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PREDICTING GROUNDWATER TRADING PARTICIPATION IN THE UPPER REPUBLICAN RIVER NATURAL RESOURCE DISTRICT

by

Elizabeth M. Juchems

A THESIS

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PREDICTING GROUNDWATER TRADING PARTICIPATION IN THE UPPER REPUBLICAN RIVER NATURAL RESOURCE DISTRICT

Elizabeth M. Juchems, M.S.
University of Nebraska, 2013

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The goal of this thesis is to predict participation in groundwater trading and the directions of trades among participants. Specifically, the paper considers both formal and informal trading of groundwater used for crop irrigation purposes and attempts to identify those characteristics that predict the probability of trade participation and whether an individual is a buyer or seller of groundwater rights. While the public benefits from efficient use of groundwater include adequate stream flow in hydrologically connected areas and future use of groundwater supplies, there are significant private benefits to landowners especially in water-short areas. Groundwater trading can help move water from low-value to high-value areas of use for the benefit of the participating traders and general public.

Previous research on water trading has focused on surface water trading and theoretical approaches to analyzing groundwater trading. Empirical analysis of groundwater trading is a relatively new area of study due in part to the previous lack of recorded usage, trade data and binding constraints on groundwater use by landowners. Results from this research indicate a strong desire to participate in trades, but high transactions costs have limited the number of trades that have occurred. Utilizing empirical models improves the accuracy of predicting trade participation and direction, and therefore the accuracy of models of trade effects on water supplies and stream flows used in policy and decision making.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

Water is one of the most important natural resource on Earth as it is needed for, but not limited to, drinking, bathing, and the production of food. The use of water for agricultural irrigation is directly responsible for food reaching the dinner table every night. Without irrigation, much of the Western United States would be unable to produce the quantity and quality of crops that have become associated with those regions.

According to United States Geological Survey (USGS) data, in 2005 nearly 85 percent of the withdrawals and 74 percent of the irrigated acres were located in the 17 most western states, where the average annual rainfall is less than 20 inches (United States Geological Survey, 2012). While Nebraska ranks fourth in the volume of water applied, it leads the nation in the number of acres under irrigation at approximately 8.56 million acres. On average, Nebraska receives 22.9 inches of precipitation each year. The southeastern corner receives the highest amount (30.1-35 inches) while moving to the far western side of the state, and the area of interest for this research, receives only 15.1-20 inches annually (U.S. Department of the Interior, 2005). This limited rainfall during the growing season in the western portion of Nebraska results in the high use of irrigation systems to produce grain crops like corn and wheat, which require about 22 inches of rainfall a growing season to reach high yielding maturity (Corn, Water Requirements, 2008).

The primary source of the water used for irrigation is pulled from groundwater wells over the High Plains Aquifer that are often hydrologically connected to the many rivers and watersheds located in the state. According to the Nebraska Department of Natural Resources Well Registry Database, as of May 2012 there were over 122,000 wells registered for use for irrigation. Over 80 percent of the acres irrigated in Nebraska are done so using sprinkler systems, which provide higher water-use efficiency over gravity or flood irrigation systems. Nearly all of the sprinkler systems utilize center pivot technology with an estimated 55,000 systems used on over 77 percent of the irrigated acres (Johnson, Thompson, Giri, & Van NewKirk, 2011).

Republican River Compact

The Republican River Compact is a legal agreement supported by the Federal Government between the three states where the Republican River flows: Colorado, Nebraska and Kansas. The motivation behind the compact was two-fold: first, a prolonged drought during the 1930s followed by a devastating flood in 1935 inspired concern about water usage, and second the need to distribute proper shares of the water before the federal development and funding of flood prevention projects could be started. Starting in 1940, governor-appointed representatives from the three states met to begin discussing how to appropriate the waters of the Republican River above the connection of the Republican and Smoky Hill Rivers in Kansas. By March of 1941, the representatives had signed and submitted a proposed compact to Congress. The three state legislatures had ratified the proposed compact and Congress approved and sent the compact for President Roosevelt's consent. He vetoed the compact due to objections from federal agencies; another bill was passed that called for further negotiations with a federal representative involved. A few changes were made to fulfill the federal government requirements, but they had no impact on the previously agreed-to allocations of water between the states. This second compact was then signed by the state representatives, submitted, and approved by each state legislatures and Congress, and was approved by the President in 1943 (Republican River Water Conservation District, 2005).

The six major goals of the Compact are to: (1) provide for the most efficient use of the waters in the Republican River Basin for multiple purposes; (2) provide for an equitable division of such waters; (3) remove all causes, present and future, which might lead to controversies; (4) promote interstate comity; (5) recognize that the most efficient utilization of the waters within the Basin is for beneficial consumptive use; and (6) promote joint action by the states and the United States in the efficient use of water and the control of destructive floods (United States Congress, 1942).

The Compact (1943) outlines the watershed area that is involved in the agreement— approximately 24,900 square miles—as "all the area in Colorado, Kansas, and Nebraska, which is naturally drained by the Republican River, and its tributaries, to its junction with the Smoky Hill River in Kansas." The Republican River begins in the high plains of northeastern Colorado and flows generally eastward before joining the Smoky Hill River and forming the Kansas River that drains into the Missouri River. The Compact also defines beneficial consumptive use as "that use by which the water supply of the Basin is consumed through activities of man, and shall include water consumed by evaporation from any reservoir, canal, ditch, or irrigated area." A map of the area of interest is available in the appendix as Figure A.1.

Article IV of the Compact outlines each state's total allocation for beneficial consumptive use and the quantities that are physically available from particular portions of the River. Colorado is allocated 54,100 acre-feet of water annually; Kansas receives 190,300 acre-feet of water annually; and Nebraska is allowed to use 234,500 acre-feet of water annually. The Compact also allows public water officials from each state to administer the Compact; in 1959, the three officials organized themselves into the Republican River Compact Administration (RRCA).

For nearly 40 years the Compact existed with few disagreements among the states. However, in the 1980's Kansas began to advocate for the regulation of groundwater use in connection with the Compact. After failing to reach an agreement within the RRCA, Kansas filed a complaint to the U.S. Supreme Court on May 26, 1998, that claimed the State of Nebraska had violated the Compact "by allowing the proliferation and use of thousands of wells hydraulically connected to the Republican Rivers and its tributaries, but the failure to protect surface flows from unauthorized appropriation by Nebraska users, and by other acts and omissions." (State of Kansas v. State of Nebraska and State of Colorado, 1998) The lawsuit was accepted by the Supreme Court and became known as Kansas v. Nebraska and Colorado, No. 126 Original. Colorado was included in the lawsuit because the Republican River's origin is within that state and it is a member of the Compact.

In June of 1999, Nebraska was allowed to file a Motion to Dismiss upon the premise that the Compact did not specifically mention groundwater, and therefore groundwater cannot be restricted or included in the allocation for beneficial consumptive use. Kansas argued the opposite, that all groundwater should be included in the computation of the virgin water supply and consumptive use. Colorado offered an intermediate position that alluvial ground water should be included in the allocation, but not wells located on the tablelands that pump from the High Plains Aquifer. The Supreme Court appointed Special Master McKusick to receive oral arguments from the three states. After careful review of all presented testimony and documents, Special Master McKusick denied Nebraska's Motion to Dismiss and concluded that both upland wells and alluvial wells are to be included if they deplete stream flow. The ruling that all sources of groundwater were to be included in the allocation system motivated the states to begin mediation with three members representing each state. The Final Settlement Stipulation was presented and approved by Special Master McKusick on December 15, 2002.

The Final Settlement Stipulation contained the following agreements: (1) forever waive all claims against each other that related to the use of water in the Republican River prior to December 15, 2002; (2) form a committee composed of representatives from each state to construct a comprehensive ground water model to determine the amount, timing, and location of depletions from groundwater pumping that accrue to the Republican River and its tributaries by July 1, 2003; (3) moratorium on the construction of new wells, specifically in Nebraska to match existing moratoriums in Kansas and Colorado; (4) numerous clarifications and accounting improvements that will assist the RRCA in administration of the Compact; (5) establish specific procedures to encourage the resolution of disputes, including binding arbitration; and (6) commitments to future joint efforts to maximize the beneficial consumptive use of water.

Responsibility for Nebraska's compliance with the new Final Settlement Stipulations falls upon the individual Natural Resource Districts (NRD) within the Basin and the Nebraska Department of Natural Resources (DNR). The NRDs are responsible for identifying and certifying the number of acres being irrigated by each groundwater well. To accurately measure the amount of groundwater used, each well needs to be metered and allocations enforced so that data from each meter is accurate. The NRDs are currently working with the DNR to create and implement integrated management plans that will help with compliance issues. The NRD is again responsible for enforcing the management plan and, alongside the DNR, is charged with the collection of accurate data to provide the greatest possible accuracy for the RRCA's Republican River Groundwater Model's determination of allocation rights to each state in the Compact.

Upper Republican Natural Resource District

The Upper Republican Natural Resource District (URNRD) covers the three counties in the far southwest corner of Nebraska: Perkins, Chase and Dundy (see Figure A.2 in the appendix). The total land area is 2,697 square miles, with a population of 8,944 in 2010 (United States Census Bureau, 2012). The majority of the land is used for grain production and cattle ranching. Land used for grain production is either irrigated to produce corn, soybeans or wheat or used for dryland production of wheat and edible beans. The URNRD has a total of 3,179 active irrigation wells servicing a total of 452,395 certified acres (Palazzo & Brozovic, 2012).

As a result of the Final Settlement Stipulation of 2002 regarding the Republican River Compact, the URNRD jointly developed an Integrated Management Plan (IMP) with the Nebraska DNR to promote compliance and further reduction in groundwater usage. The Final Settlement Stipulation and resulting changes had a profound effect on the Nebraska portion of the Basin, as indicated above. Unlike the Middle Republican, Lower Republican and Tri-Basin NRDs, the URNRD had been certifying irrigation acreage and actively monitoring all wells using meters prior to the dispute between states. Starting in 1978, the URNRD has been actively involved in the management of the groundwater resources within the district through the adoption and enforcement of rules and regulations. Along with monitoring pumping from each well, the URNRD has established correlative irrigation allocation rights. Since the first allocation limits were established in 1983, the annual irrigation allocation has decreased from 20 inches per year to the current allocation of 13 inches per year. These allocations are issued as an aggregate amount to be allocated over five years. Groundwater right holders are then allowed to carry forward the unused portion of their allocation, together with any unused portions from previous years, into succeeding allocation periods. The most recent allocation periods were 2005-2007 and 2008-2012. The first was only three years due to a reduction in the allocation after the first two years of a five-year period. The URNRD also allows for the pooling of well-specific allocations into an aggregate allocation for groups of wells owned by the same person, partnerships, corporations, or other individuals, subject to a signed agreement.

The amount of carry forward recorded in the URNRD indicates that most of the groundwater users are not fully constrained and are able to pump enough to produce a high yielding crop while staying below the restricted allocation. However, one of the 2010 IMP objectives is to further reduce groundwater use in the URNRD by 20 percent from the 1998-2002 baseline pumping volumes under average precipitation conditions. The goal of the objective is to help the district and state stay in compliance with the Compact according to the RRCA Groundwater Model. (Nebraska DNR and the Upper Republican NRD, 2010).

Through ongoing revisions to the rules and regulations, the URNRD has developed a new system that better incorporates the hydrological effect of pools and restricts the pooling and trading distance to that of a floating township or 36 square miles. The URNRD also has established a moratorium on new wells within the District and has established procedures for monitoring the quality of the aquifer underlying the District. Most important to this research is the portion of the rules pertaining to the transfer of the groundwater allocation rights assigned to each well. The current trading process utilizes administrative rules designed to help the District remain in compliance, take into consideration the hydraulic connectivity of the wells, and minimize third-party externalities that may exist. The downfall of the current system is that it is time-consuming and results in high transaction costs limiting the amount of beneficial transfers that could have occurred. However, 35 transfers, involving 100 fields, have occurred since 2006, indicating the demand for a water trading market within the District. (Upper Republican NRD, 2010).

1.1 Objectives

The primary objective of this research is to understand how well hydroeconomic models can predict actual trading participation and behavior. The research focuses on the URNRD and breaks the data into six groups to model participation and direction of formal permanent trades, as well as participation and direction for informal trades during the two most recent allocation periods. Formal trading is defined as the permanent transfer of allocation acres as approved by the URNRD board. We define informal trades as the temporary transfer of water use within a pool, as determined by the difference between the individual field's use and the pool's average use during an allocation period. The results from these models will be important for ex-ante evaluation of groundwater trading in other regions.

1.2 Organization

The organization of this document is intended to guide the reader through the research problem by outlining the motivation and background through Chapter 1. Chapter 2 identifies pervious literature relevant to water trading markets and a theoretical foundation for proceeding with an empirical model. Chapter 3 outlines the data used and the methodology of probit binary regression models used for the analysis. The results of each of the models is presented and discussed in Chapter 4. The final remarks and conclusions draw the research to a close and are found in Chapter 5.

CHAPTER 2: LITERATURE REVIEW

The previous literature on water markets have primarily focused on surface water trading, but interest in developing markets for groundwater trading has begun to increase in recent years. The majority of surface water rights in the western US, including surface water rights in Nebraska, are issued under an appropriation doctrine of "first in time, first in right." This idea implies that the earliest issued rights are considered to be senior rights and the newest rights are referred to as junior rights. If there is a shortage of water along with an increased demand—usually from drought or drought-like conditions—those with more junior rights are forced to cut back or stop use of the water until the water source reaches the maximum diversion or pumping allowance. Some regions, such as Texas, choose to apply the right to capture or use the water under the land you own when allocating groundwater rights. The landowners do not own the water beneath their property, but simply have the right to pump and capture whatever water is available, regardless of the effects of that pumping on neighboring wells.

Groundwater rights in Nebraska utilize the correlative rights doctrine that is administered by the local NRD. The correlative rights doctrine ties all appropriated water rights together and assigns equal priority to all rights. This idea implies that when a shortage in groundwater within a NRD has been triggered, all groundwater-rights holders within that NRD have their allocation, or supply, decreased proportionally. In order to meet certain policy goals regarding the amount of total water used and its impact on the aquifer and surrounding water bodies, the NRDs (under state supervision) can control the amount of water pumped, or the total number of irrigated acres, or a combination of the two. Each NRD is allowed to specify the exact terms of the groundwater rights and most choose to use a combination approach that registers the amount of certified irrigation acres and then allocates pumping rights that restrict the amount of water that can be used over a 3-5 year period.

Water trading markets face some unique issues that are not present in other resource markets, such as markets for land and mineral deposits. The use of groundwater from an aquifer lies between a completely nonexclusive resource (such as the ocean fisheries) and an exclusive resource (such as the harvest of privately owned timber). Because of this distinctive property of water, much literature has been written exploring the possibility of market transactions as a more efficient allocation method and discussing the possible negative impacts and concerns of water markets.

Defining water as a tradable resource can be difficult due to the nonstandard nature of the commodity. Scientists have determined that water can neither be created nor destroyed, but cycles through the Earth's hydrological cycle. Freshwater is necessary to sustain human and plant life outside of the oceans, and the quantity of usable freshwater is at the core of the majority of water policy. Quantity of water is a major component of considerations of water as a commodity and is often calculated as a stock, not as it naturally occurs as precipitation and flows. An important note is that not all water use is consumptive, such as hydropower generation. Complicating the situation further is that precipitation and flows vary significantly over time due to weather patterns, and the availability of water directly influences the value of the water. Of particular importance for surface water trading is that water is bulky and incompressible, resulting in expensive storage and transportation. To minimize the third-party impacts and transaction costs, the nonstandard nature of water requires special consideration when constructing the institutions that will manage the water rights market (Chong & Sunding, 2006).

