PREDICTING GROUNDWATER TRADING PARTICIPATION IN THE UPPER REPUBLICAN NATURAL RESOURCE DISTRICT

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

Abstract:

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 new area of study due in part to the previous lack of recorded usage, trade data and binding constraints on groundwater use by landowners. 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. The paper predicts 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. 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.

INTRODUCTION

While surface water trading has occurred regularly throughout the western United States and the rest of the world for decades, the use of any type of groundwater trading has been very limited. However, groundwater is increasingly under stress from overuse and many areas are starting to regulate groundwater use. While the public benefits from efficient use of groundwater include adequate stream flow in hydrologically connected areas and future availability 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. Previous work on water trading has focused on surface water trading and theoretical approaches to analyzing groundwater trading. Empirical analysis of groundwater trading is a new area of research due in part to the lack of recorded usage, trade data and binding constraints on groundwater use by landowners.

Unlike many other groundwater-dependent areas across the nation, the Upper Republican Natural Resource District (URNRD) has had metering and use restrictions in place for over 30 years. The URNRD has also developed some mechanisms to help producers use water most efficiently under allocation restrictions. Two of the tools available include creating pools and formally trading water. Formal water trading occurs when the irrigation rights are permanently transferred from one field to another field. When multiple fields are combined to create a pool, a producer can temporarily move a water allocation from one field to another field in the same pool. Within-pool transfers are conducted when fields under the same owner aggregate their total allocations into a pool, as approved by the URNRD board, and then redistribute the water to each field at the owner's discretion. These within-pool transfers have much lower transaction costs than the formal trades due to less time and money spent finding a trading partner and gaining board approval. Therefore, the URNRD provides a great opportunity to better understand the impacts of allowing some restricted trading. Results are useful both for the potential expansion of groundwater trading in the URNRD and the rest of Nebraska as well as in other areas.

Our study examines formal trading and within pool transfers (i.e., informal trades) using thirty years of water use and field level characteristics provided by the URNRD. The district has historically allocated water over three to five year periods which allow the landowners more flexibility in planning their irrigation schedules. Allocations began at 22 inches per certified acre in 1980 and have since been reduced to 13 inches per certified acre for the 2008-2012 allocation period. Specifically, we want to determine if standard economic criteria based on the cost of pumping groundwater and the expected yield are useful indicators in determining trading behavior.

Previous research 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. Although the majority of surface water rights use the appropriation doctrine of "first in time, first in right", groundwater rights in Nebraska utilize the correlative rights doctrine that is administered by the local Natural Resource District (NRD). The NRD system in Nebraska includes 23 districts that are responsible for management of natural resources such as soil and groundwater. 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.

Water 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 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. 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 and Sunding, 2006).

Necessary Elements to Establish a Water Market

Much research has been done to identify the general requirements for a competitive market system. Dinar et. al. (1997) and Saliba (1987) agree that efficient water markets require: 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; 4) participants are assumed to be maximizing profits; 5) completely specified, enforceable, and transferable property rights.

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, so long as the gains in value are large enough to offset the costs of completing the transaction. 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.

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. 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.

BACKGROUND ON THE STUDY REGION

On average, the study area (the Upper Republican Natural Resource District or URNRD) 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 groundwater from the High Plains Aquifer, much of which is hydrologically connected to 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 in the state.

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 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 452,395 certified acres (Palazzo & Brozovic, 2012).

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 22 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 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.

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 contains technical information on each well, including pump depth, pump rate, date of drilling, and the current status of the well (e.g, active, abandoned) and on the use (e.g., irrigation, livestock, domestic). Specific geographic location information and well ownership information is also included within the file. There are 4,604 wells in the URNRD region 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 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.

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, we only use the pools in the two recent allocation periods in this analysis. The URNRD also provided data on the following for each field ID: owner/operator IDs in 2011, the associated well ID, annual certified acres, crop planted, pool ID (if applicable), and water use by year. When reconciled, the final dataset contained information on 3,179 unique field IDs.

