technology.

Strategic Management

Recent work in the area of strategic management may shed some light on why someone would adopt an innovation. The following discussion will suggest a rationale for explaining why farmers adopt an innovation like dead level fields on their land.

Strategic management involves developing a competitive strategy relating a company to its environment. The theory assumes that there are benefits to the firm for having all its departments working toward common goals. For the farmer this means determining long term goals and working to achieve them.

Four general factors determine the effectiveness of any management strategy. The first, company strengths and weaknesses, are the assets and liabilities, both monetary and nonmonetary, in relation to competitors. Second, the personal values of the implementers, are the goals and abilities of personnel carrying out the strategies. The third factor is the industry opportunities and threats. This is the competitive environment that the firm faces. Societal expectations is the fourth factor. These expectations represent government policies and changing social concerns. The first two factors are internal to the firm and the last two are external to the firm, and probably can not be changed.

Porter (1980) identified five competitive forces underlying the industrial structure - the strength of competition and industry profitability. These five are: the threat of entry, the threat of substitution, the bargaining power of buyers, the bargaining power of sellers, and rivalry among current competitors. A sixth force, government, may be added since it can affect several of the other forces. Analyzing these forces with respect to the firm can identify the strengths and weaknesses of the firm relative to the industry. Firm strengths and weaknesses determine the best management strategy for the firm to pursue.

Effective strategy takes "offensive or defensive actions to create a defendable position in an industry, to cope successfully with the five competitive forces and thereby yield a superior rate of return on investment to the firm (Porter, 1980, page 34)." To this end Porter suggested three generic strategies: focus, differentiating the product, and overall cost leadership. Focus involves targeting the product to a particular segment, area, or buyer. Differentiating the product means making it appear unique to buyers. Overall cost leadership requires becoming the low cost producer of the product.

The competitive strategy framework is easily applied to the farm firm. The Central Arizona farmer produces a product that is perfectly substitutable (cotton,wheat, etc.). Production is so large that the power of buyers and sellers is negligible. High start up costs and the Groundwater Management Act, preventing new land from being brought into production, form substantial barriers to entry. A host of government programs affect various aspects of the farm business.

Given the industry structure, overall cost leadership is the most relevant strategy for ensuring farm business growth and survival. Becoming a low cost producer requires the use of the most efficient and low cost means of production available. This may involve using new seed varieties, new chemicals, investing in new efficient equipment, or changing the input mix. It may also involve investing in a "strategic investment".

A strategic investment has several general characteristics. One characteristic is a high cost per unit of the innovation implemented. The investment will be expensive and the costs will not be able to be spread over more units. A second characteristic is that once it is implemented, its use can't be discontinued easily or cheaply. The investment changes the production process so that it is difficult to return to the previous practice.

The third characteristic is that the investment relates to a longer planning horizon. Beneficial results may not be apparent immediately but the firm will be better off in the long run.

The adoption of leveling fields to 0 percent slope, drip irrigation systems, and sprinkler systems are all strategic investments consistent with a strategic management plan. Leveling fields to 0 percent slope is a large capital investment requiring large sums of money per acre. Once leveled to 0 percent slope a field can't be changed back easily. To replace the slope would require the same amount of money to be spent again. However, the gains from dead level fields may take several years to become apparent. It may take some time for yields to increase over prelevel years. The results of non-strategic investments such as new seed varieties, chemicals, or fertilizers occur immediately. The long-run benefits of the strategic investment, like leveling, may be the key to the adoption of leveling.

There are risks involved in maintaining cost leadership. Profit may have to be reinvested to keep costs low, maintain efficiency, or replace old equipment. There is also the danger that a new technology may nullify past investments and learning.

Cost leadership closely parallels the treadmill model proposed by Cochrane (1979). It holds that a farmer who adopts a new and improved technology first will reduce his unit costs. This "early bird" farmer finds his profits increased. As more farmers adopt, supply increases, and profits fall. Non-adopters eventually fail and go out of business. This technological treadmill continues with each technological advance.

Logistic Curve Estimation

As discussed previously, the logistic curve has been widely used to map the diffusion of an innovation over time. The logistic curve will provide a framework for estimating the diffusion of the risky strategic investment, dead level fields. The logistic curve is represented by:

$$Z_t = \frac{K}{1 + e^{-(c + \varnothing t)}} \qquad 3.4$$

Where $Z_t$ is the number of adopters, K is the number of adopters when the diffusion process stops, $\varnothing$ is the rate at which adoption occurs, and c is the constant term. Taking the reciprocal of the RHS and multiplying both sides yields

$$\frac{\left(1 + e^{-(c + \varnothing t)}\right) Z_t}{K} = 1 \qquad 3.5$$

moving K and $Z_t$ to the RHS leaves

$$e^{-(c+\varnothing t)} = \frac{K - Z_t}{Z_t} \quad 3.6$$

and rearranging yields

$$\frac{Z_t}{K - Z_t} = e^{-(c+\varnothing t)} \quad 3.7$$

This equation can be estimated linearly using logarithms if K is known. If K is not known (diffusion has not stopped) then it can be varied based on a percentage of total adopters until the highest $R^2$ is reached (Jarvis). The equation with the highest $R^2$ is assumed to be the best estimate of K and $\varnothing$.

Equation 3.4 may also be estimated in a nonlinear fashion using an iterative linearization method (see Pindyck and Rubinfeld, 1981, pg. 263). This method linearizes a nonlinear equation around a set of coefficient values. Ordinary least squares is performed on the linear equation yielding a new set of coefficient values. The equation is relinearized around the new values and OLS is performed again to get new values. This procedure is followed until the coefficient values do not change significantly from one

OLS regression to the next. Logistic curve estimation using the log-linear method and the nonlinear iterative method generate results that are essentially identical.

The estimates of K and Ø provide a way to predict diffusion. Plotting the estimated fuction yields a curve with time on the horizontal axis and the percent cumulative adopters on the vertical axis up to the designated ceiling level used in the function. The year the ceiling level is reached can then be predicted from the graph.

Economic variables, such as output and input prices, and variables representing institutional and environmental events can be added to the basic logistic equation. These institutional variables may represent laws or regulations that affect the farmer. The environmental variables may represent the weather occurences such as floods.

$$Z_t = \frac{K}{1 + e^{-(c + \emptyset t + \emptyset P t)}} \qquad 3.8$$

P represents the economic variable included.

The models to be presented later will estimate the ceiling and rate of diffusion of dead level fields based on three different possible ceilings; 50%, 60%, and 70%. Each of these ceilings were a priori estimates of what the actual diffusion of dead level fields could be. The year 95% and

99% of the ceiling is reached will be predicted in each case.

Six price of cost related economic variables will be added to the analysis. The first two are real and nominal cotton prices. Since cotton is the major crop in the area these varibles attempt to measure the affect of higher cotton prices, hence higher income, on the diffusion of dead level fields. The Producers Price Index of crop prices received by farmers will be the third variable used because there are other crops grown in the area. Water is primarily pumped by electric motors. To measure the affect of electrical and energy prices on the diffusion of dead level fields two variables will be used. The first is an average of prices paid for electricity around the AMA. The second is the Producers Price Index of energy prices paid by farmers. Since leveling requires a large amount of capital to implement the sixth variable is the prime rate of interest in the United States over the period 1968 to 1989.

Three institutional variables that may have affected the diffusion of dead level fields will included in the analysis. The first is a dummy variable for the 1980 Groundwater Management Act. The variable equals one for the years 1980 through 1989. The second variable is the Central

Arizona Project. Most surveyed farmers began to receive CAP water in 1988. The CAP dummy variable equals one in the years 1988 and 1989. The third institutional variable is the introduction of laser leveling in the Wellton-Mohawk area of Arizona in order to comply with treaty obligations with Mexico.