2.1 Necessary Elements to Establish a Water Market

The general requirements for a competitive market system include: 1) many sellers and buyers with full knowledge of the market institutions and facing similar transaction costs; 2) participation decisions are made independent from other buyers and sellers; 3) outcomes are not affected by the decisions of other participants; and 4) participants are assumed to be maximizing profits. Market systems that have met these requirements will move resources from low value uses to high value uses, resulting in an economically efficient allocation of resources for both individuals and society. Because markets move water from low value to high value by allowing compensation for the water sold, they provide an incentive for more efficient use of water and reduce the stress on the water supply from high value uses. A well-designed water market requires the measurement and monitoring of water withdrawals, enforcement of withdrawal rules, and should consider any externalities or third party effects (Dinar, Rosegrant, & Meinzen-Dick, 1997).

Saliba (1987) evaluated five existing water markets in the Southwest and defined the transfer water rights as those rights which were sold on their own (not as part of a land transfer), with buyers and sellers participating voluntarily and using a negotiable price. Many authors agree that the major element needed for a water market is completely specified, enforceable, and transferable property rights. When a water market is efficient, water will be transferred from uses that are lower value to uses that are considered to be of higher value, so long as the gains in value are large enough to offset the costs of completing the transaction. When transaction costs are low, the price of water rights is similar among uses, such as agriculture, industrial, and urban. However, if high transaction costs persist, differences in marginal water values will continue to influence the market and the prices of water rights will vary between uses. Because detailed water rights are generally heterogeneous, transaction costs tend to be higher as buyers and sellers must engage in market searches that fulfill the institutional regulations on legal and hydrological characteristics of the water rights involved. High transaction costs reduce the level of profitable transactions but are not necessarily a sign of an inefficient market. High transaction costs that are the result of law and institutional requirements consider the impact of trades on third parties and the public interest which can be negatively impacted if ignored. Saliba (1987) concluded that water markets are in fact functioning well where the economic incentives for transfers outweigh the transaction costs involved and where the policies regarding markets are not costless, but are necessary.

Howe, et al. (1986) identified six criteria that can be used to compare mechanisms of water allocation. The first criterion is flexibility in the allocation of existing water supplies to allow water to be moved from use to use and from place to place as needs and information change. Flexibility to adjust to changes in demand allows a market to equate marginal values over many uses at the lowest costs. This does not require that all water be allowed to transfer, only that a tradable margin should exist within a water-using area. The second criterion involves the security of tenure for existing users, which motivates the users to invest in and maintain water diversion systems, promoting efficient resource use. Security does not conflict with flexibility as long as water right holders can voluntarily respond to incentives for reallocating water. The allocation mechanism must also consider the real opportunity costs of the resource. This cost is paid by the users to internalize the other demand and externality effects, such as the impact on environmental uses with a non-market value. The predictability of the market process outcome is necessary to motivate participation in the market by reducing fear of uncertainty and minimizing the transaction costs. Equity and fairness of the market should be perceived by the public and water users should not impose uncompensated costs on other parties. This requires that those giving up water should be compensated, as should those injured by changes in points of diversion and return flows. Any mechanism must be politically and publicly acceptable and consider the values that may not be considered by the individual water users, such as water quality and in-stream flow maintenance. Evaluating the fulfillment of each of the six criteria, the authors argue that markets are superior to other allocation mechanisms in many situations and therefore are better suited to appropriately allocate water to achieve the optimal allocation (Howe, Schurmeier, & Shaw, Jr., 1986).

The efficiency gains of water markets requires the allocation of private property rights which can only be accomplished if there is an efficient mechanism, such as a computer based market, to allocate and trade the water rights. As technology continues to improve and the adoption of high-speed communication continues, computer-based water markets can better achieve the efficiency gains of allocating water to the highest-value use than traditional institutional procedures that are slow and costly to change. Laboratory experiments by Murphy, et al. have shown that “smart,” computer-based markets provide the ability to incorporate the same allocation criteria used by regulators;

also, unlike other institutional systems of allocation, the prices discovered in the computer-based system provide information about the current state of the system and are better equipped to adapt to new information (Murphy, Dinar, Howitt, Rassenti, & Smith, 2000).

2.2 Benefits of Water Markets

In most Western states, water fees are based on diversion costs, which are only a partial valuation of the total value of the water. This has led the price of water to be artificially held below the market equilibrium price that would set marginal cost equal to marginal benefit. This artificially lower price has created excess demand for water at that price and has multiplied the scarcity issue of water. Multiple empirical studies have concluded that there exist negative demand elasticities and significant consumer responses to changes in water prices. In the standard economic analysis of all else equal, including the absence of institutional, social and legal restraints, these studies have shown that those with a greater ability to pay can attract water rights and that there is a negatively-sloped demand curve for water. By implementing a market system for water, the seriousness of the idea of total water scarcity is reduced and replaced by the idea that cheap water is indeed scarce (Brajer & Martin, 1989).

Under market conditions for water rights, the seller has an opportunity to increase profitability and the buyer benefits from the encouragement of water availability. Water markets also promote improved water management and efficiency, which can benefit the environment through reduced water-related pollution. Water markets have also been shown to: empower water users by requiring consent and compensation, provide security of water rights, which encourages investment, encourage water users to consider the full opportunity cost of water, and motivate users to consider the extent of the external costs imposed by their use. Water markets also provide flexibility as they can reflect the changes in crop prices, costs, and water values as demand patterns change (Dinar, Rosegrant, & Meinzen-Dick, 1997).

2.3 Detriments of Markets

The formation and management of efficient water markets is not without significant obstacles. Along with identifying the necessary criteria for water market formation, Howe, et al. (1986) also examined four major shortcomings of water markets. The first is that water prices may fail to reflect full opportunity costs due to geographical limits and the omission of negative externalities. Unfortunately, markets are less predictable than allocations through long-term contracts or water use licensing, making it difficult to encourage participation. Water markets are typically designed to provide equity between buyer and seller, but run the risk of ignoring third parties that are negatively impacted. The market often understates public good values of instream flows and water quality. However, these issues can be addressed through institutional requirements that aim to minimize these effects (Howe, Schurmeier, & Shaw, Jr., 1986).

It is important to consider the hydrological connectivity of the water involved in the markets, as transfers can negatively impact return flows and a third party. Externalities—such as changes downstream and return flows, pollution, overdraft of water tables, waterlogging, and other adverse environmental impacts—are the basis of most arguments against water markets. This is where efficiency and equity goals often conflict. Efficiency would say that these externalities should be included in the cost of the transfer, while equity would call for the compensation of those third parties impacted by the transfer.

Minimizing these potential negative impacts should be a goal for the state, basin and/or district governments in water markets for tradable rights (Dinar, Rosegrant, & Meinzen-Dick, 1997).

Chong and Sunding (2006) consider four current arguments against trading water, with the first being that water markets mean reallocation from agricultural to urban uses. While there are significant transfers of water from agriculture to urban sectors, the trades within the agriculture sector are also significant. This argument against market formation does not apply to the URNRD, as the urban population has been shrinking and is not allowed in the water trading market.

The second argument is that the transfers result in large economic losses for areas of origin, which becomes a concern when trades are allowed outside of the basin (Chong & Sunding, 2006). Within the URNRD, the trades are restricted geographically to be within a floating township and must be within the district. This restriction, along with the fact that all trades are within the agricultural sector, eliminates the potential for this concern in the URNRD.

The next argument is that interbasin trade should be prohibited because of large hydrologic effects (Chong & Sunding, 2006). Again, the geographic restriction within the URNRD helps minimize the hydrologic effects of trades and was designed to help minimize the impact of groundwater pumping on the flow of the Republican River. Understanding how the water is hydrologically connected is an important consideration when designing water markets because economic market theory promotes inter-state or inter-basin trades that have enough eligible participants and water available to motivate trade. There needs to be a balance that allows for a large trade area with enough participants for the market to exist but with minimal third-party and externality impacts, which is made possible through an understanding of the area's hydrology.

The final argument is that water is a public good and should not be subject to market forces (Chong & Sunding, 2006). The majority of literature promotes the development of water markets under appropriate conditions with the idea of achieving the social optimum of economic efficiency. To address the concerns of the public value of water, appropriate and effective institutions need to be developed that recognize the public good qualities of water, incorporate appropriate transactions costs, and address externalities such as potential negative consequences of groundwater use on neighboring wells, on endangered aquatic species, on adjacent stream flow, and on the future of water supplies for growing populations (Palazzo & Brozovic, 2012).

CHAPTER 3: DATA SOURCES AND METHODS

The data used in the analysis includes publicly available well data from the Nebraska DNR and proprietary data collected and provided by the URNRD.

The Nebraska DNR well database for the Upper Republican NRD provided the starting point for analysis. It contains all wells within the geographic boundaries of the URNRD, including those used for domestic, livestock, and irrigation purposes. The file also contains technical information on each well, including pump depth, pump rate, date of drilling, and the current status of the well. Specific geographic location information and well ownership information is also included within the file. There are 4,604 wells listed in the DNR database; however, only 3,274 are used for active irrigation after reconciling with the data provided by the URNRD.

The URNRD provided many datasets to help analyze the trades within the district. An important dataset contained 126 records of formal allocation transfers of groundwater for irrigation beginning in 2006 and ending in 2011. This file was used to identify 35 formal trades involving 100 unique field IDs and was verified using the allocation adjustment data set. A map of the participating wells is provided in the appendix as Figure A.3.

The URNRD also provided a dataset identifying the owner(s) and operator(s) of each field with certified irrigation acres. Also provided was the District's key to matching the DNR well IDs to the field IDs used within their datasets. When reconciled, the final dataset contained 3,179 unique field IDs and their owner/operator information for the certified acres in 2011. The final dataset provided by the URNRD is a large file tracking historical use from 1980 to 2012 for 3,346 unique field IDs. The file contains the annual certified acres, crops planted, pool ID (if applicable), beginning allocation, and county ID.

The remaining data was gathered from previous published works focusing on Nebraska and the Republican River Basin. Precipitation data used is from Schlenker and Roberts (2009).

Price and quantity values used to generate the marginal abatement cost, MAC, indicators were generated by Palazzo and Brozovic (2012). The model utilized well-characteristic data available through the Nebraska DNR and results from the use of the Water Optimizer program developed at University of Nebraska-Lincoln (Martin, Supalla, McMullen, & Nedved, 2007). The initial abatement cost points were calculated as the difference in the well's profits under unconstrained and constrained pumping. Each point in the MAC curve is determined by calculating the change in the profit associated with increasing the stringency of the pumping constraint. To determine the value of the MAC indicator used, the relationship of the curves was modeled, as shown in Figure 1. In the figure below, Well A is shown in red while Well B is shown in blue. To determine the direction of trade predicted by the MAC curves for these two wells, the quantity was set at two inches—or equal to the average transfer size in the district. For example, at two inches of water abated, the cost or price of abatement calculated by mentally calculating the integral is lower (~$0/year) for Well A than Well B (~$9.00/year). This indicates that cutting back water use is less expensive for Well A and it would be a net seller to Well B, where reducing allocations is more expensive.

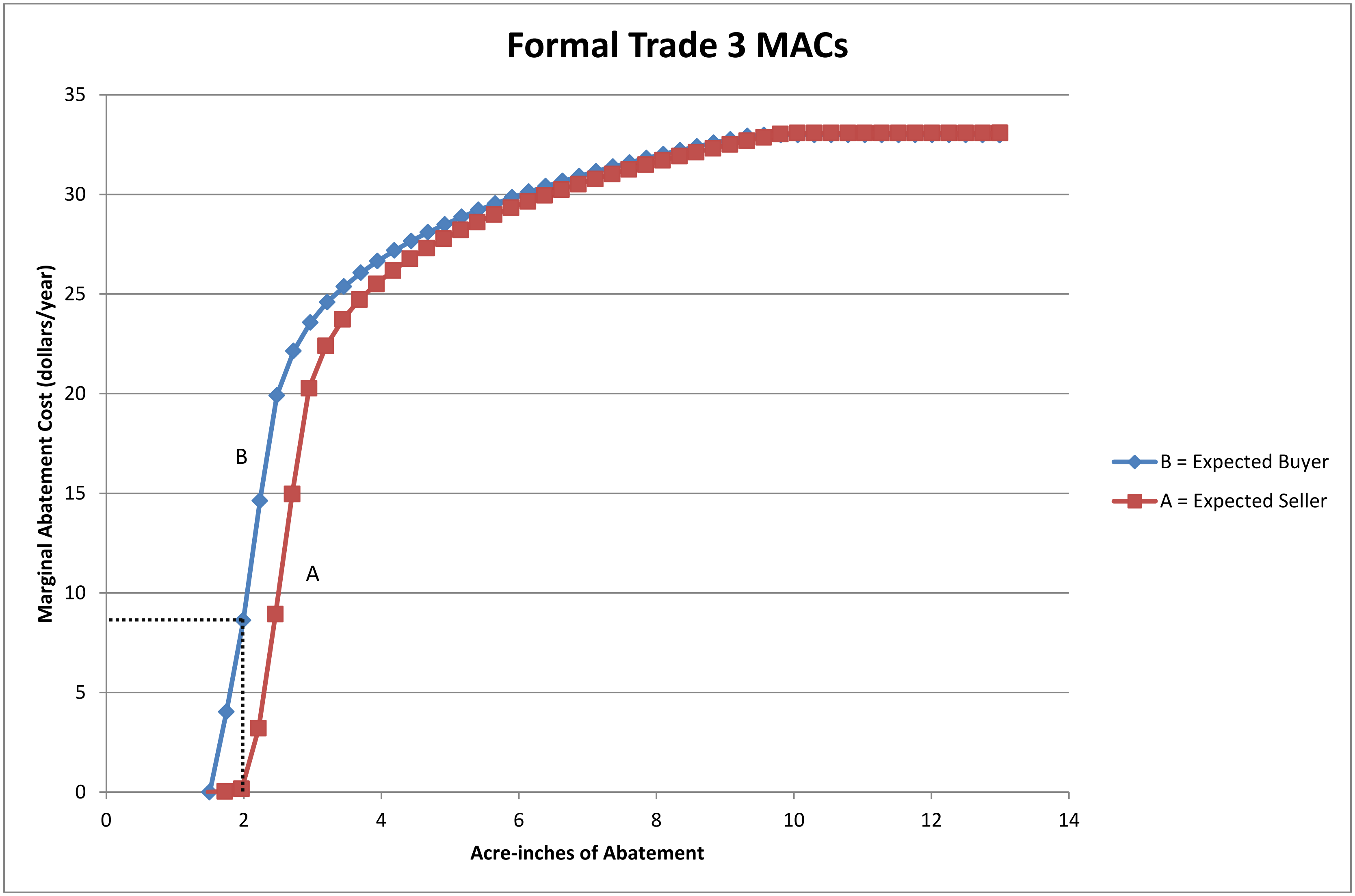

Figure 3.1 Marginal Abatement Cost Curve Plot for Formal Trade 3.

The stream depletion factor is not a deciding factor in the approval under the current trading rules; however the URNRD understands the importance of the measure on maintaining compact compliance and are seeking to add the requirement in the near future. The variable was included in the models to test if producers were already considering stream depletion as a motivator for trade participation. Research in hydrology has shed light on the potential negative impact of groundwater pumping on nearby streams through the process of stream depletion. The hydrology models show that due to the diffusion properties of groundwater movement, flow impacts from pumping further from a stream will take longer than closer wells. This indicates that over a finite time period, wells closer to the stream will have a greater impact on flow by removing more water that those wells farther away, indicating that marginal damage of groundwater pumping varies over space (Glover and Balmer, 1954; Kuwayama & Brozovic, In Press).

Kuwayama and Brozovic utilized the time path of stream depletion caused by a unit for groundwater pumping by a specified well to define a transfer function that expresses the stream depletion factor, SDF, as a proportion of the volume of water that was pumped by the wells in the past. The function can be considered a density function that ranges from 0 to 1 that characterizes how the lagged effect of pumping in one year is distributed across future years. The distance between the well and the stream and other physical characteristics of the well determine the shape of the function with respect to time. Using standard hydrology assumptions, they created a linear weighted sum of pumping for a specific well for years preceding the one of interest and then aggregated the sum of stream depletion caused by individual wells. The structure of the aggregation allows for the assumption that the externality of pumping from one well is independent of the externality caused by pumping at other wells. Due to the seasonality of groundwater pumping and the assumption that the stream flow is replenished every year by precipitation and snowmelt, the dynamic optimization problem indicates that the stream depletion externality does impact stream flow as opposed to stream stock, which is the measurement of concern for the Compact compliance at the Nebraska-Kansas border (Kuwayama & Brozovic, In Press).