Groundwater price and quantity values used to calculate the marginal abatement cost (MAC) indicators were generated by Palazzo and Brozovic (2012). The MAC values are determined using the Nebraska DNR well data and results from the Water Optimizer program (Martin, Supalla, McMullen, & Nedved, 2007). Each point in the MAC curve is determined by calculating the change in the profit associated with increasing the stringency of the pumping constraint, starting from the current allocation of 13 inches per year. These values are based on well and field level characteristics (e.g., depth to groundwater, soil type), average values for weather variables, average prices of inputs including energy for irrigation pumps, and average market prices for harvested crops. To determine the value of the MAC indicator used, the relationship of the curves was modeled, as shown in Figure A.4. In the figure, 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 is lower (~$0/year) for Well A than Well B (~$9.00/year). This indicates that reducing water use is less expensive for Well A than Well B, predicting that Well A is a net seller.

Due to various changes in state law and interstate compacts, the effect of groundwater use regulations on stream depletion is of critical importance. Research in hydrology has shed light on the potential negative impact of groundwater pumping on nearby streams through the process of stream depletion. The stream depletion factor (SDF) is not a deciding factor in the approval process under past 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. 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 (Kuwayama & Brozovic, In Press). The variable was included in the models to test if producers were already considering stream depletion as a motivator for trade participation.

Owner/Operator Descriptive Statistics

According to 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. 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.

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

[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.

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.

Among unique operators, 53% participated in the pooling process while 50% of the unique owners participated in pools. These significantly higher participation rates for informal trades within pools leads to the hypothesis that there is demand for formal trading, but current rules and procedures are limiting the participation level.

Usage Trends

We examined usage trends in each county and in the entire district to determine if the current allocation restrictions were binding[2]. Looking at overall trends of usage plotted in Figure A.4 in the Appendix, usage appears to fluctuate around a mean of approximately 11 inches in the period 1980-1999. From 2000-2003 the average usage jumped up significantly; 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.

Methodology

The primary goal of our research is to determine who participates in trades, and what factors determine if an individual is a buyer or a seller. To do this we create two different types of models: a trade participation model and a trade direction model. Each type of model is applied to both formal and informal trades. The entire sample of fields was used in the participation models while only trade participants are included in the trade direction models. Two sets of models are estimated for informal trades. This is motivated by a change in the pool naming

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[2]More detailed information regarding the exploration of usage trends is available. See Juchems, E. M. (2013). *Predicting groundwater trading participation in the Upper Republican River Natural Resource District*. (Master's thesis).

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 are summarized in Table 1 with descriptive statistics presented in Table A.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 choice of variables to include 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.

Table 1: 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

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 reach 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 with positive water use (i.e., fallow years are not included). This allows the variable to be continuous between zero and one. 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 URNRD ownership 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 have positive coefficients in the trade direction estimates. This expectation is based on interviews with producers in the URNRD. Producers 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. The URNRD has not passed, but is considering rules to require trades to be adjusted by SDF. With such rules we would expect a positive coefficient. While these rules have not been approved yet, net streamflow depletion has been a concern since 2002. Thus we expect that even without a formal rule, SDF may have a positive sign, indicating that water is moving away from high stream depletion wells to those that have less of an impact on streamflow.

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.

Testing for Heterogeneity among Pools

To test if constrained pools behaved the same as unconstrained pools the data was divided and coefficients tested using the hypothesis that the coefficients were the same across groups. 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.

In the 2005 - 2007 allocation period, 552 fields were members of a constrained pool while 1,422 were members of unconstrained pools. In the 2008-2012 allocation period, only 247 fields were members of a constrained pool, leaving 1,667 in unconstrained pools. Using the method developed by Allison (1999) we test the coefficients on the models to determine if there are systematic differences between the constrained and unconstrained pools or if we are able to combine them in our analysis. The results indicate that constrained pools behave similar to unconstrained pools and the data can be grouped together for one model. Descriptive statistics for the variables in each of the six final models are listed in the Table 3.11 in the appendix.