Three price risk measurements will be used in the estimated model. These are the coefficients of variation for real and nominal cotton prices and the average of electrical prices in the AMA. The coefficients are calculated by dividing the standard deviation of a three year moving average of prices by the mean of the same three years prices.

One environmental factor will be used. This factor is a dummy variable for floods. A major flood in 1983 inundated a large amount of farm land in the AMA. The flood may have slowed the rate of diffusion of dead level fields.

Logit Analysis

In many situations the decision to adopt a new technology is a "yes" or "no" decision. In the economic framework described earlier the farmer decides whether or not to adopt the innovation and how many acres to put the innovation on. The outcome of the decision depends, in part, on the characteristics of the individuals. Information on the attributes of those people in the survey can be used to predict the likelihood that a person will decide one way or another. Logit analysis provides a way to predict the decision of individuals outside the sample.

The logit model is based on the logistic function and is represented by:

$$P_i = \frac{1}{1 + e^{-Z_i}} \qquad 3.10$$

where e is the natural base of logarithms, P is the probability that a person will make a certain decision based on $Z_i$. The independent variables are represented by $Z_i$ .

To estimate equation 3.10 first multiply both sides by 1+e to get

$$\left(1 + e^{-Z_i}\right)P_i = 1 \qquad 3.11$$

Dividing by P and subtracting 1 yields

$$e^{Z_i} = \frac{P_i}{1 - P_i} \qquad 3.12$$

since $e^{-Z_i} = 1/e^{Z_i}$ then

$$e^{-Z_i} = \frac{1 - P_i}{P_i} \qquad 3.13$$

taking the natural logarithm gives

$$\log \left(P_i/1 - P_i\right) = Z_i$$

The dependent variable is now the logarithm of the odds that a certain choice will be made. In the case of this thesis the dependent variable is the logarithm of the odds that dead level fields will be adopted on the farm.

The maximum likelihood method of estimation is used to estimate the logit model. This is easily estimated using the statistical package Limdep (Greene, 1989). This package also estimates the predictive ability of the model by stating the percent predicted correctly and the percent predicted incorrectly.

Three general models will be estimated. Model 1 is the probability of adoption based on farmer characteristics. These characteristics are age, college education, ownership, and total acres farmed. The second model is based on the farm characteristics soil intake rate, farm size, and irrigation district. The third model is a combination of the variables in first two. The third model is split into models one and two to see if individual characteristics predict adoption better than farm characteristics, or vice versa.

Data Acquisition

The Pinal AMA Department of Water Resources records that there are nearly 1450 grandfathered irrigation rights issued in the Pinal AMA. The farms detailed by these rights vary in size from two acres to more than 1000 acres. Many of these farms are less than 40 acres in size, and are known as "ranchettes". Ranchettes are large lots with homes built on them suitable for horses, cows, sheep, and small recreational farming operations. 558 of these 1450 "farms" are greater than 100 acres in size.

Survey Design and Construction

An attempt was made to only survey actual commercial farms and to limit the number of farms surveyed to 100 farms. Only farms greater than 100 acres were included in the survey. One hundred farms were chosen because of cost considerations of interviewing and it was considered a number that could be surveyed in a reasonable period of time. One hundred surveys would also represent a confidence interval of approximately five percent which was considered acceptable.

Snedecor and Cochrane (1967) provided the equation for determining the confidence interval for a selected sample size. This equation is:

$$L = \frac{X\sigma}{\sqrt{n}}$$

The selected allowable error in the sample mean is denoted by L. The t-value associated with the confidence interval for the chosen sample size is x. The standard deviation of the population is $\sigma$. The standard deviation, L, and desired sample size are known. Plugging these values into the equation and solving for x yields:

$$41.39 = \frac{x(206.97)}{10}$$

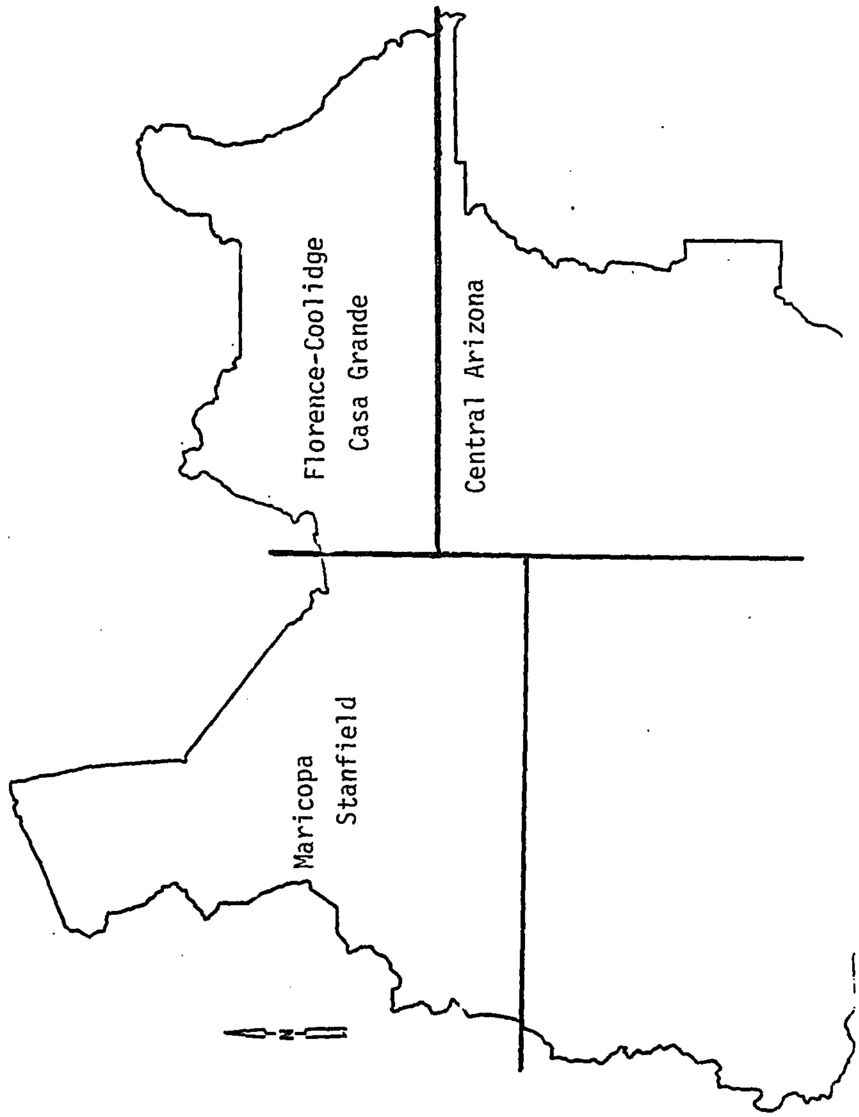
$$X = 1.99$$

The t-value for the sample size of 100 gives a confidence interval of plus or minus approximately five percent.

The remaining 558 commercial farms in the Pinal AMA were stratified two ways. The first was by size. Four sizes were chosen; 100-199 acres, 200-499 acres, 500-999 acres, and 1000 plus acres. These size categories were chosen to be similar to USDA size categories in other publications. The 100-199 range also allows for adequate sampling of smaller farms.

The second stratification was by geographic area. The DWR considered, for simplicity, the Pinal AMA to consist of three general farming and irrigation areas; Florence-Coolidge-Casa Grande (FCC), Central Arizona (CA), and Maricopa-Stanfield (MS). Figure 3.1 is a map of the general

Figure 3.1 Irrigation Areas in the Pinal AMA




source: Arizona Department of Water Resources, Pinal AMA Second Management Plan, 1988 boundaries of the three areas in the AMA. The Florence-Coolidge-Casa Grande area includes all the farm land around these three communities. The Central Arizona area includes the Eloy and Red Rock areas and is largely made up of the Central Arizona Irrigation District. The Maricopa-Stanfield area is generally made up of farms in the Maricopa-Stanfield Irrigation District and includes the towns of Maricopa and Stanfield. Farms were surveyed from each size category in each of the three districts.