3.1 Owner/Operator Descriptive Statistics

According the owner/operator information provided by the URNRD, there are 524 unique operators in the district who manage the 3,179 fields. The average number of fields per operator is 6.05 fields, with a maximum of 94 fields and minimum of one field. There are 144 unique operators managing just one field. This large number of single field operators causes the distribution of fields among operators to be skewed to the left, with nearly 53% of the operators managing three fields or less.

Examining the unique owner data, 731 different individuals or entities were identified as owning the 3,179 fields in the district. The average number of fields per unique owner is 4.35 fields, with a maximum of 94 fields and minimum of one field. There are 217 unique owners that own just one field. Again, having a large portion of the owners owning one field, the distribution of ownership is skewed to the left, with over 64% of the owners claiming three fields or less.

We find differences between the average values in the URNRD and in those operators who participate in formal trades, which are permanent transfers of water. Among the 49 unique operators who participated in formal trades, the average number of fields is 14.27 fields per operator. Even with omitting the largest operator,[1] the average number of fields among operators participating in trades is 13.31 fields, over twice as large as the district average. This indicates that larger operations are more likely to participate in the trade process. A similar pattern emerged when examining the 52 unique owners participating in formal trades. The calculation of the average number of fields per unique owner that participated in formal trades resulted in an average of 9.52 fields, or 2.18 times larger than the district average.

Also of interest is the participation in pooling of fields, or the informal trade of water between fields. Pooling is defined as the low transaction cost and informal version of trades, as it is much easier to get a pooling application approved through the District Council than a formal trade. Pooling is also viewed as a temporary trade as it only considers one year at a time, and the original certified acre allocation for each field remains the same after the pool is dissolved.

Using the historical usage data provided by the district, 1,974 fields were identified as participating in pools during 2005-2007 and 1,914 during 2008-2012. Due to a change in the pool naming convention that made it difficult to track the history of the pools to those that existed before the name change, the decision was made to use only the pools in the two recent allocation periods in this analysis. Among unique operators, 53% participated in the pooling process while 50% of the unique owners participated in pools. Of the unique operators participating in pools, 83% of the total fields were pooled, leaving the remaining 17% of fields un-pooled. Slightly higher percentages, 90%, of fields owned by unique parties participating in pools were actually enrolled in pools. This

[1] There is one large operator in the URNRD who manages 60 fields. This is an anomaly in the district as the next largest operation has 49 fields.

indicates that although about half of the operators and owners have at least one field pooled, not every field under their management is pooled.

An interesting result that emerged shows that 37 of the 49 (76%) unique operators who participated in trades have participated in pools. A similar result was found for the unique owners, where 36 of the 52 (69%) owners who participated in a trade had also pooled their fields. This leads to the hypothesis that there is demand for formal trading, but current rules and procedures are limiting the participation level.

3.2 Usage Trends

Examining usage trends within each county and the aggregate district was a way to study whether the current allocation restrictions were binding. Table 3.1 shows the given allocations for the 1980-2012 allocation periods.

Table 3.1 URNRD Irrigation Allocation Levels.

Years	Allocation (inches/certified acre)
1980-1983	22.0
1984-1987	20 flood, 16 pivot
1988-1992	15.0
1993-2004	14.5
2005-2007	13.5
2007-2012	13.0

The Table 3.2 outlines the average usage for those fields that were used for crop production from 1980-2012. We separated those fields that were in production for the entire period and those that came into production later to examine whether there are measureable differences in the characteristics of the two groups. For example, one could hypothesize that fields brought into production later are of lower quality, and that this may affect irrigation water demand. Those fields that had been enrolled in conservation programs like the Conservation Reserve Program (CRP) or the Conservation Reserve

Enhancement Program (CREP) were omitted, as we focused on those field that were used for crop production for the entire thirty-two years. On average, usage in any single year was below the allocation limit except during the exceptionally dry years of 2000, 2002 and 2012, where the usage exceeded the allocation limit. However, over the respective allocation period, aggregate county usage did not exceed the limit. This implies that the counties and district as a whole have not experienced a binding allocation restriction.

Looking at overall trends of usage plotted in Figure 3.2, usage appears to fluctuate around 11 inches from 1980-1999. From 2000-2003 the average usage jumped up significantly; however, this is primarily due to drought conditions in two of the four years. Between 2004 and 2011, the usage showed a distinct downward trend—well below the allocation restriction—with a significant spike in usage in 2012, again the result of drought conditions.

In Figure 3.3, the precipitation data for 1980-2010 for the three counties was plotted against the district usage on the same graph to examine the relationship between usage and precipitation events in the district. It was clear that precipitation fluctuations are negatively correlated to the average usage. A simple regression revealed that precipitation, specifically what was recorded between May and August, explained approximately 74% of the variation in aggregate district usage.

The remaining fields that were used for crop production during the period of 1980-2012 but not for the entirety were also examined to see if usage varied for these fields. The records of fields enrolled in CRP or CREP were omitted for only those years enrolled. Table 3.2 contains the usage averages for the three counties and the aggregate district level.

Table 3.2 Average Usage for Fields Used in Crop Production Every Year from 1980-2012, Excluding Those Enrolled in CREP or CRP.

Year	Dundy	Chase	Perkins	District
1980	12.93	13.2	10.49	12.19
1981	12.26	12.4	9.03	11.24
1982	10.84	10.0	7.40	9.40
1983	11.12	12.2	9.78	11.02
1984	15.03	14.4	12.14	13.84
1985	15.75	15.3	12.85	14.65
1986	13.73	12.1	10.32	12.05
1987	11.86	11.5	9.58	10.98
1988	13.18	13.2	10.78	12.40
1989	13.84	12.0	10.61	12.16
1990	15.08	15.1	11.86	14.01
1991	13.04	13.0	11.65	12.55
1992	10.73	9.8	7.48	9.34
1993	7.73	6.0	5.80	6.52
1994	14.87	13.0	12.21	13.35
1995	13.41	11.6	10.74	11.92
1996	10.16	9.1	6.71	8.66
1997	16.38	13.3	10.34	13.33
1998	16.41	13.5	10.72	13.55
1999	11.42	9.3	8.53	9.75
2000	18.73	17.6	16.50	17.62
2001	14.82	12.8	12.26	13.28
2002	19.95	18.4	16.57	18.31
2003	15.56	15.4	14.24	15.06
2004	13.05	12.7	11.87	12.53
2005	11.64	11.9	11.38	11.64
2006	13.32	13.1	13.32	13.26
2007	11.65	11.4	9.88	10.98
2008	13.01	11.5	11.61	12.03
2009	10.55	8.5	9.33	9.47
2010	11.97	10.4	9.97	10.78
2011	11.43	9.5	9.33	10.08
2012	17.68	19.9	18.53	18.71
Average	13.43	12.52	11.02	12.32

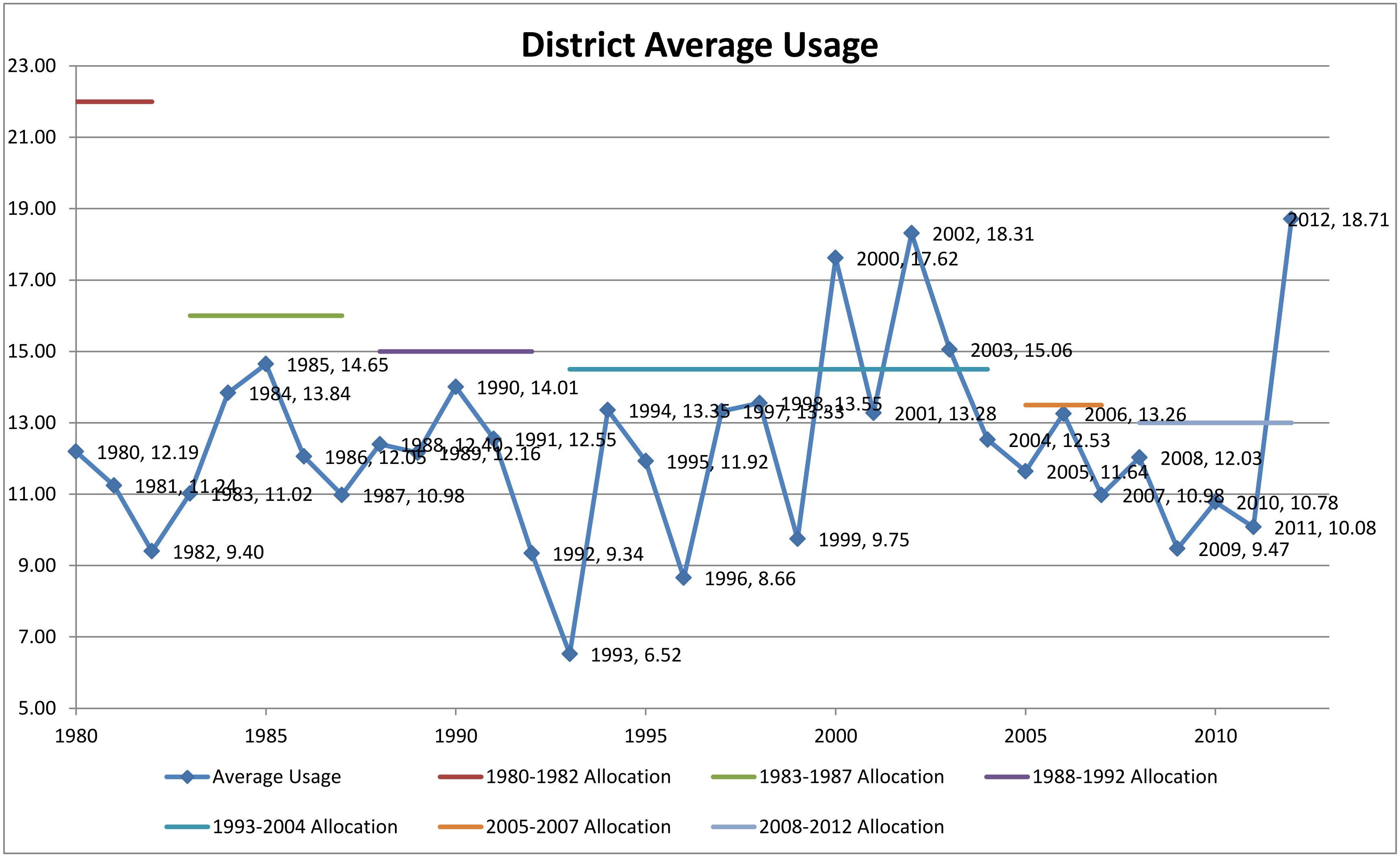

Figure 3.2 District Average Use and Allocation Limits.

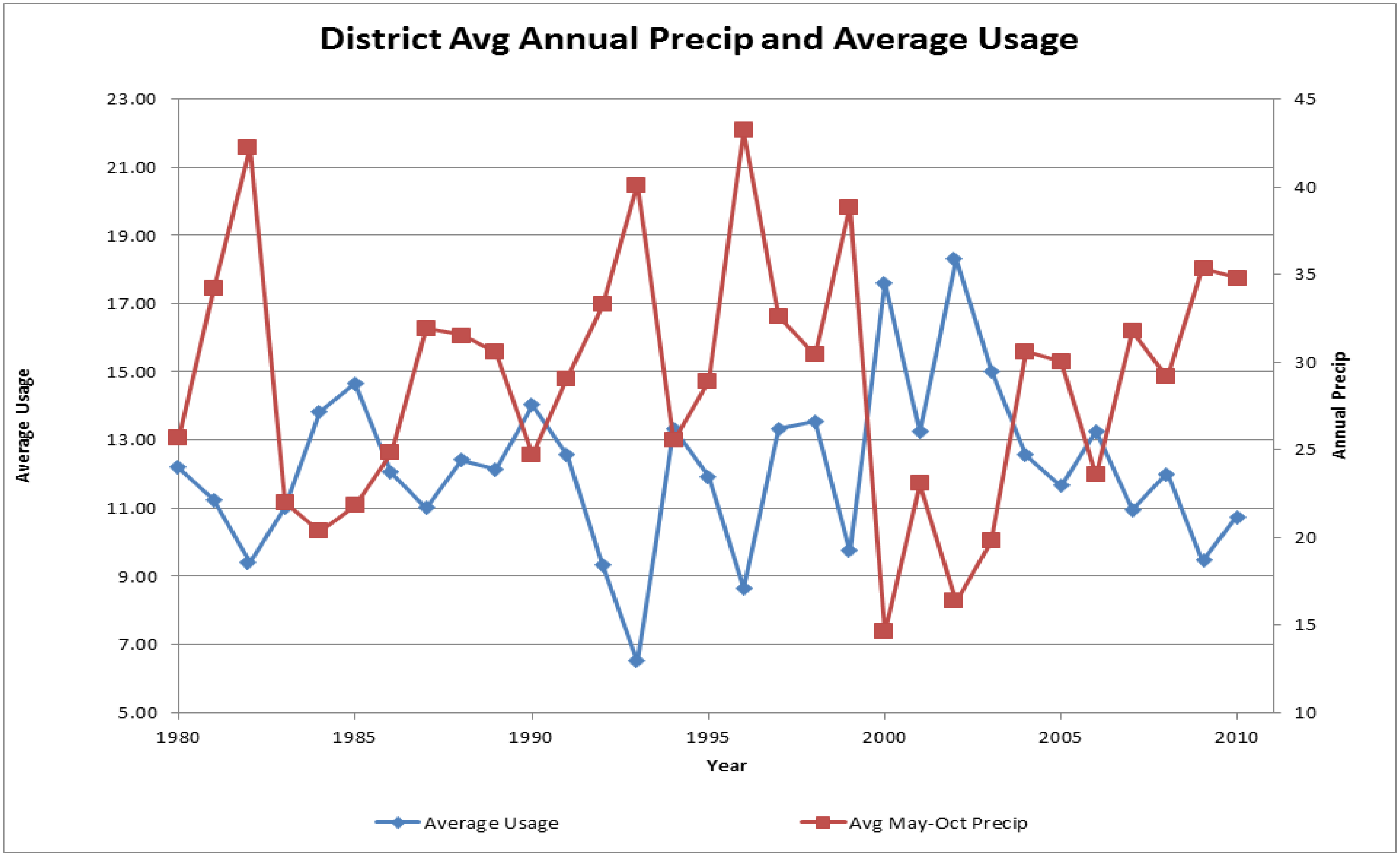

Figure 3.3 District Average Annual Precipitation and Average Annual Water Usage.

Table 3.3 Average Usage for Fields Used in Crop Production for Less Than Thirty Years During 1980-2012, Excluding Those Enrolled in CREP or CRP.

Year	Dundy	Chase	Perkins	District
1980	9.90	12.87	13.57	12.11
1981	8.68	12.11	8.93	9.91
1982	8.65	9.38	7.11	8.38
1983	10.61	11.78	8.10	10.16
1984	14.35	15.02	10.74	13.37
1985	14.81	14.97	11.82	13.87
1986	13.47	11.11	8.84	11.14
1987	9.77	10.09	8.21	9.36
1988	12.18	11.79	9.62	11.20
1989	12.49	11.48	10.55	11.51
1990	13.27	14.74	11.27	13.09
1991	11.95	12.64	11.04	11.88
1992	10.73	9.67	6.33	8.91
1993	8.21	5.82	5.02	6.35
1994	15.32	12.70	12.01	13.34
1995	12.95	11.30	11.39	11.88
1996	10.41	8.61	6.47	8.50
1997	16.40	12.59	10.26	13.08
1998	15.44	12.76	10.56	12.92
1999	10.21	8.67	8.58	9.15
2000	16.78	17.75	16.77	17.10
2001	13.35	12.73	13.23	13.10
2002	17.69	17.99	17.73	17.80
2003	13.45	14.10	14.80	14.12
2004	11.84	12.50	12.53	12.29
2005	9.85	11.22	10.81	10.62
2006	12.21	12.60	13.36	12.72
2007	10.01	10.87	10.10	10.33
2008	12.22	11.39	11.91	11.84
2009	9.88	8.31	9.98	9.39
2010	9.98	10.10	9.07	9.72
2011	8.67	7.44	8.29	8.13
2012	13.90	15.50	17.58	15.66
Average	12.11	11.86	10.81	11.60

The usage trends for those fields used for crop production the entire 30 years exhibit a higher usage rate than those fields that are not used the entire time. However, as shown in Figure 3.4, the usage pattern is similar. When T-tests were performed, it was determined that for the aggregate district, Chase and Dundy counties, the difference in usage were significantly different from zero but that the general usage pattern is similar between the two usage groups. The T-test performed on Perkins County concluded that there is no significant difference between the average usage for fields employed for the full 30 years and those fields that were not.