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).

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.

Model 1: 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:

(3) $P(Trade = 1) = G(\alpha + \beta_1$*acres + β_2* useavg12 + β_3*percorn12 +

β_4* ownop + β_5*opsize + β_6* medium + β_7*coarse + β_8*unksoil+ β_9*Perkins +

β_{10}*Dundy + β_{11}*gpm + β_{12}*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. During the most recent allocation period, 1,914 of the 3,179 observations participated in pools. The marginal effects, which provide the most interpretational power, are available in Table 2. 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 model exhibits similar results of coefficient signs and significance as the previous allocation period model[3], but this paper will focus primarily on the most recent allocation period.

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

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[3] The results of the earlier allocation period are available in Juchems, E. M. (2013). *Predicting groundwater trading participation in the Upper Republican River Natural Resource District*. (Master's thesis).

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. 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 0.34%. 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 10.4% more likely to participate and fields with coarse soil-types are 13.6% 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 negative coefficients are consistent with the fact that the majority of fields eligible for pooling are located 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 coefficient on 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 0.04%. 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.

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 weak 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. The model correctly identifies 2,140 of the 3,170 observations, or 67.3 percent. 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 2: Marginal Effect Estimates for Model 1.

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			

Model 2: Informal Trade Direction 2008-2012

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

$$(4)\ P(Seller = 1) = G(\alpha + \beta_1 {*} acres + \beta_2 {*}\ useavg07 + \beta_3 {*} percorn07 + \beta_4 {*} medium + \beta_5 {*}\ coarse + \beta_6 {*}\ unksoil + \beta_7 {*}\ transfersize + \beta_8 {*}\ MAC2 + \beta_9 {*}\ constr + \beta_{10} {*} (MAC2 {*} Constr)\ )$$

For those fields that participated in pools during the 2008-2012 allocation period, there are 945 informal sellers and 969 informal buyers. The marginal effects are presented in Table 3. The model focused on those variables that are unique to the field to better model the decision process faced by the producer.[4].

[4] The analysis that uses data from the 2005-2007 period has similar coefficient signs and significance levels. The results are available in Juchems, E. M. (2013). *Predicting groundwater trading participation in the Upper Republican River Natural Resource District*. (Master's thesis).

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.

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 10.6% 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 7.3% 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 4.3% more likely to be a seller, which is once again consistent with the convexity of the curves. 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, and 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 3: Marginal Effect Estimates for Model 2.

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			

Model 3: Formal Trade Participation

The previous models examined trade behavior in informal trades within an existing pool. These trades have close to zero transaction costs. In contrast, formal trades have high transaction costs and we are interested in determining if the behavior from Models (1) and (2) can also be observed with formal trades. The model applied to the formal trade participation for the permanent transfers of groundwater is as follows:

$$(5)\ P(Trade = 1) = G(\alpha + \beta_1*acres + \beta_2*useavg12 + \beta_3*percorn12 + \beta_4*ownop + \beta_5*opsize + \beta_6*medium + \beta_7*coarse + \beta_8*unksoil + \beta_9*Perkins + \beta_{10}*Dundy + \beta_{11}*gpm + \beta_{12}*pwl)$$

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 marginal effects are presented in Table 4. 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: Marginal Effect Estimates for Model 3.

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			

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 marginal effects can be found in Table 5. 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 5: 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			

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 a unique set of data from a region where groundwater is constrained and monitored to analyze the factors that predict the probability of participating in formal and informal trades, as well as the direction of trade among participants. The participation models use field-level variables and provide insight into the participation decision process. The trade direction models relied on some of the same factors, but also those factors that are unique to the field and trade.

The results of the model support our previous trading behavior hypotheses 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 differences in the constrained and unconstrained populations.