Tom Carr and Randy Edmond from the DWR and Chris Haynes of the Casa Grande SCS suggested questions that should be asked. Appendix 3.1 is the actual survey questionnaire used.

Question three refers to the number of irrigated acres on the farm in question. This question was designed to measure farm size. This is the size of the farm surveyed, not the total number of acres farmed by the farmer. Three different responses were often gathered. One was given by the DWR and refers to the number of water duty acres. Another came from SCS records and the third was given by the farmer. The farm was stratified for the survey according to the number of acres supplied by the DWR. The answer given by the farmer was used in the analysis. Question four asked what irrigation districts or electrical districts the farm was in. The surveyed farm may lie in a combination of districts. This question was suggested by the DWR. It was included because each of the stratified areas has different irrigation districts in it. Question five asked if the farm received CAP water. If the farm did receive CAP water then the year water deliveries began was asked. Since soils are hypothesized to play a large role in the adoption of dead level fields, question seven asked about the intake rate and average water holding capacity of the soil. The soil intake rate is the rate at which water soaks into the soil. The intake rate is measured in inches per hour. The average water holding capacity of the soil is the amount of water that is available in the soil for tha plant to use. It is measured in inches of water per foot of soil. The relationship between the average water holding capacity and the intake rate is a negative one. A soil with a higher intake rate will generally have a lower water holding capacity. These data were gathered at the Soil Conservation Service office in Casa Grande, Arizona. Question eight was designed to elicit the data for the diffusion of dead leveling. The farmers were asked: the number of sloped acres on the surveyed farm, acres leveled to 0 percent slope, acres devoted to other irrigation systems and the total acres in the surveyed farm for each individual year from 1968 to 1989. This time period was chosen after looking at the Soil Conservation Service records. It appeared that fields began to be leveled to 0 percent slope in the late 1960s. Ownership and farming arrangement were counted as one question. If the farmer had any ownership interest at all then it was counted as ownership. This was to account for different farming arrangements for government program purposes. Other types of farming arrangements were private leases, state leases, and estates and trusts. "Total acres farmed" was used as proxy variable for net worth. It includes the surveyed farm and any other land farmed by the farmer. It may include other property that is owned or property that is leased.

Questions nine and ten were asked to get a picture of personal characteristics of the farmer. Present age was asked and then counted back to find the farmers age when he adopted dead level fields. Both age and education are hypothesized to be related to the adoption decision.

Survey Procedure

The sample was drawn in May, 1989. One hundred farms were selected with extra farms selected in each size group, in the case that no response was received. The farmers addresses and telephone numbers (when possible) were obtained from the groundwater certificates and the annual water use reports on file at the Pinal Active Management Area office of the Department of Water Resources in Casa Grande, Arizona. More phone numbers were gathered at the Soil Conservation Service office in Casa Grande, Arizona.

Soil, acreage, and leveling data were gathered at the Soil Conservation Service office in Casa Grande during the months of May and June. When files were not available for the farm in question, soil data for the farm was gathered from the soil survey maps of the county.

Letters were mailed July 7, 1989 to 69 farmers in the AMA. These farmers represented 104 sampled farms. The letter informed the farmer of our survey and requested his assistance when we telephoned in the future. An informational data sheet was included with the letter. This sheet contained the first six columns (year through total irrigated acres) of question eight in the survey.

Attempts to contact the farmers by phone began July 17, 1989. Phone calls were made during the evening hours and from 12:00 p.m. until 1:00 p.m., Monday through Thursday. Phone calls were made through November 15, 1989.

At this point 86 surveys had been completed.

Repeating the equations above to solve for the confidence interval given 86 completed surveys yields

$$41.39 = \frac{X(206.97)}{9.27}$$

$$X = 1.85$$

The confidence interval is approximately eight percent.

# CHAPTER FOUR

## Analysis of Results

Eighty six farms in the Pinal AMA were surveyed. These farms and the people who farm them have certain characteristics. Table 4.1 details some descriptive statistics for the farms in the AMA, and for each irrigation district.

Age represents the ages of the farmers when they adopted and the present ages of those farmers who have not adopted. Given this, the average age of the AMA farmers when they adopted dead level fields was 47.5 years of age. Farmer's ages ranged from 25 years to 82 years of age. The average size of the farm surveyed was 434 acres. The farms went from 40 acres in size to 1537 acres in size. The average water holding capacity of the soil (AWC), measured in inches of water per foot of soil, for all the sampled farms across the AMA was 1.9 inches. The average intake rate of the soils was .43. The average total acres farmed by the farmers was 1069. The total acres farmed ranged from 99 acres to 4500 acres. The total number of acres farmed differs from the size of the farm surveyed because one farmer may farm more than one surveyed farm or may farm land that was not part of a surveyed farm.

**Table 4.1** Descriptive Statistics for Farmers in the Pinal AMA and in Each Irrigation District[1]

| | AGE | IRRIGATED ACRES | AWC | INTAKE | TOTAL ACRES FARMED |
|---|---|---|---|---|---|
| **Pinal AMA** | 47.5 | 434 | 1.91 | .43 | 1069 |
| | (13.56) | (341.4) | (.279) | (.2105) | (792.2) |
| | (25-82) | (40-1537) | (1.27-2.4) | (.1-1.03) | (99-4500) |
| **FCC** | 47.2 | 348 | 1.905 | .4611 | 774.8 |
| | (13.56) | (309.36) | (.2449) | (.2252) | (448.4) |
| | (25-79) | (40-1300) | (1.3-2.2) | (.1-1.03) | (99-2580) |
| | (0) | (2.68) | (.147) | (2.12) | (.843) |
| **CA** | 50.7 | 526 | 1.88 | .378 | 1384.8 |
| | (15.3) | (373.3) | (.33) | (.167) | (1044) |
| | (26-82) | (135-1200) | (1.4-2.3) | (.14-.8) | (135-4000) |
| | (1.84) | (2.88) | (-.588) | (1.18) | (1.25) |
| **MS** | 45.2 | 481 | 1.93 | .434 | 1232 |
| | (12) | (341.3) | (.291) | (.22) | (836.9) |
| | (31-78) | (140-1537) | (1.3-2.4) | (.1-1.0) | (320-4500) |
| | (-1.47) | (470) | (1.67) | (.42) | (3.7) |

[1]The mean is followed by the standard deviation, minimum and maximum, and the t-ratio, in parentheses, for a difference between the irrigation district and the AMA means.

Farmers in the Florence-Coolidge-Casa Grande area were insignificantly younger, on average, than farmers in the AMA as a whole. The size of the farm surveyed was significantly smaller, at the one percent level. The soils in the area had lower average water holding capacities and significantly higher intake rates than the AMA as a whole. The average total acres farmed was insignificantly lower for this area.

Central Arizona area farmers were, on average, older than the farmers in the whole AMA. The average size of the surveyed farm was significantly larger than the average size of the farm surveyed for the entire AMA. The average water holding capacity of the soil and the average intake rate were both insignificantly smaller than the averages for the AMA. Central Arizona farmers farmed more total acres, on average, than did farmers in the AMA as a whole.

Farmers in the Maricopa-Stanfield area were younger, on average, than the farmers in the whole AMA. The average size of the surveyed farm was significantly larger than the average surveyed farm across the AMA. The average water holding capacity and intake rates of the soils were both insignificantly larger than soils across the AMA. The farmers farmed significantly more acres, on average, than did farmers in the whole AMA.