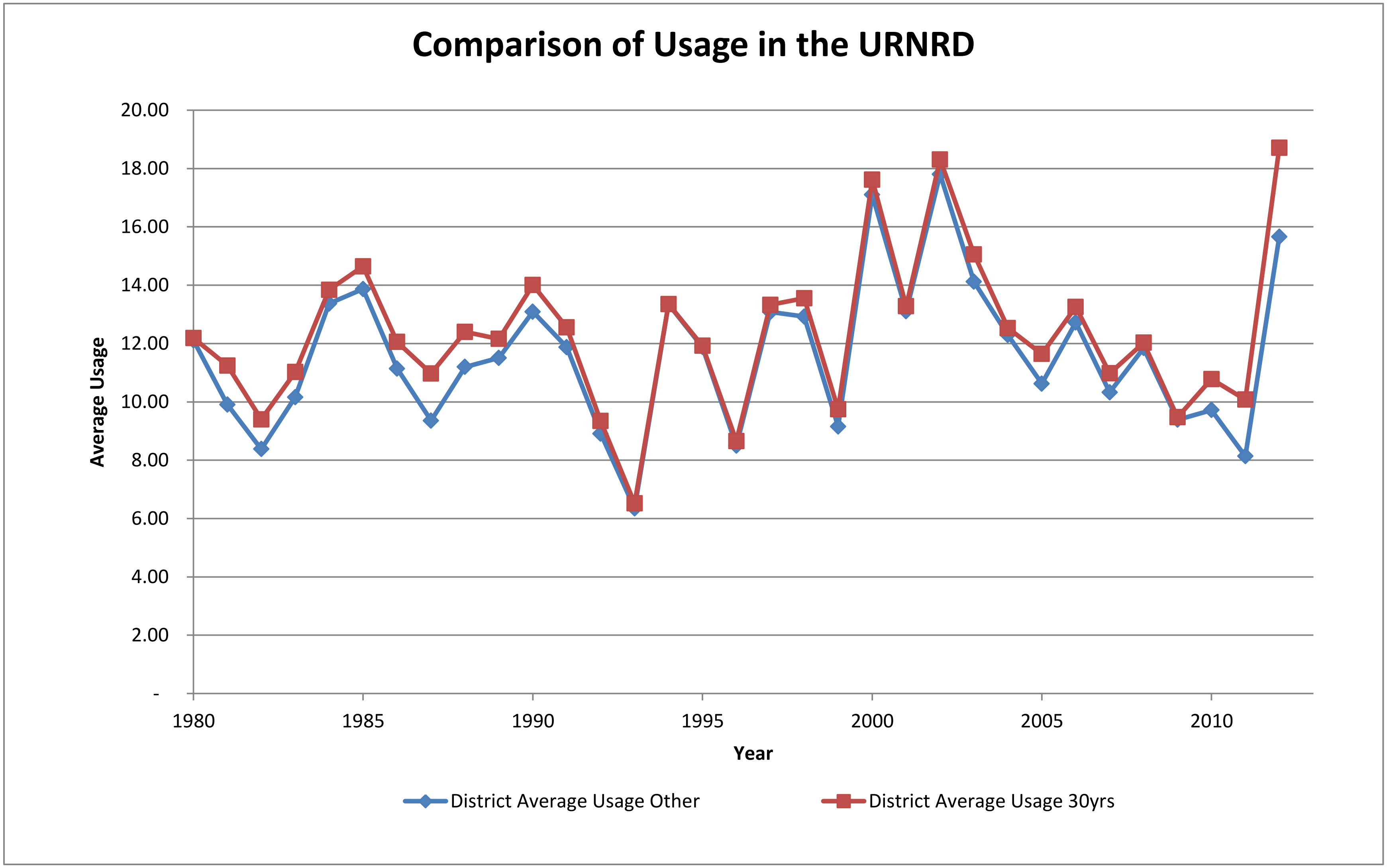

Figure 3.4 Comparison of Usage in URNRD.

3.3 Methodology

The sample was used to create six different models to examine formal permanent trade participation, informal temporary trade participation for the two most recent allocation periods, a formal trade direction model, and two informal trade direction models for the two recent allocation periods. The entire sample of fields used for irrigation was used to create a permanent trade participation model. The informal trade participation models used the same sample, with those fields participating in single field pools reclassified as those not participating in informal trading. The trade direction models used subsets of the full sample of only those who participated to predict the probability of being a buyer or seller in the trade relationship. The decision to use two models for informal trade participation and direction, respectively, was motivated by a change in the pool naming convention (begun in 2005) that made it difficult to track pools further back, and by the change in allocation limits in 2008, which triggered the dissolution and reformation of pools generating multiple observations for one field. The variables used in the various models are summarized in Table 3.4, which includes the variable's name, definition, and unit of measure.

Table 3.4 Definitions of Variables.

Dependent Variable Name	Definition
Trade	= 1 if participated in a trade
Seller	= 1 if a seller
Independent Variable Name	Definition
Acres	field size in certified irrigation acres
GPM	pumping rate in gallons per minute at the time of drilling
PWL	the distance from the soil surface to the water level during pumping, measured in feet at the time of drilling
Useavg07	field average water use from the first year of use until 2007, in inches
Percorn07	percentage of years field was in corn production from the first year until 2007
Useavg12	field average water use from the first year of use until 2012, in inches
Percorn12	percentage of years field was in corn production from the first year until 2012
Ownop	= 1 if the owner is also the operator
Opsize	total number of fields owned by the field owner
Medium	= 1 if soil is of medium soil type
Coarse	= 1 if soil if of coarse soil type
Unksoil	= 1 if soil if of unknown soil type
Perkins	= 1 if the field is in Perkins County
Dundy	= 1 if the field is in Dundy County
Avgusetrade	field average water use from the first year of use until the year before trade occurred
Percorntrade	percentage of years field was in corn production from the first year until the year before trade occurred
SDF	ranges from 0 to 1; impact on stream flow as a proportion of the volume of water that was pumped by the wells in the past
MAC	= 1 if the modeled MAC curve relationship indicates a seller
Tradesize	size of the permanent trade, in acres transferred
Transfersize	size of the temporary trade within a pool, in inches
MAC2	= 1 if the MAC curve relationship indicates a seller at 2 inches abated
Constr	= 1 if the pool is constrained by allocation limit
MAC2*constr	interaction variable between MAC2 and constr

3.2.1 Variable Description

The dependent variable for the formal and informal trade-participation models is the decision to participate in a trade (*Trade*). This variable is a binary indicator that equals one if an individual field participates in a formal trade and zero if it did not participate in a trade. The formal and informal trade-direction models use the binary variable (*Seller)* to predict the probability of the field being a buyer or seller in the permanent trade. The variable equals one if the field is a seller and zero if the field is a buyer.

The decision to use the following variables was motivated by previous research on irrigation technology adoption. Negri and Brooks (1990), as well as a technical bulletin published by the Agricultural Research Service of the USDA (1962), included many of the variables for which we had measurements, including acres irrigated, well depth, and soil type. They also included measurements of energy costs, precipitation and soil productivity. Many of these additional variables do not vary enough across the URNRD to be included directly in the models, but were used in the calculation of the MAC prices and quantities through the use of Water Optimizer.

With a few exceptions, most of the variables are unique to a specific field. The size of the irrigated fields *(acres)* is unique to each field observation and is a continuous variable. Our expectation is that this variable will be a significant positive indicator of formal trade participation as the trades are permanent and alter the amount of land that can be irrigated by the participating wells. For the direction models, the sign is also expected to be positive since larger fields are likely to have excess acres that the current irrigation system cannot cover efficiently.

The well technical variables used in the participation models measure the pumping rate *(gallons per minute)* and the distance from the soil surface to the water surface during pumping *(pumping water level)*, and are continuous variables. They are used to compare the cost of pumping and are similar to the technique applied by Negri and Brooks (1990). Our expectation is that when it becomes more expensive to pump, producers will look for ways of increasing their efficiency by participating in trades. Thus, pumping-rate effect is expected to be negative because if the pumping rate increases, it becomes less expensive to pump and less desirable to trade. When the pumping water level increases, the water must be moved a longer distance to the surface, becoming more expensive. The expectation of sign, therefore, is positive as the cost increases with increasing the pumping water level and encouraging participation in trades.

Unique to this study is the availability of water usage records for over thirty years, which allows for the continuous variables for average use (*useavg07*, *useavg12* and *avgusetrade*). The models use the appropriate usage measurement based on the time-frame examined. We expect average use to be positively related to trade participation as those fields that use more are more likely to be reaching their allocation limits and are motivated to find ways to increase the efficiency of their production in the face of decreasing allocation allotments. The sign of the average usage is expected to be negative for the trade direction models because fields that have higher average use are more likely to be constrained by the allocation limit and therefore are more likely to be a net buyer in the trade.

The percentage of corn grown (*percorn07, percorn12,* and *percorntrade*) is a measurement of crop type, which the technical bulletin (1962) identified as an important variable in determining irrigation adoption. The percentage of corn grown was calculated as the number of years corn was planted in the field divided by the number of years usage was recorded. This allows the variable to be continuous between zero and one. Our expectation of sign for the formal participation is negative because participants also includes sellers of water where corn production is less efficient and the producers seek to grow other crops that require less water, freeing up the allocation for sale. The sign for the informal trade participation is expected to be positive as those fields that grow water-intense crops, like corn, are looking for ways to temporarily increase their water allowances to finish a crop. The sign is expected to be negative for the trade direction models, as those fields that grow more corn are likely to be net buyers of water due to the higher water needs of corn compared to beans or wheat.

The land tenure indicator *(ownop)* is equal to one when the owner of the field is also the operator, based on the 2012 URNRD data. The sign of this variable in the participation models is expected to be positive as a land owner is more likely to take the time to participate because he can continue farming the field to recover the transaction cost, whereas a renter may not have the expectation of continuing to farm the field the next year. We expect a positive sign for the formal-direction models as rented land is less likely to be net sellers of water. When the operator is the same as the owner, the decision to sell is less complicated than when dealing with two decision makers that may have different goals.

The operation size (*opsize*) is unique for an entire operation and is based on data from 2012. Through the previous exploration of owner characteristics indicating that larger operations are more likely to participate in trades, the sign is expected to be positive for the participation models. The sign is expected to be negative for the formal-trade direction models as the larger operations are more likely to be net buyers of water due to their increased access to capital. Due to URNRD regulations on pool formation, the operation size does not vary significantly and provides no inference power.

The soil type indicators (*medium*, *coarse*, and *unksoil*) are binary variables that measure the soil's ability to retain water after an irrigation cycle. We expect the medium and coarse variables to be positive based on farmer comments during visits to the URNRD. They noted that their goal was to increase efficiency of their operation by moving water from sandy or coarse soils to field that have better water retention.

The county indicator variables (*Perkins*) and (*Dundy*) capture differences between the three counties in the URNRD. The variables are included in the participation models only as the trade regulations restrict the movement of water beyond the floating township, creating little variation in the county within a trade. These variables equal one when the field is in either Perkins or Dundy, respectively, and zero otherwise. Our expectation of the sign is negative because the majority of eligible fields for trade participation are located in Chase County, indicating that fields in Perkins or Dundy are less likely to participate given the current regulations on water movement.

For the direction models, only the trade size (*Tradesize* and *transfersize*) is common to all fields that participate in a formal and an informal trade, respectively. In some cases this is only two fields (a buyer and seller), but in other cases multiple fields have aggregated rights to trade a water allocation. We expect the sign to be negative as the MAC curves indicate that it is less expensive for fields to cut back a little than to cut back a large amount, indicating that smaller transfer sizes are sellers.

The stream depletion factor *(sdf)* used in the formal trading model was calculated using the methods developed by Kuwayama and Brozovic (in press) and is continuous from zero to one. It measures the impact on stream flow as a proportion of the water that is pumped by wells in the past. Our expectation is a positive sign, indicating that water is moving away from high stream depletion wells to those that have less of an impact on stream flow.

The marginal abatement cost indicators (*MAC* and *MAC2*) are used in the formal and informal trade direction models, respectively. These indicators use curves developed by Palazzo and Brozovic (2012) to determine how the curves would predict buying and selling behavior. The variable equals one when the curves predict a seller and zero if predict a buyer. We would then expect the sign to be positive, reflecting that the field behaves similarly to what theory expects.

The final variables apply only to the informal trade direction models. The first is the indicator of constraint (*constr*), which equals one when the pool is constrained by the allocation limit and zero when it is not. We would expect the sign to be positive because of the convex shape of the MAC curves within the typical transfer size. The final variable is an interaction variable between the *MAC2* and *constr*, which is used to capture any differences when a pool is constrained since we decided to run one model for each period based on the evidence below.

3.2.2 Testing for Heterogeneity Among Pools

To examine the informal trading market created by the option to pool fields within a floating township, the dataset was divided to look at the pooling and usage in the last two allocation periods. The decision to use only the pools in the two recent allocation periods was due in part to a change in pool naming convention, which made it difficult to track the history of the pools to those that existed before the name change. The resulting datasets included field information for the 2005-2007 allocation of 13.5 inches per certified acre and the 2008-2012 allocation of 13 inches per certified acre. We divide the pools into two categories: constrained and unconstrained. The category is based on the average annual water use in all fields associated with the pool. The earlier dataset was divided at 13.4 inches to catch those pools that are close enough to the limit to be constrained, while the later dataset was divided at 12.9 inches for the same reasons.

Pooling fields is a tool producers can use to more efficiently allocate water among fields given the allocation restrictions. The allocation is aggregated across the fields and then can be applied at the producer's discretion. As mentioned earlier in the introduction to the research area and exploration of the usage, most of the fields in the URNRD have significant amounts of carry-forward and thus are not fully constrained by the allocation limits. However, in a single allocation period, the pool may be constrained and use more than the aggregate allocations by drawing down on the participating fields' carry-forward. To look for any differences in characteristics between pools that were constrained and those that were not, summary statistics of for the two groups in each allocation period of study are listed Table 3.5 and Table 3.6.

Table 3.5 Summary Statistics Comparing 2005-2007 Unconstrained and Constrained Pools.

2005-2007	Unconstrained					Constrained					
Variable	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	T-value
Field size	1420	154.830	59.624	0	640	552	158.421	76.056	0	640	1.108
Gpm	1420	1489.419	741.642	25	3217	552	1663.670	824.357	150	9756	4.537****
Pwl	1422	129.061	68.829	15	440	552	117.948	59.878	25	750	3.335****
Average use	1422	12.203	2.766	-1.059	20.325	552	13.665	2.450	2.771	21.472	10.873****
Percentage corn	1422	0.726	0.199	0	0.968	552	0.745	0.180	0	0.968	1.970****
Ownop	1422	0.584	0.493	0	1	552	0.498	0.500	0	1	3.443****
Opsize	1422	15.342	20.195	1	94	552	17.830	21.067	1	94	2.426**
Medium	1422	0.340	0.474	0	1	552	0.377	0.485	0	1	1.523
Coarse	1422	0.351	0.477	0	1	552	0.397	0.490	0	1	1.900*
Unksoil	1422	0.017	0.129	0	1	552	0.005	0.074	0	1	1.965**
Transfersize	1422	2.065	2.013	0	13.335	552	2.262	2.534	0.004	21.378	1.802*
Significance for Two Tailed Test of Differences in Mean Value *0.1, **0.05, ***0.01, ****0.001											

Table 3.6 Summary Statistics Comparing 2008-2012 Unconstrained and Constrained Pools.