A major constraint to the formal trade estimation is limited data on formal participation, resulting in a 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 significant in nearly every model. As explained in much of the literature on water markets, there are specific components are necessary for a groundwater market to exist. These include the installation of meters to record 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 are significant in predicting 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 appropriate 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). In future work we plan to use 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

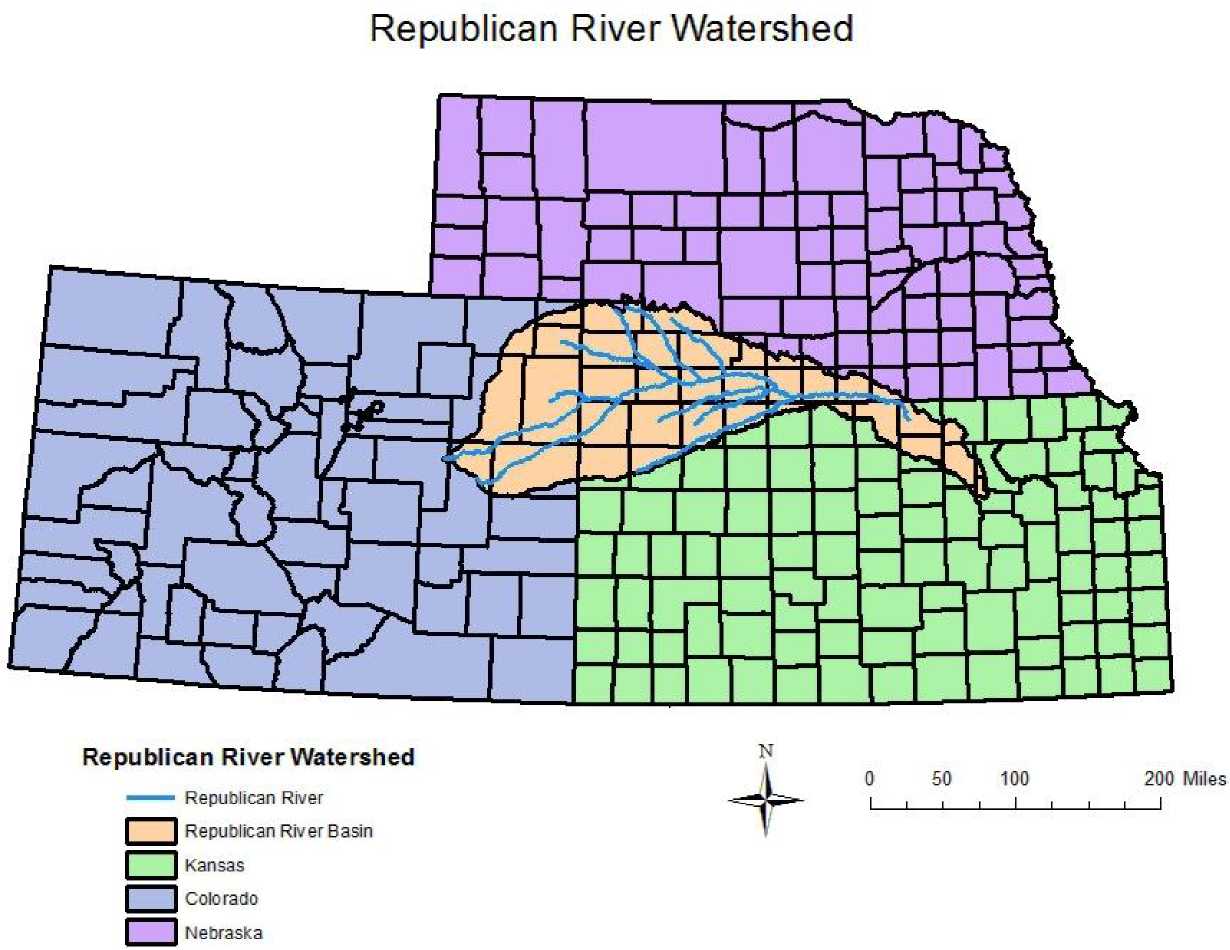

Figure A.1 Map of Republican River Watershed.