The Adoption of Dead Level Fields

Logit analysis, as detailed in chapter 3, was performed on the data gathered from all the farms. Three models were estimated. The first measured the effect of farmer characteristics on adoption. Variables in this model included age, dummy variables for college education and ownership, and total acres farmed. The second model measured the effect of farm characteristics on the adoption decision. These variables were the intake rate of the soil, the number of irrigated acres, and dummy variables for the Maricopa-Stanfield and Florence-Coolidge-Casa Grande irrigation areas. The third model includes all of the variables in the first two models. Table 4.2 shows the regression results of the models.

Only age is significant (1 percent level) in model one. Its negative sign was as hypothesized. A higher age should decrease the probability of adoption due to the farmer having a shorter planning horizon. A shorter planning horizon should reduce the probability of adoption of a strategic investment. College education and land ownership are both positive but not significant. Both were hypothesized to have a positive sign. More education should increase the probability of adoption for two reasons. One, the farmer may have access to more information. Two, more

Table 4.2 Logit regression results for the Adoption of Dead Level Fields[1]

**VARIABLES**

| | constant | age | education | ownership | total acres | irrig acres | intake | MS | FCC | % predicted correctly |
|---|---|---|---|---|---|---|---|---|---|---|
| **Model 1** | 3.56 | -.84 | .65 | .501 | -.0002 | | | | | 74.4% |
| | (1.4) | (-.023) | (.64) | (.507) | (.0003) | | | | | |
| | (2.6) | (-3.651) | (1.0) | (.998) | (-.466) | | | | | |
| **Model 2** | -.138 | | | | | .0014 | -1.65 | 1.68 | -.06 | 65.1% |
| | (.73) | | | | | (.001) | (1.189) | (.69) | (.58) | |
| | (-.19) | | | | | (1.87) | (-1.38) | (2.43) | (-.1) | |
| **Model 3** | 7.8 | -.131 | .389 | -.730 | -.0008 | .0023 | -3.47 | 1.87 | -.69 | 82.6% |
| | (2.6) | (.04) | (.8) | (.63) | (.0005) | (.001) | (1.6) | (.96) | (.87) | |
| | (2.97) | (-3.7) | (.49) | (-1.16) | (-1.7) | (2.48) | (-2.16) | (1.94) | (.8) | |

[1]The asymptotic standard error and the t-ratio are given in parentheses below the coefficient.

education may increase the farmer's ability to evaluate new technology and innovations. Perhaps it is not as significant because it doesn't take into account experience as education. Ownership was expected to have a positive relationship with adoption because the farmer controls the decisions made on the farm. When the farmer does not own the land, his decision making ability may be severely compromised.

The total number of acres farmed can be thought of as a proxy variable for net worth. It is negative but not significant, and is very small. It was hypothesized to be positively related to the probability of adoption. Farmers with a higher net worth should be more able to adopt. The negative sign may be due to farmers leasing land to increase their total acres farmed. The farmers may have less control over the leased land which may contribute to the negative sign.

Model one predicted the farmers adoption decision correctly 74.4% of the time. It predicts adoption better than nonadoption, 80.9% to 66.67%.

Model two analyzes the effect of farm characteristics on the adoption decision. In this model the number of irrigated acres in the farm surveyed is positive and significant at the 10% level. This sign was expected because farm size is hypothesized to increase the probability of adoption. A larger farm may command more resources that enable the farmer to adopt dead level fields.

The intake rate is negative, as hypothesized, but not significant. Technical information suggested that dead level fields are best suited to land that has lower intake rates. Soils with high intake rates may actually decrease the irrigation efficiency as the farmer tries to get the water across the field.

The dummy variables for the irrigation districts Maricopa-Stanfield and Florence-Coolidge-Casa Grande were positive and significant at the 1 percent, level and negative and insignificant, respectively. These signs were hypothesized because of the characteristics of the areas. Maricopa-Stanfield was expected to be positive because the area has faced higher water costs due to declining water tables and intervals of higher electrical rates. The Florence-Coolidge-Casa Grande area is supplied to a large extent by surface water from the San Carlos Irrigation District. They generally have had cheaper water. The farms in this area are also smaller, and the land has, in general, higher intake rates. These combined factors may contribute to the negative sign.

This model does not predict adoption as well as model one. It only predicts 65% of the cases correctly. The two models do predict nonadoption with the same effectiveness. Adoption was not predicted nearly as well, 80.9% to 63.8%.

Model three combines the variables from the first two models. Age is still negative and significant at the one percent level in model three. A college education is positive but insignificant. Ownership changed signs for, model to model three. It is now negative, but insignificant. The total number of acres farmed by the individual is now significant and negative at the ten percent level. Again, that may be due to more land being leased to increase the total number of acres farmed. The size of the farm surveyed is significant at the one percent level. The intake rate of the soil is significantly negative at the one percent level. The sign of the intake rate was hypothesized to be negative. The Maricopa-Stanfield area had a positive and significant effect, at the ten percent level, on the probability of adoption. This is probably due to characteristics of the area. The Maricopa-Stanfield are has experienced the largest drop in water tables and has had, at times, much higher electrical costs than the other two areas. The Florence-Coolidge-Casa Grande area has a negative and insignificant effect on the probability of adoption. This is probably because the area has higher soil intake rates and has generally had lower electric energy costs and water costs than the other two areas.

Model three predicts adoption much better than the first two models. It predicts 82.6% of the results correctly. It correctly predicts adoption and nonadoption greater than 80% of the time. The critical variables determining the probability of adoption seem to be age, the size of the farm surveyed, the soil intake rate, the total number of acres farmed, and the Maricopa-Stanfield irrigation area. These variables are significant in determing what farm is more likely to adopt dead level fields.

Early Adopters vs. Later Adopters

Early work in the adoption and diffusion of innovations suggested that there are differences between early and later adopters. To determine if there is a difference between early adopters and later adopters of dead level fields, the adopters were separated from the rest of the surveyed farms. The adopters were then separated into two groups: those who adopted before 1981 and those who adopted in or after 1981. Farms in the pre-1981 group were considered to be early adopters and farmers in the 1981 and after group were later adopters. The year 1981 was used as the cutoff between early and later adopters because laser leveling had only been available a short period of time and the Groundwater Management Act had been passed in 1980. This included farms that adopted before laser leveling became available.

Table 4.3 shows the statistics between early and later adopters. There were 15 farms that adopted prior to 1981. On average they leveled 303 acres, shown by the variable "Total", out of an average farm size of 433 acres. The number of irrigated acres and total acres farmed were lower than for later adopters, but not significantly so. Early adopters, on average, leveled more acres than later adopters. Both groups may still be dead leveling fields at this time. Later adopters may have recently begun to level which may account for them having leveled fewer acres. There was no significant difference between the ages of the two groups. Early adopters had soils with lower water holding capacities and higher intake rates. The only variable that is significantly different between the early and later adopters was the soil intake rate. The early

Table 4.3 Statistics for Early versus Later Adopters[1]

| Variable | Mean | | Std. Dev. | | Min | | Max | |
|---|---|---|---|---|---|---|---|---|
| | Early | Later | Early | Later | Early | Later | Early | Later |
| Irrig | 433.8 | 506 | 333.5 | 351.32 | 99 | 100 | 1250 | 1300 |
| | (-.66) | | | | | | | |
| Total | 303.1 | 236.07 | 308.47 | 205.11 | 68 | 35 | 1100 | 800 |
| | (.86) | | | | | | | |
| AWC | 1.9 | 1.96 | .26 | .30 | 1.37 | 1.27 | 2.26 | 2.4 |
| | (-.68) | | | | | | | |
| Intake | .49 | .35 | .21 | .16 | .13 | .1 | .83 | .87 |
| | (2.46) | | | | | | | |
| Age | 41.33 | 41.31 | 9.28 | 10.78 | 25 | 26 | 58 | 63 |
| | (.006) | | | | | | | |
| Totacres | 859.6 | 1094.1 | 317.83 | 688.39 | 99 | 100 | 1250 | 2580 |
| | (-1.25) | | | | | | | |

[1]The t-ratio is given in parentheses below the coefficient to test the difference between the two means.

adopter's intake rate was significantly higher (2 percent level). This is the opposite of what was hypothesized. A possible explanation for this may be that farms with higher intake rates were trying to reduce their costs by using less water. In doing so they hoped to increase profit.