2008-2012	Unconstrained					Constrained					
Variable	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max	T-value
Field size	1665	156.571	66.124	0	640	247	153.355	59.142	0	640	0.723
Gpm	1665	1543.728	782.472	25	9756	247	1517.632	683.115	585	3100	0.497
Pwl	1667	126.742	64.848	15	440	247	119.267	74.708	25	750	1.656*
Average use	1667	12.422	2.710	-1.059	20.957	247	13.627	2.621	4.405	21.472	6.548****
Percentage corn	1667	0.737	0.195	0	0.968	247	0.697	0.185	0.091	0.968	2.980***
Ownop	1667	0.569	0.495	0	1	247	0.547	0.499	0	1	0.655
Opsize	1667	14.899	19.799	1	94	247	23.530	23.283	1	94	6.242****
Medium	1667	0.351	0.477	0	1	247	0.324	0.469	0	1	0.833
Coarse	1667	0.342	0.474	0	1	247	0.522	0.501	0	1	5.534****
Unksoil	1667	0.014	0.119	0	1	247	0.008	0.090	0	1	0.798
Transfersize	1667	1.991	2.085	0	22.527	247	2.393	2.752	0.002	19.266	2.699***
Significance for Two Tailed Test of Differences in Mean Value *0.1, **0.05, ***0.01, ****0.001											

In the ‘05-‘07 allocation period, 552 fields were members of a constrained pool while 1,422 were members of unconstrained pools. The well technical variables for pumping rate and pumping water level are significantly different, with a higher pumping rate and a smaller pumping water level for constrained pools. This is consistent with what one would expect because if the pumping rate is higher and the pumping water level is smaller, it is less expensive to pump more water and become constrained by the allocation limit. Unsurprisingly, average field use and percentage of years in corn are both significantly higher for those pools that are constrained. It was surprising to discover that land tenure and operation size were significantly different between the two groups. A constrained pool is more likely to be managed by a renter than an unconstrained pool, which is consistent with renter’s desire to irrigate the necessary amount to produce an adequate crop to cover the cost of production expenses and the added rental expense. A plausible explanation for the larger operation size for constrained pools may be that fields that are less efficient or more expensive to irrigate are likely to be sold off after a retirement or death and likely-buyers are often the larger producers that can pool these fields together with their existing fields in the area. Soil type was only slightly significantly different between the two groups, with coarse (sandy) soils more likely to be found in constrained pools, where the water retention rate of the soil is lower. Transfer size was only slightly significantly different, while average field size was not significantly different between constrained and unconstrained pools.

For the ‘08-‘12 allocation period, only 247 fields were members of a constrained pool, leaving 1,667 in unconstrained pools. Average field size between constrained and unconstrained pools proved to be insignificantly different. Unlike the previous allocation period, the only well technical variable that was significantly different was pumping water level at the 10 percent level, indicating that those wells with higher water levels during pumping are more likely to be constrained by the allocation limit. Again the average use and percentage of years in corn is significantly higher for those pools that are constrained, which is consistent with planting a high water-need crop like irrigated corn. Land tenure is not significantly different in the most recent allocation period, but once again the constrained pools often belong to larger operation sizes. When comparing soil types against fine (clay) soil, only the coarse soil indicator was significantly different between the two groups, indicating more fields of coarse soil type were found in constrained pools. The T-value for average transfer size within the pool proved to be significantly different, with larger transfers occurring in constrained pools consistent with greater average use by the fields.

The models for the direction of trade for the temporary trades proved to be more challenging due to the informal nature of the trades. Examining the average use of the pools, it became clear that a portion of the pools were constrained by the allocation allotment. To examine whether pools that were unconstrained behaved like those who were constrained, the data was split into two groups to test the coefficients.

However, testing differences in coefficients across binary probit models is not as straight forward linear regressions and must be approached with caution. This difference is mainly due to binary regression coefficients being infused with residual variation in the form of unobserved heterogeneity. These differences in residual variation can produce differences between model coefficients that are not indications of true differences in causal effects. In his paper, Allison (1999) provides a way of testing if the variation in coefficients is due to residual variation and a way of correcting if it is suspected. The first step is to create a table of coefficient ratios and test them for significant differences. If there appears to be a pattern in which one group is consistently higher or lower than in the other group, it is an indication of a potential problem that may be resolved by adjusting for the residual variation. The tables below contain the coefficients, ratios, and chi-squared test of difference with one degree of freedom for each of the models.

This test was completed for two versions of the model for each allocation period. The first set of results, shown in Table 3.7 and Table 3.8 respectively, use field-level technical measurements for pumping rates and pumping water level. For both the ‘05-‘07 and ‘08-‘12 models, none of the coefficients are significantly different at the five-percent significance level. In the ‘05-‘07 models the pumping rate is significantly different at the ten-percent level, but for the purpose of this analysis the five-percent cut-off was used for evaluation decisions.

Table 3.7 Test of Difference in Coefficients for Pumping Rates and Pumping Water Levels in 2005-2007.

	Unconstrained		Constrained			
Variable	Coef.	Std. Err.	Coef.	Std. Err.	Ratio of Coefficients	Chi-Squared for Difference
Acres	0.000	0.001	0.000	0.001	0.594	0.152
useavg07	-0.198	0.016	-0.242	0.028	-7.124	1.899
percorn07	0.109	0.191	0.513	0.321	0.340	1.168
Ownop	-0.016	0.073	0.078	0.117	-0.138	0.471
Medium	-0.202	0.091	-0.184	-0.206	0.156	0.006
Coarse	0.056	0.091	-0.203	-0.241	0.158	1.015
Unksoil	0.071	0.309	-	-	-	-
Transfersize	0.011	0.019	0.000	0.027	0.418	0.125
Pwl	-0.002	0.001	-0.002	0.001	-1.615	0.050
Gpm	0.000	0.000	0.000	0.000	1.285	2.742*
_cons	2.655	0.272	3.494	0.508	5.229	2.117
Significance level: *10%, ** 5%, *** 1%. The constrained model contained no observations for unksoil.						

Table 3.8 Test of Difference in Coefficients for Pumping Rates and Pumping Water Levels in 2008-2012.

	Unconstrained		Constrained			
Variable	Coef.	Std. Err.	Coef.	Std. Err.	Ratio of Coefficients	Chi-Squared for Difference
acres	0.000	0.001	0.001	0.002	0.291	0.016
useavg12	-0.246	0.016	-0.237	0.044	-5.550	0.038
percorn12	0.095	0.191	0.153	0.552	0.173	0.010
ownop	0.085	0.068	0.229	0.179	0.475	0.565
medium	-0.114	0.084	-0.007	0.283	-0.403	0.132
coarse	-0.029	0.085	0.209	0.272	-0.107	0.700
unksoil	0.315	0.332	0.737	1.033	0.305	0.151
transfersize12	0.007	0.016	-0.020	0.043	0.155	0.338
pwl	-0.002	0.001	-0.002	0.001	-1.458	0.003
gpm	0.000	0.000	0.000	0.000	0.961	2.641
_cons	2.997	0.268	3.262	0.825	3.635	0.093
Significance level: *10%, ** 5%, *** 1%						

The second set of models uses an indicator variable, MAC2, for the MAC curve prediction at the quantity level of two inches of abatement, and the coefficient and chi-squared test results are shown in Table 3.9 and Table 3.10. Again, neither the ‘05-‘07 nor ‘08-‘12 models showed a significant difference at the five-percent significance level. The lack of ratio patterns and significant differences indicate that there is not a problem with residual variation and that the dataset of constrained and unconstrained pools may be combined for one model in each allocation period. Observing the lack of significant difference in the coefficients across constrained and unconstrained pools, one model was used for each allocation period. Descriptive statistics for the variables in each of the six final models are listed in the Table 3.11.

Table 3.9 Test of Difference in Coefficients Test for MAC2 in 2005-2007.

	Unconstrained		Constrained			
Variable	Coef.	Std. Err.	Coef.	Std. Err.	Ratio of Coefficients	Chi-Squared for Difference
acres	0.001	0.001	0.000	0.001	0.847	0.346
useavg07	-0.176	0.015	-0.226	0.026	-6.741	2.828*
percorn07	0.007	0.184	0.447	0.316	0.023	1.451
ownop	-0.065	0.071	0.056	0.116	-0.561	0.785
medium	-0.181	0.088	-0.187	0.155	-1.167	0.001
coarse	0.033	0.095	-0.092	0.160	0.209	0.453
unksoil	-0.040	0.295	-	-	-	-
transfersize	0.015	0.019	-0.001	0.027	0.547	0.227
MAC2	-0.015	0.078	0.219	0.131	-0.111	2.333
_cons	2.134	0.240	2.801	0.435	4.903	1.804
Significance level: *10%, ** 5%, *** 1%. The constrained model contained no observations for unksoil.						

Table 3.10 Test of Difference in Coefficients Test for MAC2 in 2008-2012.

	Unconstrained		Constrained			
Variable	Coef.	Std. Err.	Coef.	Std. Err.	Ratio of Coefficients	Chi-Squared for Difference
acres	0.001	0.001	0.001	0.001	0.528	0.003
useavg12	-0.217	0.015	-0.208	0.040	-5.482	0.049
percorn12	-0.002	0.185	-0.045	0.538	-0.003	0.006
ownop	0.012	0.067	0.196	0.176	0.067	0.953
medium	-0.104	0.082	0.064	0.284	-0.367	0.325
coarse	0.007	0.089	0.294	0.269	0.027	1.024
unksoil	0.209	0.311	0.016	0.903	0.231	0.041
transfersize12	0.008	0.016	-0.019	0.042	0.187	0.351
MAC2	0.115	0.073	0.064	0.189	0.607	0.063
_cons	2.543	0.239	2.475	0.707	3.598	0.008
Significance level: *10%, ** 5%, *** 1%						

Table 3.11 Descriptive Statistics.

	Formal Trade Participation		‘05-‘07 Informal Trade Participation		‘08-‘12 Informal Trade Participation		Formal Trade Direction		‘05-‘07 Informal Trade Direction		‘08-‘12 Informal Trade Direction	
Variables	n=	3179	n=	3119	n=	3122	n=	100	n=	1974	n=	1914
Continuous	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
acres	155.966	67.194	155.469	66.320	155.470	66.330	167.439	76.301	155.835	64.646	156.155	65.259
gpm	1512.162	757.449	1508.731	756.953	1508.672	756.879	1489.140	711.857	1538.196	769.472	1540.356	770.243
pwl	136.192	73.506	136.511	73.518	136.504	73.535	113.473	57.704	125.953	66.620	125.778	66.229
opsize	13.383	18.519	13.461	18.600	13.460	18.594	14.030	13.841	16.038	20.467	16.013	20.481
useavg12	12.008	2.976	-	-	12.007	2.985	-	-	-	-	12.706	2.709
percorn12	0.743	0.220	-	-	0.743	0.220	-	-	-	-	0.761	0.196
useavg07	-	-	12.061	3.139	-	-	-	-	12.808	2.860	-	-
percorn07	-	-	0.725	0.233	-	-	-	-	0.746	0.207	-	-
avgusetrade	-	-	-	-	-	-	11.363	4.360	-	-	-	-
percorntrade	-	-	-	-	-	-	0.642	0.263	-	-	-	-
SDF	-	-	-	-	-	-	0.583	0.234	-	-	-	-
Tradesize	-	-	-	-	-	-	34.759	37.547	-	-	-	-
transfersize	-	-	-	-	-	-	-	-	2.120	2.172	2.060	2.297
Binary =1	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
ownop	1,812	57	1,778	57.01	1,782	57.08	53	53	1,105	55.98	1,083	56.58
medium	1,069	33.63	1,048	33.6	1,050	33.63	46	46	692	35.06	665	34.74
coarse	1,007	31.68	991	31.77	992	31.77	21	21	718	36.37	699	36.52
unksoil	50	1.57	49	1.57	49	1.57	-	-	27	1.37	26	1.36
Perkins	913	28.72	908	29.11	907	29.05	-	-	-	-	-	-
Dundy	909	28.59	887	28.44	889	28.48	-	-	-	-	-	-
MAC	-	-	-	-	-	-	45	45	-	-	-	-
MAC2	-	-	-	-	-	-	-	-	1,009	51.11	977	51.04
constr	-	-	-	-	-	-	-	-	552	27.96	247	12.9

3.3.3 Probit Model Estimation

The use of binary or limited response variable models, such as probit and logit, have grown in popularity for modeling choice behaviors similar to groundwater trading—such as irrigation and rainwater harvesting adoption (He, Cao, & Li, 2007)—and for determining irrigation technology choice (Negri & Brooks, 1990). Probit models were selected as the best-fitting models to show the factors that affect the likelihood of participating in a formal and informal trade as well as to predict the direction of trade between participants. The response variables for each model are binary variables equal to one or zero. A probit model is of the form:

$$(1)\ P(y = 1|x) = G(\beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k) = G(\beta_0 + x\beta)$$

Where G is a standard normal cumulative distribution function taking on values strictly between zero and one: $0<G(z)<1$ for all real numbers z (Wooldridge, 2003). This functional form of G (z) requires that estimated response probabilities of the model are strictly between zero and one and will not result in a negative probability or a probability greater than one. For the general probit model, as well as those used here, a standard normal distribution for the error term, ε, is assumed. The model estimations and tests are all done in the STATA software package.

The resulting sign of the coefficients in each model can be interpreted as the individual influence of each explanatory variable on the response probability of the model, ceteris paribus. The statistical significance of each variable is determined by whether we can reject H_0: $B_j = 0$ at a sufficiently small significance level. To find the magnitude of effect of a one unit change in an explanatory variable, holding all other variables fixed, the marginal effect of that change is of the form:

$$(2)\ G[\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k(c_k + 1)] - G(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k c_k)$$

There are two widely accepted measures of goodness-of-fit for binary response models discussed in econometric literature. The first is known as the percent correctly predicted. This method first estimates the probability that the predicted value ($\hat{y}_i$) takes on the value of one for each i. The predicted probabilities must then be converted to binary values of one or zero for comparison with the observed values (y_i). A pitfall of this measure is that it is possible to get high percentages of correctly predicted observations without the model being of much use when the sample contains a high proportion of one value to the other, which is why it is important to report the percent correctly predicted for each of the two outcomes (Wooldridge, 2003).

The second measure of fit is the reported pseudo R-squared value for binary response. A pseudo R-squared is similar to the R-squared value for an OLS model, which is a measure of how closely $\hat{y}_i$ is to y_i. The value for the pseudo R-squared is not expected to be as high as a conventional OLS R-squared because it is unlikely that the predicted values of the probit model will be exactly one or zero; they are more likely to be found somewhere in between (Wooldridge, 2003).

CHAPTER 4: RESULTS

Using STATA 12.1, each of the probit models was executed and the results are reported below. For each model, the sign of the coefficients were compared to expectations, marginal effects were interpreted, and the overall fit of the models were evaluated.

4.1 Model 1: Formal Trade Participation

The model applied to the formal trade participation for the permanent transfers of groundwater is as follows:

$$(3)\ P(Trade = 1) = G(\alpha + \beta_1*acres + \beta_2*useavg12 + \beta_3*percorn12 + \beta_4*ownop + \beta_5*opsize + \beta_6*medium + \beta_7*coarse + \beta_8*unksoil + \beta_9*Perkins + \beta_{10}*Dundy + \beta_{11}*gpm + \beta_{12}*pwl)$$

Due to only recent interest and rule allowances, 100 of the 3,179 observations have participated in trades, skewing the distribution severely to non-participation. The model results are presented in Table 4.1 and the marginal effects are presented in Table 4.2. Although the number of observations for participating is very small, the model reveals results that are generally consistent with expected behavior. The variables with the highest levels of significance include the size of the field, the amount of corn grown, and the county location of the fields.