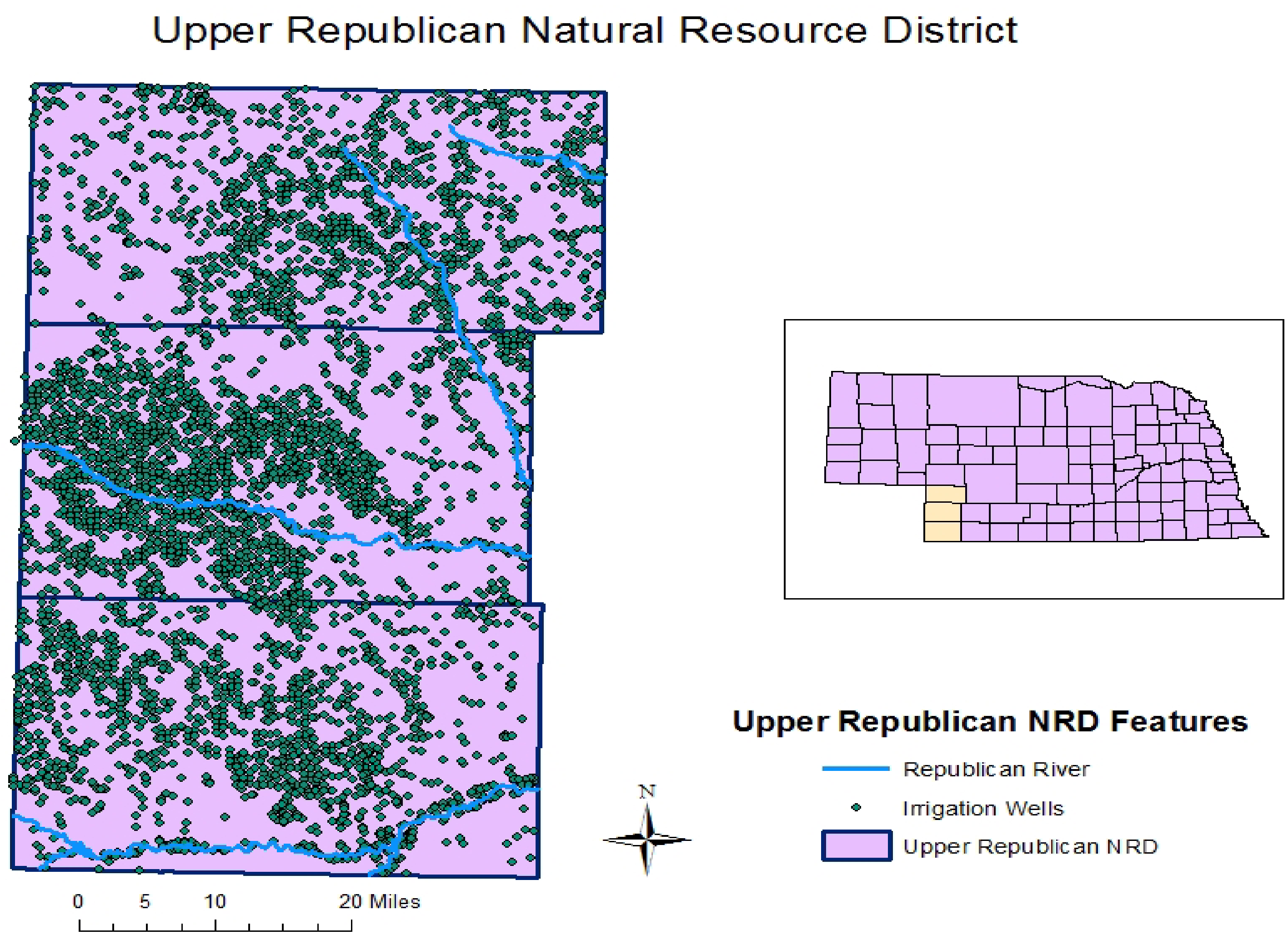

Figure A.2 Map of Upper Republican Natural Resource District.