In summary, the combined logit model (model 3) for all the farms in the AMA gives some results that are consistent with previous studies. Farm size and a college education positively affected the probability of adoption. Age had a negative affect on the probability of adoption. The soil intake rate and the Florence-Coolidge-Casa Grande area had a negative effect on the probability of adoption. The Maricopa-Stanfield area had a positive effect on the probability of adoption.

Surprisingly, ownership and total acres farmed had negative signs. Ownership may be linked to older farmers. Since older farmers are less likely to adopt then ownership may have a negative sign also. The negative sign on the total number of acres farmed may be due to farmers leasing more land to increase the total size of their operation. The farmers may have less control over the leased land which may lower the probability of adoption of dead level fields.

The only significant difference between early and later adopters was the soil intake rate. It was significantly larger, at the two percent level, for the early adopters. Otherwise there was no statistically significant difference between the adopters.

The Diffusion of Dead Level Fields

A S-shaped diffusion curve was estimated from the data elicited in the survey. Three different ceiling levels were used, 50%, 60%, and 70%, to plot the diffusion of dead level fields. The DWR has suggested that an eventual diffusion ceiling of 70% can be expected. These three ceilings were used in the diffusion equations as estimates of what the eventual actual diffusion ceiling could be. Fourteen models were estimated for the 60% ceiling level. The 60% ceiling level was chosen because the data seemed to suggest that it was the most likely diffusion ceiling. The first uses only the year as a variable. The other thirteen use one different variable in addition to the year. These variables, as discussed earlier, are: nominal (nomprc) and real cotton price (realprc), an average of electrical rates in the AMA (elrates), indexes of energy prices paid by farmers (enerind) and crop prices received by farmers (cropind), the prime rate of interest (prate), and dummy variables for the 1980 GMA (GMA1980), receiving CAP water

(CAP), laser leveling (laser), and floods (floods). To measure the effects of price risk on the diffusion of dead level fields, the coefficients of variation for real cotton prices (realvar), nominal cotton prices (nomvar), and electrical rates (elvar) were used in the analysis.

The data for electrical rates were taken from the crop budgets for Pinal County. Cotton prices were taken from the Arizona Agricultural Statistics. The index values were taken from the Producers Price Index for agricultural products. The variable for the GMA is zero prior to 1980 and one after 1980. The variable for CAP water equals one in the years 1988 and 1989, when most farmers were able to receive CAP water. The value for laser leveling is one starting in 1981 when laser technology became widely available. The variable for floods equals one in 1983 when a large flood inundated much of the farmland in the AMA. The flood may have affected the rate of diffusion because it may have delayed or moved up the farmer's leveling plans. The coefficients of variation are calculated by taking the standard deviation of a three year moving average of prices divided by the mean of the same three year moving average. The rate of diffusion is made a function of each of the variables.

When these models were estimated a positive autocorrelation problem was discovered. This occurs when the error terms from different time periods are correlated. This occurs often in time series data. Autocorrelation generally does not affect the unbiasedness or consistency of OLS regression estimates. It does effect the efficiency of the estimates by biasing the standard error downwards.

The Cochrane-Orcutt procedure was used to correct for the autocorrelation problem. This procedure involves a series of iterations to estimate P (correlation coefficient between errors). Each iteration produces a better estimate than the previous one. This process transforms the residuals. The tables of results will include the Durbin-Watson for transformed residuals. A transformed D-W statistic between 1.5 and 2.5 is within the non-correlated range.

Table 4.4 contains the results of the models at the 60% ceiling level. Model one is the basic estimate of the diffusion of dead level fields in the Pinal AMA. The sign of the coefficient of year is positive. This is the estimated rate of diffusion. The $R^2$ of model one is .987. The Durbin-Watson statistic for the transformed residual is 1.8. This is well within the uncorrelated boundaries for

**Table 4.4** Estimation Results for the Diffusion of Dead Level Fields[1]

**VARIABLES**

| | constant | year | GMA1980 | CAP | laser | floods | prate | cropindex | $R^2$ | DW |
|---|---|---|---|---|---|---|---|---|---|---|
| **Model 1** | -487.4 | .245 | | | | | | | .987 | 1.8 |
| | (17.4) | (17.32) | | | | | | | | |
| **Model 2** | -462.6 | .233 | .116 | | | | | | .992 | 1.9 |
| | (-17) | (16.9) | (.81) | | | | | | | |
| **Model 3** | -501.8 | .25 | | -.15 | | | | | .987 | 1.9 |
| | (-16.4) | (16.3) | | (-1.1) | | | | | | |
| **Model 4** | -481.3 | .24 | | | .008 | | | | .991 | 1.8 |
| | (-15.6) | (15.5) | | | (.06) | | | | | |
| **Model 5** | -483.1 | .24 | | | | -.02 | | | .987 | 1.8 |
| | (21.2) | (24.0) | | | | (-.17) | | | | |
| **Model 6** | -486.6 | .25 | | | | | .2E-6 | | .987 | 1.8 |
| | (-16.4) | (16.3) | | | | | (.001) | | | |
| **Model 7** | -486.7 | .25 | | | | | | .3E-5 | .987 | 1.8 |
| | (-16.2) | (16.2) | | | | | | (.002) | | |

**Table 4.4** Estimation Results for the Diffusion of Dead Level Fields (cont.)[1]

**VARIABLES**

| | constant | year | energyindex | elrate | rprc | nomprc | nomvar | realvar | elvar | $R^2$ | DW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Model 8 | -486.9 | .25 | .1E-4 | | | | | | | .987 | 1.8 |
| | (17.40) | (17.3) | (.124) | | | | | | | | |
| Model 9 | -479.1 | .24 | | 2.5 | | | | | | .986 | 1.6 |
| | (-11.0) | (10.9) | | (.385) | | | | | | | |
| Model 10 | -487.6 | .25 | | | .2E-4 | | | | | .985 | 1.5 |
| | (-10.2) | (10.2) | | | (.126) | | | | | | |
| Model 11 | -488.2 | .25 | | | | .2E-4 | | | | .985 | 1.5 |
| | (-10.3) | (10.3) | | | | (.148) | | | | | |
| Model 12 | -480.4 | .212 | | | | | -.367 | | | .987 | 1.8 |
| | (-19.8) | (19.7) | | | | | (-.93) | | | | |
| Model 13 | -485.6 | .244 | | | | | | -.179 | | .987 | 1.8 |
| | (-18.3) | (18.2) | | | | | | (.44) | | | |
| Model 14 | -390.3 | .196 | | | | | | | -.132 | .976 | 1.9 |
| | (-7.2) | (7.2) | | | | | | | (-.81) | | |

[1] The t-ratio is given in parentheses below the coefficient.

the DW test.

The second model includes a dummy variable for the 1980 Groundwater Management Act. The variable equals zero prior to 1980, and is equal to one in 1980 and after. The sign of the 1980 GMA is positive, as hypothesized, and not significant. The positive sign does reflect that the Groundwater management Act increased the rate of diffusion of dead level fields.