While the model indicates a high level of significance for the size of the field, the marginal effect is very small and designates that a one acre increase in field size increases the probability of participation by only 0.01%. This small marginal effect may be the result of the lack of variation in field size for those that did participate in formal trades. The positive sign implies that larger fields are more likely to participate in formal trades, indicating that with the current time-intensive trading process, larger fields are more likely to benefit from the effort of participating in trades.

The percentage of years the field was in corn production is highly significant in the model, and the marginal effect indicates that increasing the variable by one percent decreases the probability of participating in a formal trade by 3.4%. This is consistent with expectations as participants include both buyers and sellers of water. Those fields where it is less efficient to produce corn, thus those field that grow it less often, are more likely to seek out a trade opportunity to get the benefits of their pumping rights since they are not being fully utilized under the current management practices.

The final significant variables are the county indicator variables for Perkins and Dundy counties. Both variables exhibit negative coefficients, and their marginal effects indicate that a Perkins County field is 2.8% less likely to participate and a Dundy County field is 2.4% less likely to participate, compared to a field located in Chase County. These results are as expected due to the high concentration of irrigated fields in Chase County and the current regulations restricting the distance water can be traded.

Evaluating the formal trade participation model has implications regarding the application of the trade direction model explained below. With the lack of participating field observation points, the model did not do a very good job of fitting the data—the pseudo R-squared value is 0.0634—and so caution must be used when applying the formal trade direction model to the entire district. The goodness-of-fit calculation reports that the model correctly predicted participation for 3,072 of the 3,179 of the observations or 96.6% but was unable to correctly identify any of the fields that actually participated in the formal trading process.

Table 4.1 Probit Regression Estimates and Standard Errors for Model 1.

Variable	Coefficient	Standard Error	Z-Score
Field size, acres	0.0015**	0.0006	2.46
Average use through 2012	-0.0215	0.0169	-1.28
Percentage of years planted to corn through 2012	-0.6022***	0.2303	-2.62
Owner = operator indicator	-0.0412	0.0964	-0.43
Operation size	0.0036	0.0030	1.23
Medium soil type	0.1787	0.1142	1.57
Coarse soil type	-0.1014	0.1358	-0.75
Unknown soil type	0.2786	0.3244	0.86
Perkins	-0.4853***	0.1563	-3.11
Dundy	-0.4201***	0.1266	-3.32
Gallons per minute	-0.0001	0.0001	-1.43
Pumping water level	-0.0012	0.0009	-1.36
Constant	-0.9857***	0.2472	-3.99
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

Table 4.2 Marginal Effect Estimates for Model 1.

Margins	dy/dx	Delta-method Standard Error	Z-Score
Field size, acres	0.0001**	0.0000	2.47
Average use through 2012	-0.0012	0.0010	-1.27
Percentage of years planted to corn through 2012	-0.0348***	0.0132	-2.63
Owner = operator indicator	-0.0024	0.0056	-0.43
Operation size	0.0002	0.0002	1.23
Medium soil type	0.0103	0.0066	1.56
Coarse soil type	-0.0059	0.0078	-0.75
Unknown soil type	0.0161	0.0188	0.86
Perkins	-0.0280***	0.0087	-3.22
Dundy	-0.0243***	0.0072	-3.35
Gallons per minute	0.0000	0.0000	-1.43
Pumping water level	-0.0001	0.0000	-1.37
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

4.2 Model 2: Informal Trade Participation 2005-2007

The model applied to the informal trade participation for temporary transfers of groundwater during the 2005-2007 allocation period is as follows:

$$(4)\ P(\text{Trade} = 1) = G(\alpha + \beta_1\text{*acres} + \beta_2\text{* useavg07} + \beta_3\text{*percorn07} + \beta_4\text{* ownop} + \beta_5\text{*opsize} + \beta_6\text{* medium} + \beta_7\text{*coarse} + \beta_8\text{*unksoil} + \beta_9\text{*Perkins} + \beta_{10}\text{*Dundy} + \beta_{11}\text{*gpm} + \beta_{12}\text{*pwl})$$

Due to the comparative ease of creating an informal trade versus a formal trade, participation in the informal trading market is much more prolific, with 1,974 of the 3,179 fields participating during the 2005-2007 allocation period. The model results are presented in Table 4.3 and the marginal effects are available in Table 4.4. The majority of the variables included in the model prove to be highly significant, which aligns with expected significance provided by previous literature on irrigation technology adoption and water trading.

The first significant variable included in the model is the measure of average use over the life of the field's recorded use until 2007. The positive sign and marginal effect indicate that when the average use increases by one inch, the probability of participating in a pool increases by 4%. This result is consistent with expected producer behavior and with comments during interviews in which producers said that one of their major goals is to efficiently manage their water allocations. By participating in an informal trade within a pool, a producer is able to increase average use on more efficient fields by cutting back use on less efficient fields, where it may be more expensive to pump or less productive land. Given the current district rules resulting from the Compact settlement, if the producer's goal is to increase average use, their options include participating in a relatively easy-to-form pool or complete the more time-intensive formal trade process, which has proved to be a less popular management choice.

The size of the operation is highly significant when predicting informal trade participation. The marginal effects indicate that increasing the operation size by one field increases the probability of participating by 1.3%. Traditionally, most pools have been formed with one owner for all the participating fields, indicating that in order to form an efficient pool, an operation must have at minimum two fields. Restrictions on the distance water can be moved further restrict the access of pool formation for small operations that may have multiple fields but do not fulfill the distance limitation rules. Thus larger operations have greater opportunities to participate in informal trades.

Compared to fine soils, both medium and coarse soil-type fields are more likely to participate in informal trading. Their marginal effects indicate fields with medium soil-types are 10.8% more likely to participate and fields with coarse soil-types are 13.2% more likely to participate than fields with fine soil-types. Medium or coarse (sandy) soil-types have poorer soil water retention rates than fields with fine soil, which may direct fields with the former soil-types to consider all management options for increasing water use efficiency, including participating in informal trading pools.

Similar to the formal trading model, the informal trading model shows that fields in Perkins and Dundy counties are less likely to participate. The marginal effects show that fields are 14% less likely to participate in informal trading if they are located in either Perkins or Dundy counties compared to Chase County. The negative coefficients are consistent with the fact that the majority of fields eligible for pooling are located in Chase County.

The coefficient of pumping water levels exhibits a negative sign and is highly significant. The pumping water level measures the distance from the soil surface to the water surface during pumping. When this number increases by one foot, pumping become more expensive as it requires more energy to move the water over a greater distance. The marginal effect of the one foot increase indicates that the probability of participation decreases by 0.02%. This result was inconsistent with prior hypothesis, that producers with higher-expense wells would be looking for ways to increase efficiency of allocated water by moving the water to wells were it is less expensive to pump. This may indicate that other factors that influence cost of pumping—such as pumping rates, irrigation system types and weather patterns—have a greater influence on pumping decisions than the pumping water levels.

The fit of the informal trade participation model for the 2005-2007 allocation period is much better than the formal trade model presented earlier. The fit was aided by the larger number of participating observations and resulted in a pseudo R-squared of 0.1075. The goodness-of-fit method calculated that the model correctly identified 2,187 of the 3,179 observations or 68.8%. The model over-predicted the number of participants but did a much better job predicting participation than non-participation by misidentifying 269 participants and 732 non-participants.

Table 4.3 Probit Regression Estimates and Standard Errors for Model 2.

Variable	Coefficient	Standard Error	Z-Score
Field size, acres	-0.0001	0.0004	-0.24
Average use through 2007	0.1057***	0.0097	10.93
Percentage of years planted to corn through 2007	0.1605	0.1198	1.34
Owner = operator indicator	0.0341	0.0518	0.66
Operation size	0.0098***	0.0018	5.59
Medium soil type	0.2888***	0.0622	4.64
Coarse soil type	0.3535***	0.0654	5.41
Unknown soil type	0.3328	0.2097	1.59
Perkins	-0.3728***	0.0704	-5.29
Dundy	-0.3724***	0.0670	-5.56
Gallons per minute	-0.0001	0.0000	-1.42
Pumping water level	-0.0007*	0.0004	-1.77
Constant	-1.0058***	0.1465	-6.86
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

Table 4.4 Marginal Effect Estimates for Model 2.

Margins	dy/dx	Delta-method Standard Error	Z-Score
Field size, acres	0.0000	0.0001	-0.24
Average use through 2007	0.0397***	0.0036	10.94
Percentage of years planted to corn through 2007	0.0603	0.0450	1.34
Owner = operator indicator	0.0128	0.0195	0.66
Operation size	0.0037***	0.0007	5.6
Medium soil type	0.1085***	0.0234	4.64
Coarse soil type	0.1328***	0.0246	5.4
Unknown soil type	0.1250	0.0788	1.59
Perkins	-0.1400***	0.0265	-5.29
Dundy	-0.1399***	0.0251	-5.56
Gallons per minute	0.0000	0.0000	-1.42
Pumping water level	-0.0003*	0.0002	-1.77
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

4.3 Model 3: Informal Trade Participation 2008-2012

The model applied to the informal trade participation for temporary transfers of groundwater during the 2008-2012 allocation period is as follows:

(5) $P(Trade = 1) = G(\alpha + \beta_1*acres + \beta_2* useavg12 + \beta_3*percorn12 +$

$\beta_4* ownop + \beta_5*opsize + \beta_6* medium + \beta_7*coarse + \beta_8*unksoil+$

$\beta_9*Perkins + \beta_{10}*Dundy + \beta_{11}*gpm + \beta_{12}*pwl)$

Similar to the previous allocation period, the participation in informal trading is more common than the participation in formal trades. During the most recent allocation period, 1,914 of the 3,179 observations participated in pools. The model results are displayed in Table 4.5, and the marginal effects are available in Table 4.6. The model exhibits similar results of coefficient signs and significance as the previous allocation period model.

The most significant variables include the field's average groundwater use, operation size, soil type, location in the district, and pumping water level. Although the two periods were separated to account for the change in allocation limits, the sign, significance, and magnitude of the marginal effects are similar to the earlier model and allow for the same conclusions to be drawn.

The marginal effect of increasing average use by one inch indicates a 3.9% increase in the probability of participating in an informal trade. Adding an additional field to an operation shows a marginal effect of a 0.34% increase in the probability of participating, a smaller impact than the previous model's 1% increase. Having either medium or coarse soil instead of fine soil demonstrates a marginal effect of increasing the probability of participating by 10.4% and 13.6%, respectively. Due to the concentration of irrigated fields in Chase County, the marginal effect of having a field in either Perkins or Dundy County decreases the probability of participating by 14% and 17.6% respectively. The final highly significant variable was the well technical variable of pumping water level. When the distance of pumping increases by one foot, the marginal effect indicates 0.04% decrease in the probability of participating in informal trading, which again is similar to the model for the previous allocation period.

Other variables just missing the standard 10% level of significance cut-off include the percentage of years in corn production, the land tenure indicator, and the technical measure of pumping rates. When a field increases the percentage of years in corn by one percent, the marginal effect indicates an increase in participation probability by 7.4%. This is consistent with the expectation that producers are making management decisions that help them increase efficiency, such as creating pools, when producing water-intensive crops like corn.

When the land is owned and operated by the same producer, the marginal effects indicate an increase in participation probability of 3%. This is consistent with expectations that operators are more likely to file the paperwork and form a pool when they are also the land owner. It is difficult for a renter, who may not be managing the farm the following year, to realize the full benefits of forming a pool, and thus they are less likely to incur the time cost of applying for the pool formation.

The final variable of slight significance is the pumping rate measure, and it has the expected negative sign. When a field increases its pumping rate by one gallon per minute, the probability of participating in a pool decreases by 0.002%. Although the marginal effect is very small, the positive sign is consistent with expectations that fields with higher pumping rates are less likely to participate in pools because they are able to efficiently pump the needed amount of water from the single well.

Evaluating the fit of the informal trade participation models will help determine if the directional model can be applied across the entire district or only to small portions of the district. The pseudo R-squared value for the most recent allocation period is 0.099, slightly lower than the model for the previous allocation period. The goodness-of-fit returned similar results as the previous model by correctly identifying 2,140 of the 3,179 observations or 67.3%. Once again the model over-predicted participation but did a better job of predicting participation than non-participation by misidentifying 323 participants and 716 non-participants.

Table 4.5 Probit Regression Estimates and Standard Errors for Model 3.

Variable	Coefficient	Standard Error	Z-Score
Field size, acres	0.0000	0.0004	0.12
Average use through 2012	0.1019***	0.0099	10.26
Percentage of years planted to corn through 2012	0.1933	0.1254	1.54
Owner = operator indicator	0.0784	0.0513	1.53
Operation size	0.0088***	0.0017	5.21
Medium soil type	0.2726***	0.0616	4.42
Coarse soil type	0.3562***	0.0648	5.5
Unknown soil type	0.2364	0.2025	1.17
Perkins	-0.3671***	0.0698	-5.26
Dundy	-0.4587***	0.0663	-6.92
Gallons per minute	-0.0001	0.0000	-1.6
Pumping water level	-0.0011***	0.0004	-2.74
Constant	-0.9850***	0.1492	-6.6
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

Table 4.6 Marginal Effect Estimates for Model 3.

Margins	dy/dx	Delta-method Standard Error	Z-Score
Field size, acres	0.0000	0.0001	0.12
Average use through 2012	0.0390***	0.0038	10.27
Percentage of years planted to corn through 2012	0.0740	0.0480	1.54
Owner = operator indicator	0.0300	0.0197	1.53
Operation size	0.0034***	0.0006	5.22
Medium soil type	0.1044***	0.0236	4.42
Coarse soil type	0.1364***	0.0248	5.49
Unknown soil type	0.0905	0.0776	1.17
Perkins	-0.1406***	0.0267	-5.26
Dundy	-0.1756***	0.0254	-6.92
Gallons per minute	0.0000	0.0000	-1.6
Pumping water level	-0.0004***	0.0002	-2.74
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

4.4 Comparison of Model 2 and Model 3

The dataset was split into the two allocation period groups to account for the change in allocation limit, new rules that caused the dissolution of existing pools, and the general dissolution and formation of new pools that occurred at the start of the new allocation period. The dissolution of pools made it difficult to combine the datasets into one for a single model as the field would have two observations for examining participation. Adding to the difficulty was the formation of new pools with participants from recently dissolved pools. These created two observations for the field, as the average pool usage, transfer size, and even direction in some cases changed, ultimately preventing the combination of the datasets for the two allocations for a single model.

Despite the need for two models, the results for the two periods are very similar. The ratio of coefficients and chi-squared test of difference indicate no significant difference in the model's coefficients. Most of the ratios are close to one, indicating nearly identical coefficients. The chi-squared tests with one degree of freedom also show no significant difference as all the test statistic values are less than 0.5. The coefficients, the ratio and test statistics are found in Table 4.7.

Table 4.7 Test of Difference in Coefficients for Model 2 and Model 3.