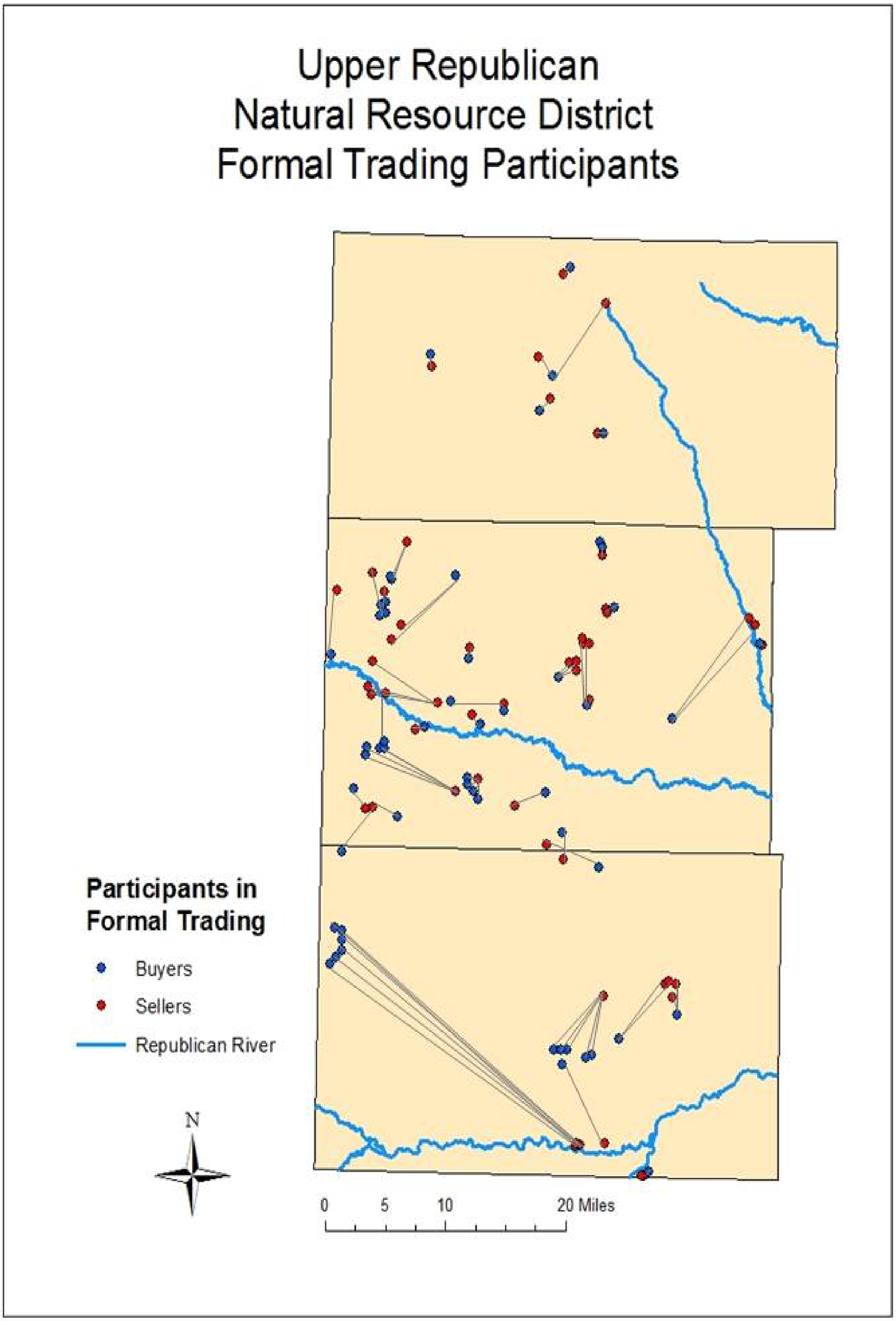

Figure A.3 Map of Wells Participating in Formal Trades.