A dummy variable for receiving Central Arizona Project water was included in model three. The variable equaled one in 1988 and 1989. These are the years that most farmers who had CAP water were going to receive it. The sign of the coefficient for CAP water was negative and insignificant. It was hypothesized to be positive. The large water flows associated with receiving CAP water allow dead level fields to be more beneficial. Receiving CAP water should then have increased the diffusion of dead level fields. Farmers may be waiting until they get CAP water to dead level their fields. Since some farmers will not receive the water until 1990 they may not have adopted, which may contribute to the negative sign. The San Carlos Irrigation District has not contracted for CAP water so farmers in that district will not receive the water, which may also have contributed to the negative sign. Model three had the same $R^2$ as model one.

Laser leveling is included in the fourth model. Its coefficient is positive and not significant. This sign was hypothesized to be positive. The advent of laser leveling made dead leveling fields easier to accomplish with precision. The $R^2$ for this model was .991.

A major flood occurred in 1983. This flood was included in model five. It was hypothesized to have a negative affect on diffusion because it would channel resources towards releveling rather than leveling for the first time. Its sign was negative and insignificant.

The prime rate of interest was hypothesized to have had a negative sign. Higher interest rates should increase the cost of borrowing money which would slow the rate of diffusion. Model six shows that the coefficient of the prime rate of interest is positive, but insignificant. That indicates that the diffusion of dead level fields is faster when interest rates are higher. A better explanation is that farmers adopted even though interest rates were high, indicating that some other force was driving diffusion.

The index for crop prices received in model seven had a negative and insignificant affect on adoption. The diffusion of dead level fields has increased while the index of crop prices has generally fallen. The index does cloud the analysis because it includes crops grown all over the country not just in the Pinal AMA.

The average electrical rates and the index for prices paid for energy are both positive and insignificant. This indicates that as energy prices rise the rate of diffusion of dead level fields increases. This sign was expected. Dead level fields reduce the amount of water needed to irrigate thereby reducing the amount of energy needed to pump the water.

Both nominal and real cotton prices had positive but insignificant effects on diffusion. The sign was hypothesized to be positive because higher prices should lead to higher incomes. Higher incomes should make the farmer better able to pay for leveling fields.

The coefficients of variation for nominal and real cotton prices and for electrical rates are all negative and insignificant. A greater degree of risk should slow the rate of diffusion. The negative sign agrees with this hypothesis.

In summary, none of the variables had a statistically significant effect on the diffusion of dead level fields.

The $R^2$ for all of the models were extremely high. None were less than .985, with .992 being the highest. The transformed D-W statistic for all models were in the acceptable range.

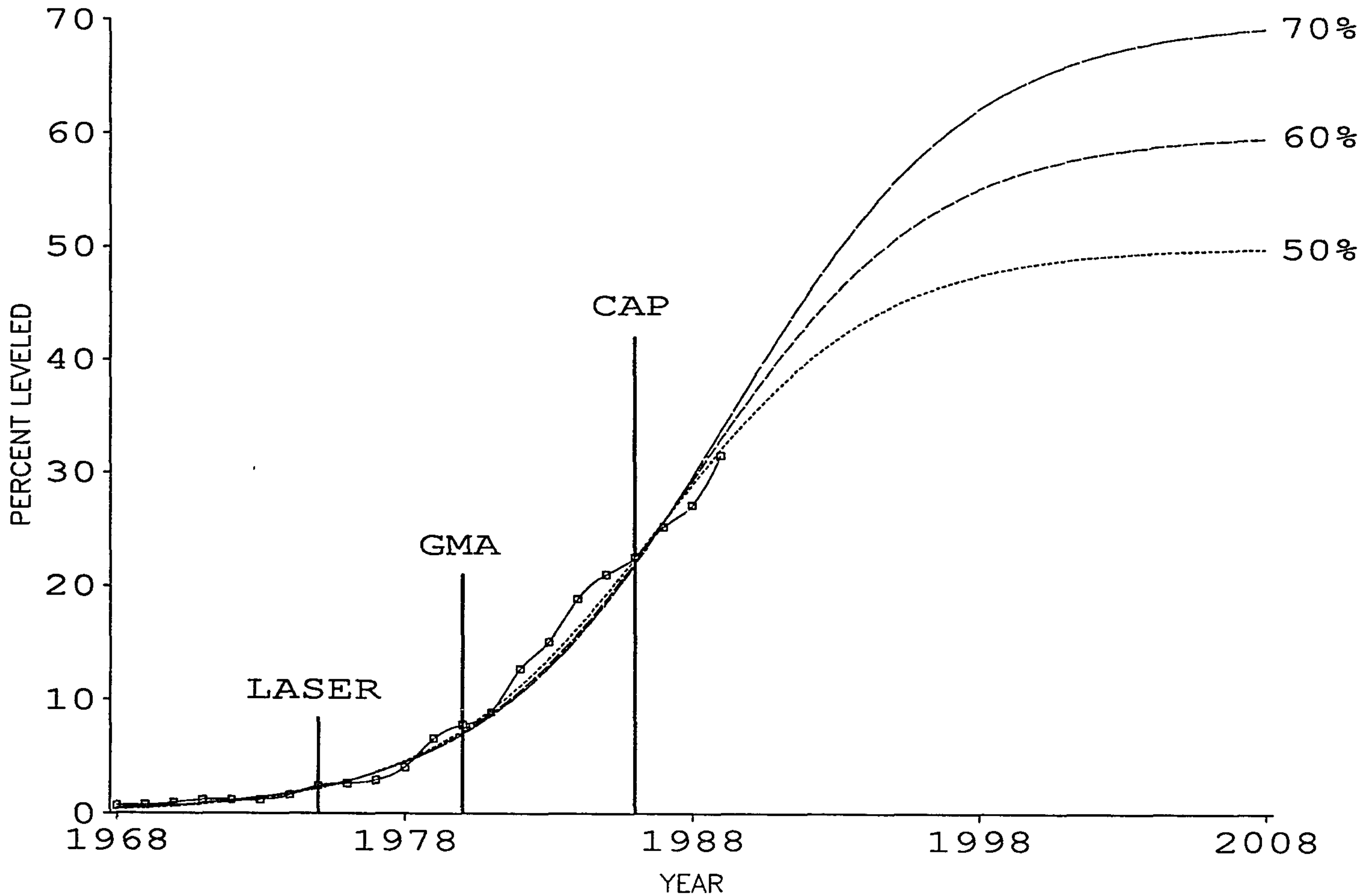
Predicting Diffusion

Predicting diffusion from the estimated diffusion curves is a relatively simple exercise. By plotting the estimated diffusion curve with the cumulative dead leveled acres on the vertical axis and time (in years) on the horizontal axis the year the ceiling is reached can be taken directly from the horizontal axis.

Figure 4.1 shows the actual data and the estimated functions at the 50%, 60%, and 70% ceiling levels using model one. 95% of the 50% ceiling level is reached in the year 1999 and 99% of the ceiling is reached by the year 2005. At the 60% ceiling, 95% and 99% are reached in the years 2001 and 2007, respectively. Diffusion reaches 95% and 99% in the years 2002 and 2009, respectively, for the 70% ceiling level. The data suggests that the 60% ceiling level is the most realistic at this time.

The actual data plotted in figure 4.1 makes the general outline of the estimated diffusion curves. The plotted data creates a "mega" diffusion curve. Within this mega curve

Figure 4.1 Actual and Predicted Diffusion



three "intra-period" diffusion curves appear. Each of these intra-period curves occur following a major shock to the technological or institutional environment facing Pinal AMA farmers which changed perceived, relative prices.

The first intra-period diffusion curve began in 1976 and lasted until 1980. Laser leveling began in 1975 in the Wellton-Mohawk Irrigation and Drainage District. As this technology moved to the central Arizona area, it appears that more farmers dead leveled their fields. The impact of laser leveling technology begins in the years 1979 and 1980 when actual dead leveling occurred more than was indicated by the estimated diffusion curve. Farmers leveled their fields in response to teh new technology being available.