	2005-2007		2008-2012			
Variable	Coefficient	Standard Error	Coefficient	Standard Error	Ratio of Coefficients	Chi-Squared for Difference
Field size, acres	-0.0001	0.0004	0.0000	0.0004	-2.03	0.06
Average use	0.1057	0.0097	0.1019	0.0099	1.04	0.07
Percentage of years planted to corn	0.1605	0.1198	0.1933	0.1254	0.83	0.04
Owner = operator indicator	0.0341	0.0518	0.0784	0.0513	0.43	0.37
Operation size	0.0098	0.0018	0.0088	0.0017	1.11	0.17
Medium soil type	0.2888	0.0622	0.2726	0.0616	1.06	0.03
Coarse soil type	0.3535	0.0654	0.3562	0.0648	0.99	0.00
Unknown soil type	0.3328	0.2097	0.2364	0.2025	1.41	0.11
Perkins	-0.3728	0.0704	-0.3671	0.0698	1.02	0.00
Dundy	-0.3724	0.0670	-0.4587	0.0663	0.81	0.84
Gallons per minute	-0.0001	0.0000	-0.0001	0.0000	0.91	0.01
Pumping water level	-0.0007	0.0004	-0.0011	0.0004	0.65	0.46
Constant	-1.0058	0.1465	-0.9850	0.1492	1.02	0.01
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively						

4.5 Model 4: Formal Trade Direction

The model applied to the formal trade direction for the permanent transfers of groundwater is as follows:

(6) $P(\text{Seller} = 1) = G(\alpha + \beta_1\text{*acres} + \beta_2\text{* avgusetrade} + \beta_3\text{*percorntrade} +$

$\beta_4\text{* ownop} + \beta_5\text{*opsize} + \beta_6\text{* medium} + \beta_7\text{*coarse} + \beta_8\text{*tradesize+}$

$\beta_9\text{*MAC} + \beta_{10}\text{*sdf})$

Of the 100 fields that have participated in permanent trades, 46 were net sellers of water and 54 were net buyers of water. The model results are summarized in Table 4.8 and the marginal effects can be found in Table 4.9. The model utilizes those variables that vary on the field level and are consistent with irrigation adoption literature and anecdotal interviews with the producers in the research area.

The model reveals that the most significant factors in determining the direction of trade for permanent transactions are the average field size, the field's average use until the time of the trade, and the MAC prediction of the relationship. Although the field size is statistically significant, the marginal effect is relatively small and indicates that increasing the field size by one acre increases the probability of being a seller by 0.19%. The positive sign of the effect is consistent with expectations as fields with more certified acres have potentially more excess certified acre allocations available to sell. Larger fields are also less likely to be buyers due to the pivot irrigation limitations of existing technology employed in the area.

The significance level of average field use up to the time of trading is the highest of the model and exhibits the expected negative sign. The variable captures the use-history prior to the trade and indicates that fields with higher average use are less likely to be sellers of water, which is consistent with expectations. When average usage increases by one inch, the marginal effect decreases the probability of being a seller by 6.5%.

The final significant variable is the MAC indicator variable, which was created by examining the curve relationships within the convex portion of the curves of the fields involved. The ability of the MAC to accurately identify a field's role in the trading scheme helps to validate its mathematical calculation and appropriateness for predicting permanent trade possibilities in the research area. When the MAC variable predicts a seller, the marginal effect indicates an increase in the probability of being seller by 30.8%.

Although the stream depletion factor is not highly statistically significant, it exhibits the expected sign and has a large positive marginal impact. When the sdf increases by 0.01, the marginal effect indicates that the field is 29.2% more likely to be a seller of water. This is great news for the URNRD water managers as it indicates that the pumping is moving away from areas where pumping has a larger impact on stream flow and is helping the district stay in compliance with the Compact.

This model performs the best of the six and is highly correct in predicting the direction of permanent formal trades according to the two measure of evaluation. The pseudo R-squared for this model is 0.2656, which is the highest among the three trade direction models. The goodness-of-fit method also resulted in the correct prediction of 75 of the 100 observations, or 75%. Of those predicted accurately, 33 or 44% were net sellers and 42 or 56% were net buyers.

Table 4.8 Probit Regression Estimates and Standard Errors for Model 4.

Variable	Coefficient	Standard Error	Z-Score
Field size, acres	0.0049**	0.0022	2.18
Average use until trade	-0.1658***	0.0509	-3.26
Percentage of years planted to corn until trade	0.8372	0.7649	1.09
Owner = operator indicator	-0.0587	0.3213	-0.18
Operation size	-0.0112	0.0139	-0.8
Medium soil type	-0.1077	0.3325	-0.32
Coarse soil type	0.0135	0.5036	0.03
Trade size	-0.0053	0.0042	-1.28
MAC indicator	0.7815**	0.3256	2.4
Stream depletion factor	0.7418	0.6644	1.12
Constant	0.0044	0.8579	0.01
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

Table 4.9 Marginal Effect Estimates for Model 4.

Margins	dy/dx	Delta-method Standard Error	Z-Score
Field size, acres	0.0019**	0.0009	2.18
Average use until trade	-0.0654***	0.0201	-3.26
Percentage of years planted to corn until trade	0.3299	0.3007	1.1
Owner = operator indicator	-0.0231	0.1266	-0.18
Operation size	-0.0044	0.0055	-0.81
Medium soil type	-0.0425	0.1310	-0.32
Coarse soil type	0.0053	0.1985	0.03
Trade size	-0.0021	0.0016	-1.28
MAC	0.3080**	0.1287	2.39
Stream depletion factor	0.2923	0.2612	1.12
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

4.6 Model 5: Informal Trade Direction 2005-2007

The model applied to the informal trade direction for the 2005-2007 allocation period pools is as follows:

(7) $P(\text{Seller} = 1) = G(\alpha + \beta_1\text{*acres} + \beta_2\text{* useavg07} + \beta_3\text{*percorn07} + \beta_4\text{*medium} + \beta_5\text{* coarse} + \beta_6\text{* unksoil} + \beta_7\text{* transfersize} + \beta_8\text{* MAC2} + \beta_9\text{* constr} + \beta_{10}\text{*(MAC2*Constr)})$

For those fields that participated in pools during the ‘05-‘07 allocation period, 995 transferred water to 979 recipients. The results of the above model are shown in Table 4.10 and the marginal effects are presented in Table 4.11. The model focuses on those variables that are unique to the field to better model the decision process faced by the producer. Operation size and land tenure were not included due to the fact that most trades occurred within one operation under the same land tenure situation and therefore did not provide useful information on trading behavior.

The most statistically significant factors in predicting the probability of a seller are the field’s average use, if the field has medium soil type, whether the pool is constrained, and the interaction variable. The negative sign of the average use coefficient is consistent with the hypothesis that fields that use more water are less likely to be net sellers of water. Examining the marginal effect indicates that when average use increases by one inch, the probability of being a seller decreases by approximately 7.5%.

When interpreting the significance of the medium soil-type variable, it is important to recognize that the variable as an indicator variable and the set of soil type variables are compared to the fine soil type. When a field is of medium soil type as opposed to fine, the marginal effect shows the probability of being a seller decreases by

7.3% due to the negative sign of the coefficient. This indicates that fields with medium soils are more likely to be net buyers of water, which may be tied to the productivity of corn production on medium soil types. Even though the variable is not statistically significant, the positive sign on the coarse variable is consistent with anecdotal evidence from farmer interviews that fields with sandy soils are likely to be sellers.

When the pool is constrained, the probability of the field being a seller is significantly higher—regardless of the MAC2 prediction—which is consistent with expected producer behavior when facing convex marginal abatement cost curves. Over the average transfer size for the allocation period of approximately 2.12 inches, the MAC curves are convex, which leads to the conclusion that it is less expensive for multiple fields to cut back a little than to have one field cut back a significant amount. Plotting several MAC curves for the dataset also revealed than many fields experience zero cost for cutting back one inch or less. The constrained variable margins indicate that when the MAC2 indicates a buyer, the field is 6.0% more likely to be a seller when the pool is constrained. However, when the pool is constrained and the MAC2 predicts a seller, the field is 16.6% more likely to be a seller. The positive marginal effects, regardless of MAC2 prediction, indicate that producers, although showing consistent behavior with the curve shape, focus on different factors when making trade decisions in the informal trade market. This is a potential result of the temporary timeframe used for decision-making, unlike making a permanent sale or purchase. Although the sign of the MAC2 coefficient is inconsistent with what was expected when the pool is not constrained, the variable is not significant at any reasonable level. The marginal effect of MAC2 when the pool is constrained is significant and results in a field being 9.1% more likely to be a seller, which is once again consistent with the convexity of the curves.

To evaluate the overall fit of the model, the pseudo R-squared measure was examined and the goodness-of-fit method was applied. The pseudo R-squared for the model is 0.1018. Even with a relatively low pseudo R-squared value, the model was able to correctly identify buyers and sellers for 1,314 of the 1,974 observations or 66.6%. Of those correctly predicted, 50.9% were predicted to be sellers and 49.1% were predicted to be buyers, which are consistent with the data sample percentage of sellers and buyers.

Table 4.10 Probit Regression Estimates and Standard Errors for Model 5.

Variable	Coefficient	Standard Error	Z-Score
Field size, acres	0.0004	0.0005	0.91
Average use through 2007	-0.1875***	0.0126	-14.91
Percentage of years planted to corn through 2007	0.1386	0.1582	0.88
Medium soil type	-0.1834**	0.0765	-2.4
Coarse soil type	-0.0054	0.0808	-0.07
Unknown soil type	-0.2085	0.2747	-0.76
Transfer size	0.0078	0.0152	0.51
MAC2 indicator	-0.0427	0.0760	-0.56
Constrained indicator	0.1687*	0.0963	1.75
MAC2*Constrained interaction	0.3058**	0.1325	2.31
Constant	2.2243***	0.2023	10.99
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

Table 4.11 Marginal Effect Estimates for Model 5.

Margins	dy/dx	Delta-method Standard Error	Z-Score
Field size, acres	0.0002	0.0002	0.91
Average use through 2007	-0.0748***	0.0050	-14.92
Percentage of years planted to corn through 2007	0.0553	0.0631	0.88
Medium soil type	-0.0731**	0.0305	-2.4
Coarse soil type	-0.0022	0.0322	-0.07
Unknown soil type	-0.0832	0.1096	-0.76
Transfer size	0.0031	0.0061	0.51
MAC2 at			
constrained = 0	-0.0151	0.0268	-0.56
constrained = 1	0.0912**	0.0405	2.25
Constrained at			
MAC2 = 0	0.0598*	0.0339	1.76
MAC2 = 1	0.1660***	0.0316	5.26
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

4.7 Model 6: Informal Trade Direction 2008-2012

The model applied to the informal trade direction for the 2008-2012 allocation period pools is as follows:

(8) P(Seller = 1) = G(α + β_1*acres + β_2* useavg07 + β_3*percorn07 + β_4*medium + β_5* coarse + β_6* unksoil + β_7* transfersize + β_8* MAC2 + β_9* constr + β_{10}*(MAC2*Constr))

For those fields that participated in pools during the '08-'12 allocation period, 945 transferred water to 969 recipients. The results of the above model are shown in Table 4.12 and the marginal effects are presented in Table 4.13. The model focused on those variables that are unique to the field to better model the decision process faced by the producer.

The variables of greatest significance are average field use, the MAC2 indicator, the constrained pool indicator and their interaction term. Similar to the model for the previous allocation period, fields with higher average use over the five years are less likely to be net sellers of water. The marginal effects indicate that when average use increases by one inch, the field is 8.6% less likely to be a net seller of water.

Similar to Model 5, the constrained indicator variable is statistically significant and positive regardless of the MAC2 prediction. Again, producers are faced with convex abatement cost curves and realize that is it less costly to cut back a little from many fields than to cut back a large amount from one field. The constrained variable margins indicate that when the MAC2 indicates a buyer, the field is 10.6% more likely to be a seller. However, when the MAC2 predicts a seller, the field is 7.3% more likely to be a seller. Although showing consistent behavior with the curve shape, it appears that producers focus on different aspects when making trade decisions in the informal trade market, which may be due to the temporary timeframe used for decision-making. The positive sign of the MAC2 coefficient is consistent with what was expected when the pool is constrained, but the variable is not significant at any reasonable level. The marginal effect of MAC2 indicating a seller when the pool is unconstrained is significant and results in a field being 4.3% more likely to be a seller.

The lack of significance of the other variables in either allocation period trade model indicates that the MAC curves—calculated using well specific characteristics, production costs and average weather conditions—are better suited for predicting the probability of being a seller or buyer in the informal market.

Evaluating the overall fit of the model was done using the pseudo R-squared measure and the goodness-of-fit method. The pseudo R-squared for the model is 0.1197, which is slightly higher than the model for 2005-2007. The goodness-of-fit evaluation determined that the model correctly predicted 1,276 of the 1,914 observations or 66.7%. Of those correctly predicted, 47.3% were predicted to be sellers and 52.7% were predicted to be buyers, which is consistent with the data sample percentage of sellers and buyers.

Table 4.12 Probit Regression Estimates and Standard Errors for Model 6.

Variable	Coefficient	Standard Error	Z-Score
Field size, acres	0.0008	0.0005	1.60
Average use through 2012	-0.2152***	0.0137	-15.69
Percentage of years planted to corn through 2012	-0.0059	0.1739	-0.03
Medium soil type	-0.0887	0.0780	-1.14
Coarse soil type	0.0437	0.0829	0.53
Unknown soil type	0.1923	0.2920	0.66
Transfer size	0.0057	0.0150	0.38
MAC2 indicator	0.1253*	0.0721	1.74
Constrained indicator	0.3066**	0.1291	2.37
MAC2*Constrained interaction	-0.0970	0.1797	-0.54
Constant	2.5101***	0.2212	11.35
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

Table 4.13 Marginal Effect Estimates for Model 6.

Margins	dy/dx	Delta-method Standard Error	Z-Score
Field size, acres	0.0003	0.0002	1.6
Average use through 2012	-0.0859***	0.0055	-15.69
Percentage of years planted to corn through 2012	-0.0024	0.0694	-0.03
Medium soil type	-0.0354	0.0311	-1.14
Coarse soil type	0.0174	0.0331	0.53
Unknown soil type	0.0767	0.1165	0.66
Transfer size	0.0023	0.0060	0.38
MAC2 at			
constrained = 0	0.0435*	0.0250	1.74
constrained = 1	0.0097	0.0584	0.17
Constrained at			
MAC2 = 0	0.1063**	0.0442	2.4
MAC2 = 1	0.0725*	0.0441	1.65
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively			

4.8 Comparison of Model 5 and Model 6

The argument for two models for informal trade direction is strongest for determining the probability of buying or selling water. The models rely on variables that that differ for some fields due to dissolution and formation of new pools such as transfer size and the MAC2 relationship of the fields involved. The change in allocation limit in 2008 directly impacted the constrained indicator variable and the interaction variable, both of which are statistically significant in the models.

Even with the need for two models, the results are generally consistent between the models and lead to the same discussion and conclusions. The ratio of coefficients test show much more variation in the coefficients and sign than the comparison of the participation models. The coefficient for percentage of years in corn changed significantly between the two periods, going from fairly large and positive to slightly less than zero. The MAC2 indicator coefficient changed from insignificant and negative to significant and positive, further demonstrating the need for two models. According to the chi-squared test of difference, the only significant difference was for the coefficient of the interaction variable at the 10% level, indicating similar behavior between the two allocation periods. The significance of the interaction variable coefficients is due largely to the difference in the MAC2 coefficients that barely miss the significance level cut-off for one degree of freedom. The results of the coefficient ration and chi-squared test are found in Table 4.14.

Table 4.14 Test of Difference in Coefficients for Model 5 and Model 6.

	2005-2007		2008-2012			
Variable	Coefficient	Standard Error	Coefficient	Standard Error	Ratio of Coefficients	Chi-Squared for Difference
Field size, acres	0.0004	0.0005	0.0008	0.0005	0.57	0.24
Average use	-0.1875	0.0126	-0.2152	0.0137	0.87	2.22
Percentage of years planted to corn	0.1386	0.1582	-0.0059	0.1739	-23.33	0.38
Medium soil type	-0.1834	0.0765	-0.0887	0.0780	2.07	0.75
Coarse soil type	-0.0054	0.0808	0.0437	0.0829	-0.12	0.18
Unknown soil type	-0.2085	0.2747	0.1923	0.2920	-1.08	1.00
Transfer size	0.0078	0.0152	0.0057	0.0150	1.37	0.01
MAC2 indicator	-0.0427	0.0760	0.1253	0.0721	-0.34	2.57
Constrained indicator	0.1687	0.0963	0.3066	0.1291	0.55	0.73
MAC2*Constrained interaction	0.3058	0.1325	-0.0970	0.1797	-3.15	3.25*
Constant	2.2243	0.2023	2.5101	0.2212	0.89	0.91
Single, double, and triple asterisks (*,**,***) denote statistical significance at the 10%, 5% and 1% levels, respectively						

CHAPTER 5: CONCLUSION

Water trading literature states that there are significant economic gains to be achieved by moving water from areas of low efficiency to areas of higher efficiency within a region. This study utilized probit models and marginal effects analysis of factors that help predict the probability of participating in formal and informal trades, as well as the direction of trade among participants, in an effort to achieve the aforementioned economic gains and to better predict the impacts of groundwater pumping. The participation models used field-level variables and provided insight into the participation decision process. The trade direction models relied on some of the same factors as participation, but also those factors that are unique to the field and the trade it participated in. The results of the model support our previous trading behavior hypothesis and can be used to guide ex-ante evaluation of groundwater trading in other regions.