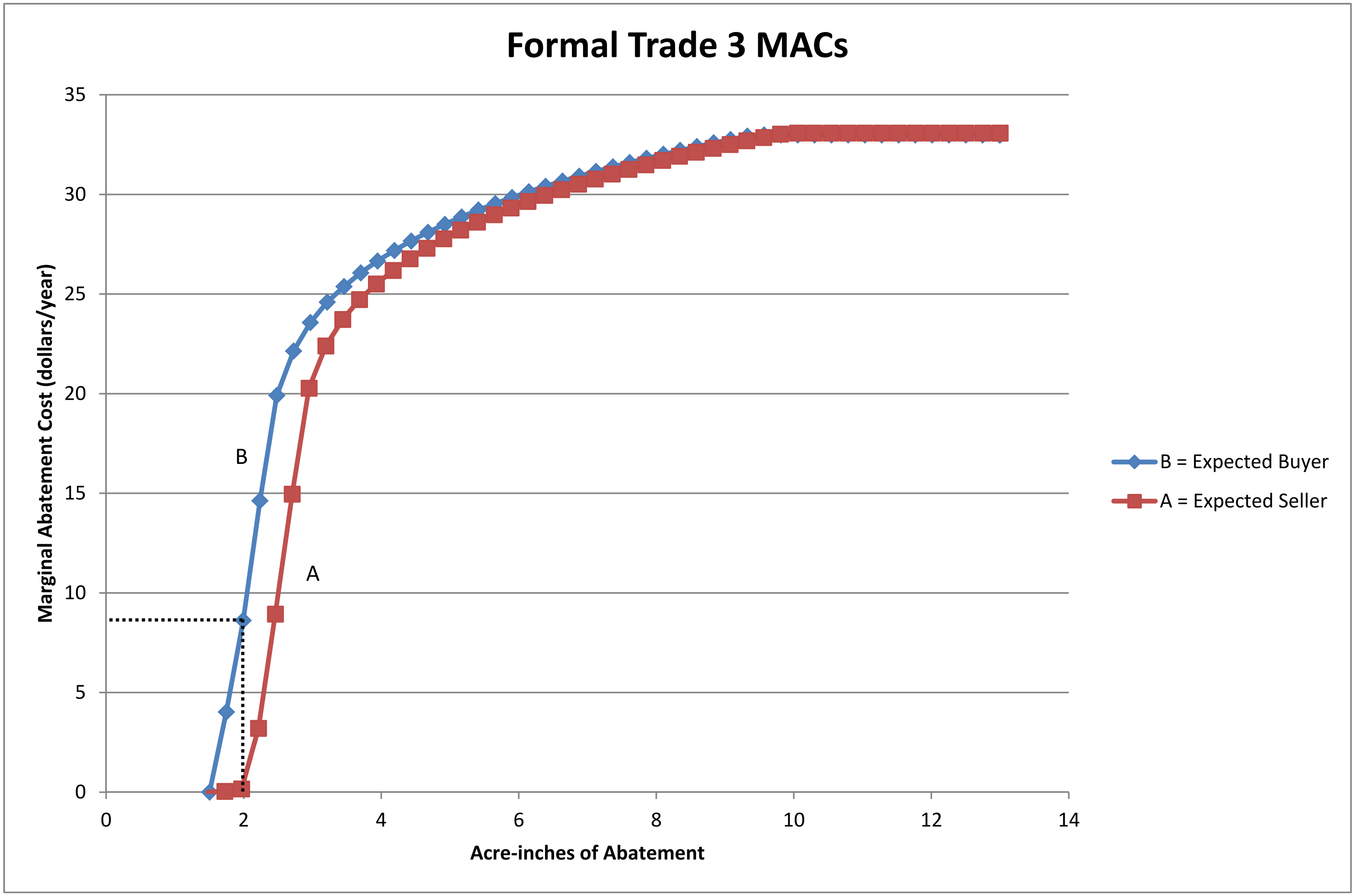

Figure A.4 Marginal Abatement Cost Curve Plot for Formal Trade 3.