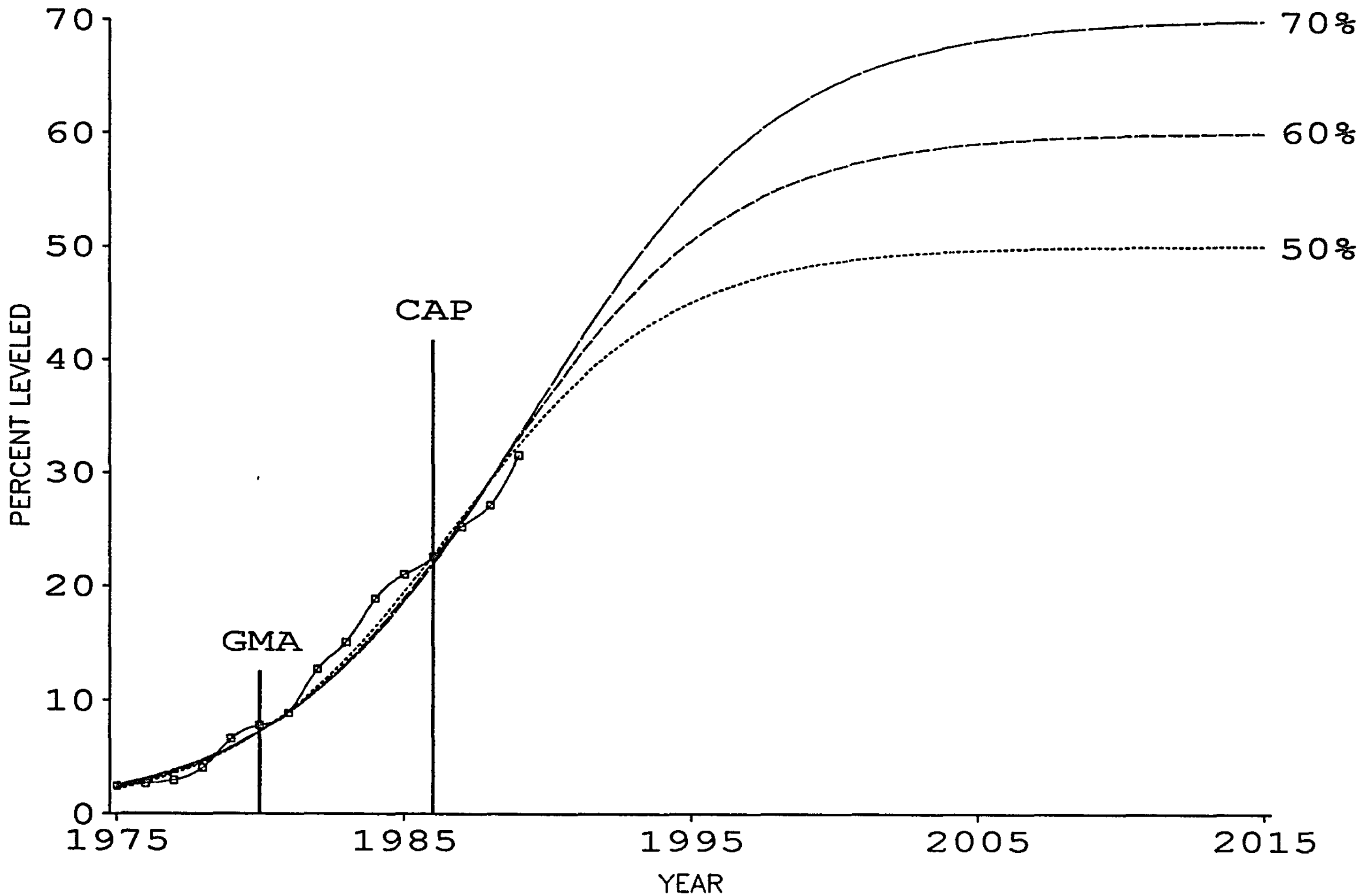
The second intra-period curve began in 1980 and ended in 1986. The Groundwater Management Act was passed in 1980. This required farmers to become more water efficient. In this time period the amount of land dead leveled jumped from about eight percent of the total to about 26 percent of the total land in the survey. Dead level fields diffused much faster than the estimated functions suggest.

The last intra-period curve began in 1986. A few central Arizona farmers began getting CAP water in 1986. By 1988 and 1989, many more were receiving the water. Large irrigation heads like those received through CAP make dead level fields more efficient. It is completely reasonable for a farmer to wait to adopt dead level fields until the CAP lateral canal that will deliver the water to him is built. Waiting to install dead level fields until you know the water will get there is one way the farmer can deal with the risk and uncertainty associated with the CAP.

Figure 4.1 and the associated curves used 1968 as the base year for analysis. This was seven years before laser leveling became available in the state. Laser leveling allowed fields to be dead leveled much easier than the old leveling techniques allowed. Using 1975 as the base year for analysis, to incorporate only the years after laser leveling was available, does not change the estimated diffusion curves to any great extent. Figure 4.2 shows the actual data and the plotted estimated functions. The mega-curve and the intra-period diffusion curves are still present in the same relation to figure 4.1.

Changing the base year has not altered the analysis which suggests that increases in diffusion only occur in response to some outside stimulus. That stimulus seems to relate not to actual relative prices but to government related action that may change perceived relative prices.

# Figure 4.2 Actual and Predicted Diffusion



While laser leveling itself was not government spawned, government was the stimulus for its first use in the Wellton-Mohawk Valley. After laser leveling dead level fields proved effective the technology diffused into central Arizona.

The investment in dead leveling fields is a strategic investment. Given this fact, it seems that government policy is what has driven this strategic investment. Prices, costs, interest rates have not. Investment occurred even though cotton prices had a downward trend over the study period, energy costs rose then fell back to earlier levels, and interest rates increased then declined.

# CHAPTER FIVE

## Conclusions and Implications

Water has been the key to Arizona's prosperity beginning with the Hohokam. The growth of agriculture in the twentieth century has resulted in a large overdraft of groundwater. To combat this overdraft problem the state passed the 1980 Groundwater Management Act. The GMA requires farmers to become more water efficient to cut the overdraft. To become more efficient farmers have the option to adopt the practice of laser leveling their fields to 0% slope.

Early work in the area of the adoption and diffusion of innovations concentrated on: one, what characteristics made farmers more likely to adopt new technologies; two, why some farmers adopted sooner than others; and three, how innovations diffused through an area.

These studies generally found that adopters were more likely to be younger, better educated, have higher incomes, have larger farms, and have higher social participation rates. These characteristics applied to adopters of all types of innovations.

Innovations were found to diffuse through time in a s-shaped pattern. There were few early adopters, more adopters a little later, then a large number of adopters, and then fewer in each time period until a ceiling level of diffusion was reached. This s-shaped pattern was closely approximated by the logistic growth function.

Later studies generally supported the findings of these early researchers. Several theoretical models were proposed explaining the diffusion of innovations and why an s-curve best estimates diffusion.

The past research had a major shortcoming in that all of the innovations studied were oriented towards operating inputs. New seed varieties and chemicals are operating inputs. Strategic investments, like dead leveling, were not studied.

A strategic investment is one that requires a large amount of capital for each unit the investment is applied to. The costs cannot be spread over more acres. The investment has a large sunk cost element. Once dead leveling is adopted it cannot be changed back easily, or inexpensively. The third element is that the strategic investment relates to the long range planning horizon of the firm. A strategic investment helps position the firm to survive in the long term. Dead leveling allows the business to position itself against the changing economic and legal environment in central Arizona.