The focus on the trade participation models is crucial for determining if it is appropriate to apply the direction of trade models to the entire district or only subsections. For example, can the models be applied to operations of all sizes? The results of the participation models indicate that operation size has a positive marginal effect and is significant for informal trade participation. This indicates that larger operations are more likely to participate in trading, but the significance may be exaggerated and is in fact an artifact of the rules set forth by the URNRD to restrict the distance water is moved. Overall, the participation models do not indicate that separate models are needed and that the general participation models can be applied to the entire district.

A major constraint to the formal trade participation is limited data on formal participation in trades and results in low accuracy model. However, the large participation in informal trades is an indicator that there is, in fact, substantial interest in trading water but that there are currently barriers preventing more formal trading. Once a pool is formed, the marginal cost of trading water is effectively zero, whereas the marginal cost of formal trading under the current process is significantly higher. The large participation in informal trading is a sign of potential economic gains for the District from reducing the transaction costs associated with formal trading. If the marginal cost of participating in a formal trade were reduced—through the aid of an online trading platform to find potential trading partners, for example—participation in formal trades would be expected to increase substantially.

Expanding the formal trading market to include annual use trades (leases of water) in addition to the permanent trades also has the potential to open the market and allow for more observations for the formal participation model. The ranking of the MAC curves are not stationary under different precipitation and crop price scenarios, indicating that buyers and sellers may switch roles under different production situations. The ability for buyers and sellers to switch roles, as predicted by their MAC relationship, indicates that annual leases would provide an additional risk management tool for producers by generating flexibility in the field's annual allocation.

The trade direction models' results perform the best and provide insight into producer behavior and decision-making when it comes to water management in water-short areas. The models indicate that for both formal and informal trading producers behave rationally and generally as expected. By improving the accuracy of trade direction probability, the models for pumping impacts are also improved and are able to more accurately predict the direct and indirect effects of groundwater pumping for irrigation.

Caution must be taken before applying similar models to other areas because field or well level usage data is critical as it is a significant variable in nearly every model. As explained in much of the literature on water markets, there are specific components that must be fulfilled before a water market can exist. These include the installation of meters to record usage (at least annual records of usage), explicit water rights, and enforcement of restrictions. Once these requirements for a groundwater trading market are met, the collection of usage information needed for these models becomes much easier.

The MAC curves are a critical component of the trade direction models and did a good job in helping predict the probability of being a buyer or seller of water. If designed appropriately for the different regions, the curves and MAC indicators can be used to predict direction and ultimately the impacts of groundwater trading in an area. The Water Optimizer program, a key factor in the generation of the MAC values, can be used to model any area of Nebraska, and with slight modification, can be applied to other regions outside Nebraska.

For the URNRD specifically, the large positive marginal effect of the stream depletion factor indicates that formal trading does align with their policy goal of reducing the negative impact on stream flow in the Republican River by groundwater pumping in the District. The marginal effect shows that water is moving from wells that have a large impact on the stream flow (as a percentage of their pumping) to wells that have lower impact on the stream flow. Relaxing the rules on formal trades and increasing participation with lower transaction costs may still be consistent with URNRD goals and more economically desirable.

This research is one of the first to empirically study groundwater trading and provide model results. The results from this research can be used ex-ante to prepare similar models for other areas, include using data from the other Republican River NRDs and expanding to other water-short regions. The main obstacle for application of this research is the lack of usage measurements that will take time to gather as more and more regions are looking to apply meters and enforce restrictions.

Future plans to improve the URNRD models include the generation of more refined measures of relative soil type and other characteristics to separate average characteristics from field characteristics so as to capture more detailed differences at the field level. Creating and conducting a survey of producers would provide additional information about factors that influence the decision-making process, such as education levels, operation structure, and other field characteristics (such as productivity). A major goal of improving this study for future journal publications includes attempting a matching technique for the formal participation model to generate a higher accuracy model than the current method applied. Testing for selection between informal and formal trades will allow for further insight into the behavioral decision of trade participation.

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APPENDIX

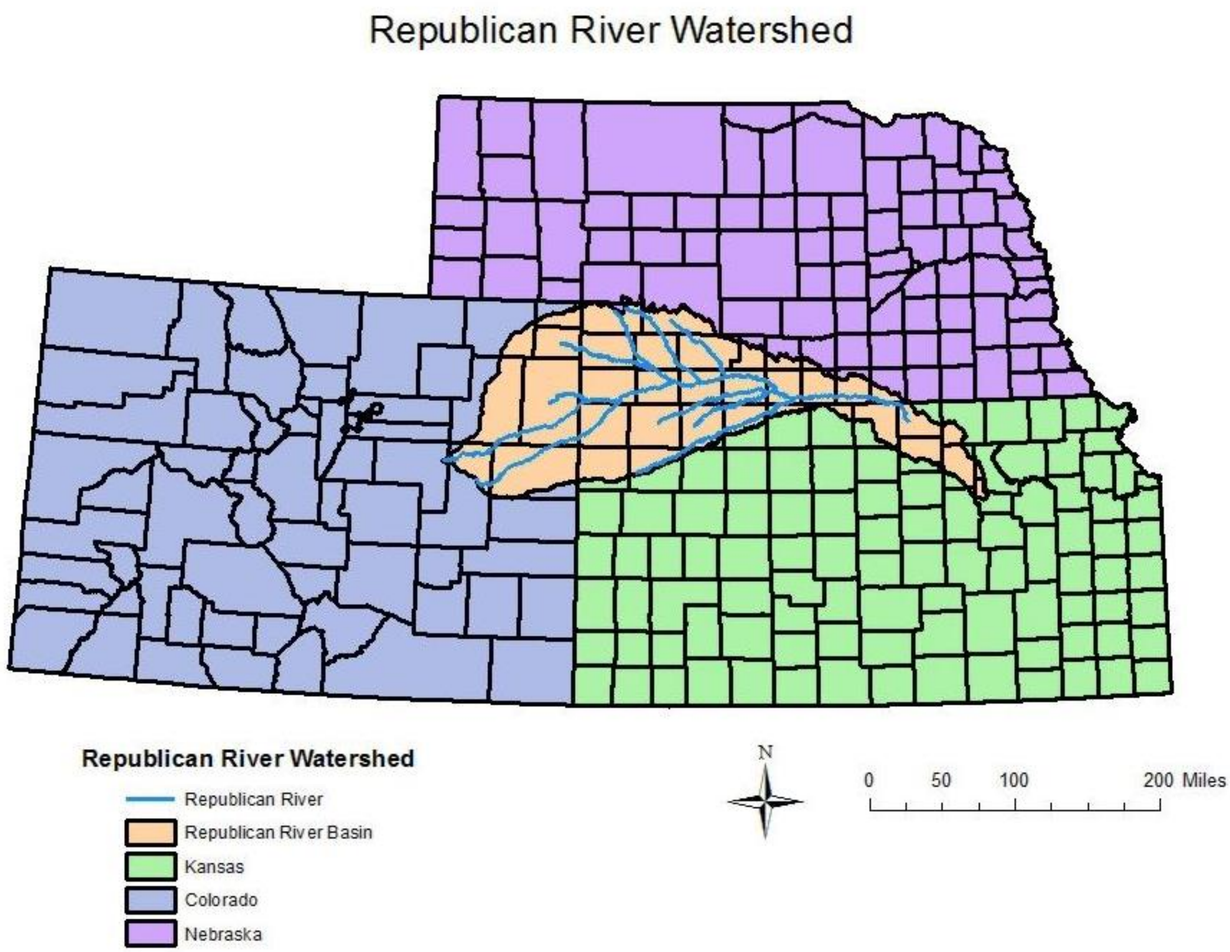

Figure A.1 Map of Republican River Watershed.

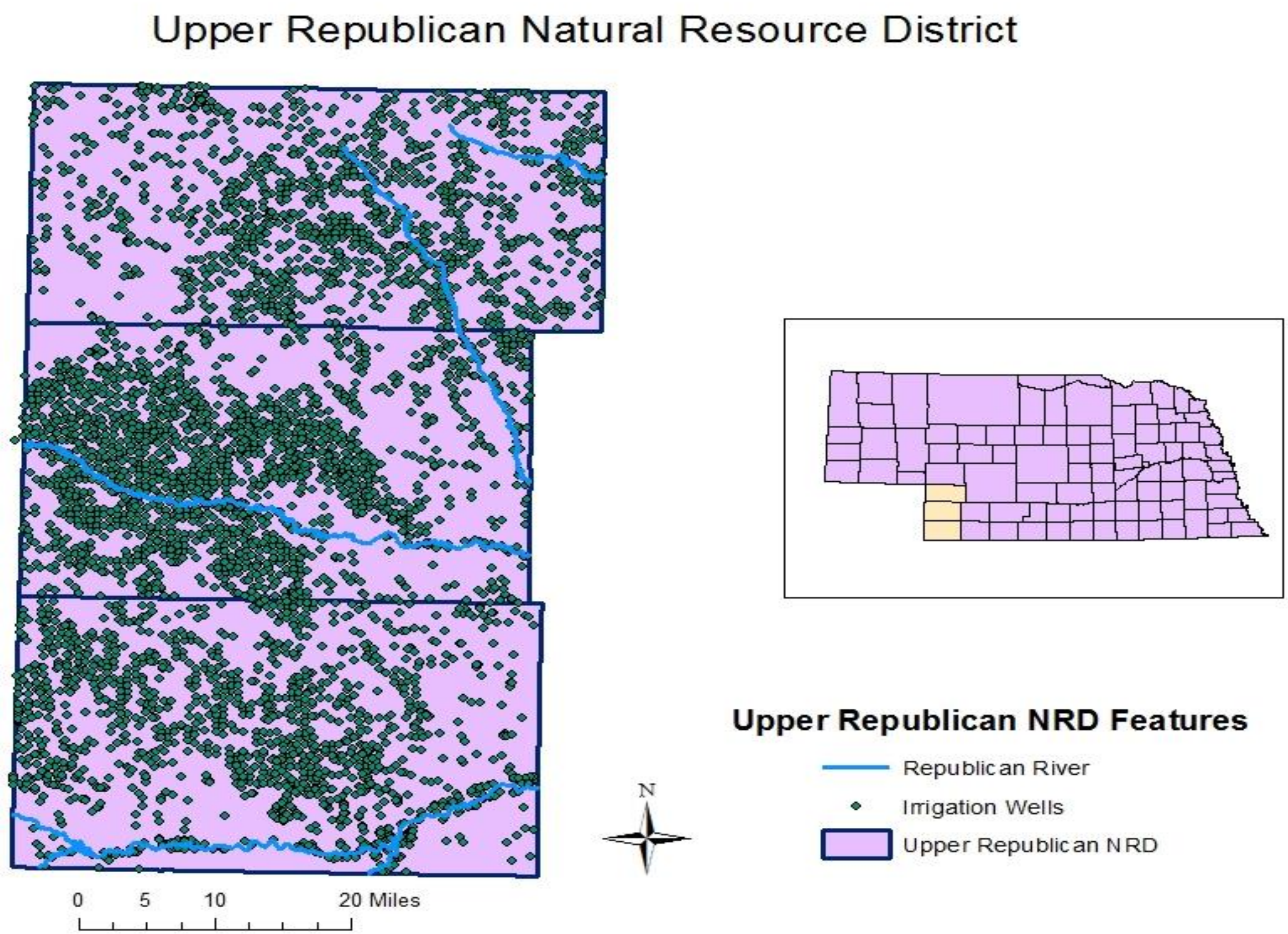

Figure A.2 Map of Upper Republican Natural Resource District.

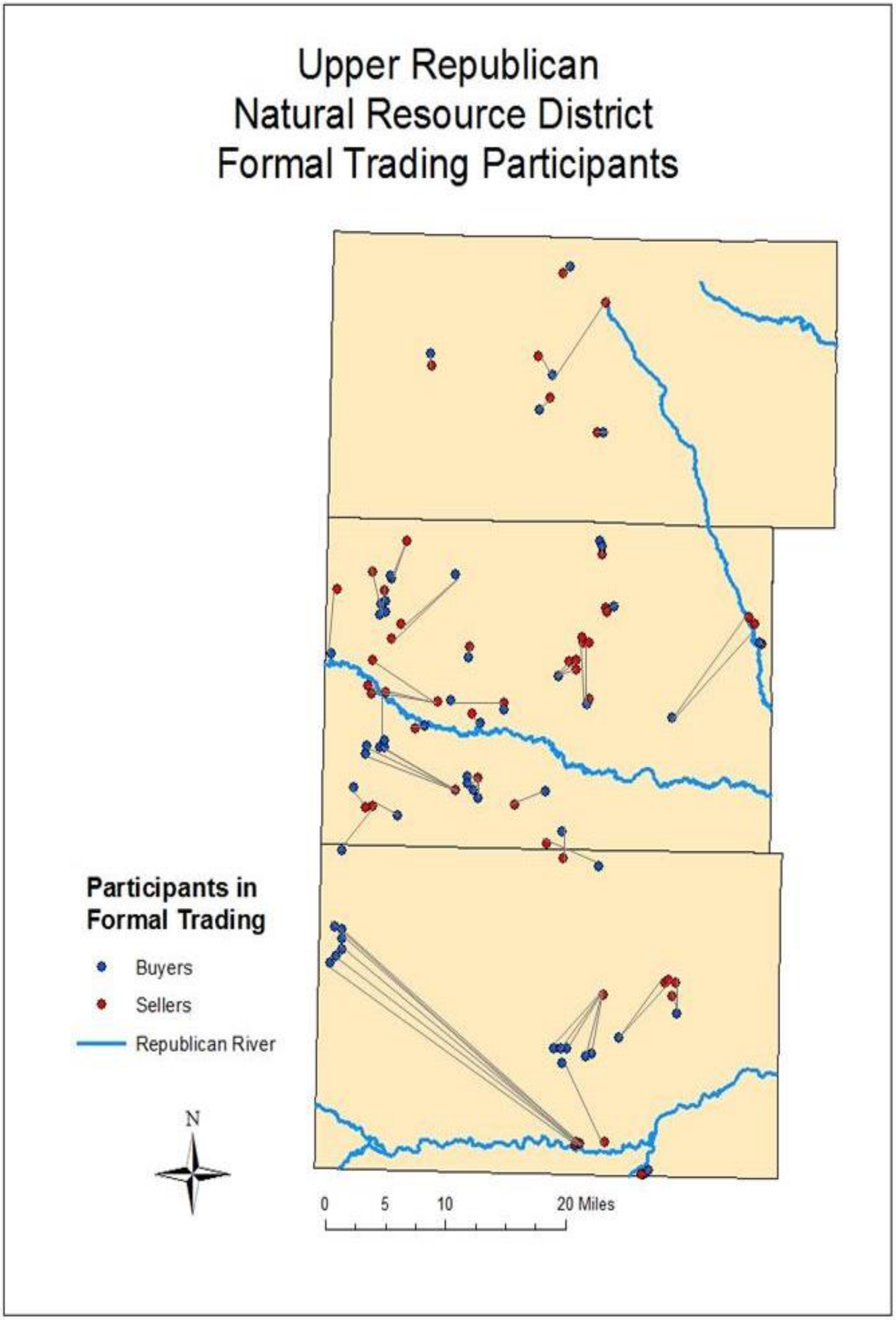

Figure A.3 Map of Wells Participating in Formal Trades.