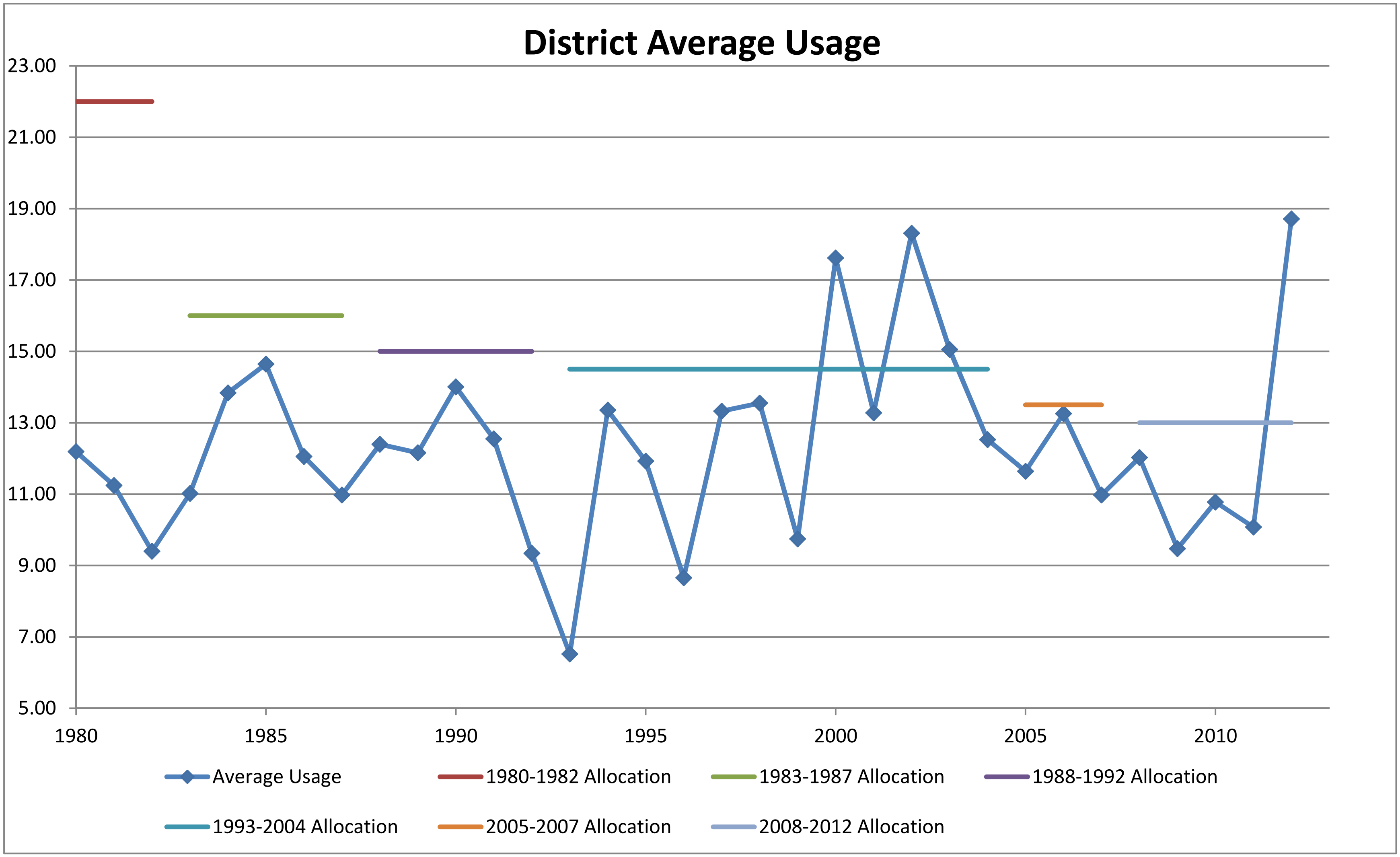

Figure A.4 District Average Use and Allocation Limits.

Table A.1 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