I found that the characteristics that make a farmer more likely to adopt the strategic investment, dead level fields, are generally the same as those affecting the adoption of other non-strategic innovations. Age significantly decreased the probability of adoption. Farm ownership and total acres farmed also decreased the probability of adoption, but insignificantly in a statistical sense. A college education increased, insignificantly, the probability of adoption. Larger farms, based on unit surveyed, increased significantly the probability of adoption. The rate that the soil absorbs the water, and farms in the Florence-Coolidge-Casa Grande area, which has higher intake rates, decreased significantly and insignificantly, respectively, the odds of adoption. Farms in the Maricopa-Stanfield area, had significantly higher odds of adoption.

The adoption model results suggest that there is a general profile of a farmer more likely to adopt dead level fields. The farmer is younger, college educated, and probably has an ownership stake in the farm, or at least a longer term lease than from year to year. The farm is in the Maricopa-Stanfield or Central Arizona irrigation areas.

The soil probably has a low intake rate. The individual farm unit, as given by the size of the surveyed farm (irrigacres), will also probably be fairly large in relation to other farm units.

Embedded in the actual diffusion "mega curve" are three "intra-period" diffusion curves. Each of the intra-period curves corresponds to governmental action that affected farmers in the AMA. The first intra-period curve, from 1978-1980, followed the advent of laser leveling dead level fields in the Wellton-Mohawk Valley. The federal government subsidized the cost of dead leveling to encourage farmers to dead level fields to use less water. A treaty with Mexico forced the government to increase the quality of water flowing from the Colorado River into Mexico. Using less water for irrigation would increase the quality of Colorado River water flowing into Mexico.

The 1980 GMA caused the second intra-period curve beginning in 1981 and continuing until 1986. The GMA has required producers to become more water efficient. For the firm to remain viable in the future, many farmers must adopt more efficient water use measures.

The last mini curve began in 1986 and appears to be continuing at this time. This is a response to the CAP.

Farmers in the AMA began receiving CAP water in 1986. As the lateral canals are extended farmers are adopting dead level fields to efficiently use the large flows of water. That farmers are just now responding to the CAP is probably a response to uncertainty, a "wait and see" response. Farmers will make sure they are going to get CAP water before they spend the money to install the dead level systems.

The stimulus for each intra-period curve was a crisis of some kind. The first was a new technology spurred originally by government treaty, the second was government action to reduce groundwater overdraft, and the last was receiving water from the federally built CAP. The idea that producers must be forced to change can be traced back to Rogers' work in the 1960s. Rogers suggested that relative advantages may not be realized until a crisis develops. The crisis then forces the potential adopter to make a decison to adopt or not. Each shock to the Pinal AMA forced some farmers to decide whether of not to adopt dead level fields.

The results suggest that relative prices do not provide a large incentive to adopt a strategic investment like dead level fields. Pinal AMA farmers have subsidized power costs and price supported output prices. These supports have kept output prices at high levels relative to costs. The results generated by this thesis support the hypothesis that in industries with significant government intervention strategic changes only occur when producers are forced into it. The force is government supplied through the original use of laser leveling, the Groundwater Management Act, and the Central Arizona Project.

This thesis has an additional implication for the adoption and diffusion of strategic investments. The factors affecting the decision to adopt an innovation appear to be the same for all innovations, both strategic and non-strategic. The difference comes in what makes that adoption decision necessary. This stimulus to force the decision to be made comes from forces internal to the farmer's environment. The most powerful of these forces seems to be government action. Government policy is made far from the Pinal AMA but its affects are part of the farmers decision process.

How can these results be put to use? Perhaps the most immediate use would be by the Department of Water Resources. The DWR has based its water conservation goals on dead level fields being the best long-term farm practice. They suggest that most farms can install a dead level system, farm wide by the year 2000. The DWR has projected cutting the annual groundwater overdraft in the Pinal AMA by about 400,000 acre feet annually by the year 2000. This thesis predicts that only 60% of the farm land will have dead level systems installed by the year 2000. That may leave the DWR short of its water conservation goals.

It is possible that additional shocks to the Pinal AMA may increase diffusion beyond the predicted 60% ceiling. The Pinal AMA Second Management Plan takes effect in 1990. Its more stringent water conservation requirements may increase diffusion. The possible future contracting for CAP water by the San Carlos Irrigation District may provide more impetus for the diffusion of dead level fields. The diffusion ceiling may also increase in the future as CAP water reaches farms in 1990.

By targeting those people most likely to adopt dead level fields the DWR may be able to increase the diffusion of dead level systems rather easily. The difficult part is in persuading farmers who are not likely to adopt on their own. These farms will require an intensive effort to begin adoption.

Unanswered Questions

As with many research projects there are more questions at the end of the project than are answered by the results. Several questions present themselves at this time. Does the original slope of the land have an affect on adoption? Land with more slope would be more expensive to level. Does the land's proximity to cities or value in other uses affect adoption of dead level fields? Have strategic investments like dead leveling diffused in a like manner in Maricopa County, Arizona? Have strategic investments in other industries diffused similarly? And are there better measures of risk that might have more explanatory power?

This thesis has been a start in the direction of filling this gap in the literature. The answers to these other questions would go a long way towards filling this area of the literature.

Respondent No. 121 ____

# ADOPTION AND DIFFUSION STUDY

1. Name ______________________________

   Address/Zip Code ______________________________

   ______________________________

   ______________________________

   Telephone No. ______________________________

2. Farm No. (ASCS) ______________

3. Irrigated Acres ______________

4. Irrigation District and/or Electrical District:

   - Central Arizona ☐
   - Maricopa-Stanfield ☐
   - Hohokam/ED2 ☐
   - San Carlos ☐
   - San Carlos/ED2 ☐
   - San Carlos/Hohokam/ED2 ☐
   - ED2 ☐

5. Do you receive CAP water? ______
   When did you begin to recieve it? ______

7. Soils:

| | Soil Names | # | %A | AWC | Intake |
|---|---|---|---|---|---|
| 1. | ________ | __ | __ | __ | __ |
| 2. | ________ | __ | __ | __ | __ |
| 3. | ________ | __ | __ | __ | __ |
| 4. | ________ | __ | __ | __ | __ |
| 5. | ________ | __ | __ | __ | __ |
| 6. | ________ | __ | __ | __ | __ |
| 7. | ________ | __ | __ | __ | __ |
| Total | | | | __ | __ |

8. Data Sheet

| | Acreage | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Leveled to 0 Slope | | | Total | Total | | | |
| | | | | Other Systems | Irrigated | Acres | Water Cost | Elec. Rate | |
| Year | Sloped (1) | Leveled (2) | Cam. Leveled (3) | (Drip, Sprinkler, Level Basin & Ports) (4) | Acres (1&3&4) | Farmed | ($/af) | ($/kwh) | Ownership[1] |
| 1968 | | | | | | | | | |
| 1969 | | | | | | | | | |
| 1970 | | | | | | | | | |
| 1971 | | | | | | | | | |
| 1972 | | | | | | | | | |
| 1973 | | | | | | | | | |
| 1974 | | | | | | | | | |
| 1975 | | | | | | | | | |
| 1976 | | | | | | | | | |
| 1977 | | | | | | | | | |
| 1978 | | | | | | | | | |
| 1979 | | | | | | | | | |
| 1980 | | | | | | | | | |
| 1981 | | | | | | | | | |
| 1982 | | | | | | | | | |
| 1983 | | | | | | | | | |
| 1984 | | | | | | | | | |
| 1985 | | | | | | | | | |
| 1986 | | | | | | | | | |
| 1987 | | | | | | | | | |
| 1988 | | | | | | | | | |
| 1989 | | | | | | | | | |

[1] 1=Sole proprietorship
2=Partnership
3=Corporation
4=Estate, Trust or Investor
5=Lease (Private)
6=Lease (State)

9. Age ____

10. Education

| | |
|---|---|
| Less than High School Graduate | ☐ |
| High School Graduate | ☐ |
| Some College or Technical School | ☐ |
| University or College Graduate | ☐ |

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