12-2017

The Impact of Groundwater and Well Characteristics on Irrigator Energy Contract Choice

Taylor Hackbart

University of Nebraska-Lincoln, thackbart@hotmail.com

The Impact of Groundwater and Well Characteristics on Irrigator Energy Contract Choice

By

Taylor Hackbart

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Agricultural Economics

Under the Supervision of Professor Karina Schoengold and Taro Mieno

Lincoln, Nebraska

December 2017

The Impact of Groundwater and Well Characteristics on Irrigator Energy Contract Choice

Taylor Hackbart, M.S.
University of Nebraska, 2017

Advisor: Karina Schoengold, and Taro Mieno

The thesis uses cross sectional data from the year 2009 to analyze irrigator choice of electricity contract. The data includes irrigators from the Midwest Electric Cooperative Corporation (MECC), which covers portions of three of Nebraska's Natural Resource Districts (the Middle Republican, Twin Platte, and Upper Republican NRDs). Each of these institutions tries to reduce the pressure its users place on limited natural resources.

To accomplish this the MECC has established interruptible contracts with irrigators. These contracts allow the MECC to control the electricity supply for an irrigator's well for a pre-determined number of days, which allows it to better manage stress on the electricity grid. In return, the MECC provides a discount on the irrigator's electricity charge. For the NRDs, groundwater allocation limits are used to restrict the amount of water an irrigator can use. However, if interruptible electricity contracts increase the amount of water an irrigator extracts, these policies may not jointly be as effective as possible. Determining if this is the case requires an understanding of how an irrigator chooses his/her electricity contract. The objective of this study is to determine which factors affect an irrigator's choice of contract, and how those factors are correlated with water and energy use. If these interruptible contracts conflict with the goals of either institution, policy changes could help to achieve agency goals.

Results show that well yield (defined as well capacity in gallons per minute) is positively associated with total water use and uncorrelated with total energy use, and that

soil quality significantly affects both outcomes. A multinomial logistic regression is used to determine what factors affect an irrigator's contract choice. We then use the results of the model to predict contract choice. Results show that irrigators with a low well yield (defined as gallons per minute of capacity) and a low water holding capacity in the soil are less likely to select interruptible energy supply contracts.

ACKNOWLEDGEMENTS

I would like to thank both my advisors for everything they have helped me with over the last few years. I really appreciate the guidance and patience they have given me. Your confidence in my abilities has been invaluable. Dr. Schoengold, I very much appreciate the opportunity to assist you during my time in graduate school. The experience I obtained during my assistantship will help me for years to come. Dr. Mieno, thank you for all your assistance, especially for the introduction into coding. I would also like to thank Dr. Fulginiti. Without your belief in me as an undergraduate, I may not have considered graduate school.

Finally I would like to thank my family. The confidence my parents have had in me has helped me achieve more than I ever believed I could. Thank you for always believing in me and pushing me to never quit. I would also like to thank my brothers. Though we don’t always get along, you have pushed me to always do my best. To all of my extended family, I appreciate the support and words of encouragement over the many years.

This work was also supported by the USDA National Institute of Food and Agriculture, Hatch project 1006120.

Table of Contents

CHAPTER 1: INTRODUCTION

The role of water and energy in agriculture is vital to the success of a producer. When managed appropriately, these inputs aid in the production of greater yields. Another benefit from proper management is maintaining a quality environment for future production. These yields have produced the greatest abundance of agricultural products in the world. With food security becoming critical in areas of the world, the agricultural sector must create greater yields to meet these demands. In order to meet this demand inputs are being consumed in greater quantities, creating issues with the environment.

Agriculture relies on inputs such as nutrients, sunlight, air, and water to grow. Irrigation has existed for thousands of years. It has mostly come from surface water, which is unreliable. Rainfall is sporadic in areas, and environmental hazards make water security difficult to manage. From then up until the Industrial Revolution, producers relied on water collected in lakes, streams, rivers, and from rainfall. Surface water security is inconsistent though, as it's dependent on the weather. This causes big swings in the wellbeing of producers; as one year large amounts of rainfall could occur, and the next a drought, decreasing crop yield. Producers could over-invest on inputs for that year, and then find themselves falling very short financially the following year.

In order to increase their water security, groundwater users utilize mechanical pumps to obtain greater amounts of water. This method though uses large amounts of water, and a fair portion of it is lost to runoff and evaporation (Perlman, 2016). In the late 1940's, the first center pivots were developed to distribute groundwater more precisely (Ganzel, 2006). These systems, widely used by groundwater users, can provide water directly to the point of absorption for crops. This improves the efficiency of water application, as less water is absorbed by the soil and atmosphere. From then on the technology has evolved to where it is today, with drip irrigation being the next improvement in efficiency.

Basic economic theory tells us that an irrigator should add an input until the input's effect on yield is less than the cost for said input. In Economic terms, the irrigator should add an input until the marginal effect equals the marginal cost. Producers do not always efficiently apply their inputs. Over application of inputs can lead to nutrients leeching into the water table, eutrophication of surface water from nutrient runoff, increased production costs, depletion of the local aquifer, and greater energy grid stress. These issues diminish future yields, by deteriorating the natural inputs required to grow crops.

This mismanagement increases costs to everyone who relies on these inputs, not only agricultural producers. Areas, such as southwestern Nebraska, deal with these ground water use problems on a daily basis. For a time the Republican River Basin has overexploited their water resources, creating shortages downstream. To ensure shortages do not happen in the future, the Republican River Basin Compact (RRC) was modified to ensure that there is enough water downstream. Due to irrigator's overexploitation, they now have legal requirements to meet for future uses. Though this compact directly regulates surface water quantities, the overexploitation of groundwater along the basin has resulted in stream depletion.

This study analyzes how the electrical contract structure, as well as environmental and well properties factor into Irrigator's choice of electrical contract. There are a few other studies that examine the interactions between groundwater and electricity contract structure. This study is unique though as it analyzes a different region, with different policies, and different rate structures. This analysis may be important to multiple entities as these resources are critical to many. The most obvious entities are the three NRDs, the MECC, irrigators, as well as tax payers.

This analysis may find that irrigators are selecting contracts that lead to them to use more water (and energy) than necessary. Groundwater use might increase based on contract selection. This increase interferes with the goals of the NRDs, and also could create an issue for the state, as the mismanagement of water could lead to violation of the RRC.

1.1 Objective

The objective of this study is to analyze how a number of characteristics including soil type, the energy contract structure, the soil's holding capacity, and the charge applied per horsepower for a given well affected the irrigator's choice of energy contract in 2009. This analysis utilized the mlogit package in R to analyze the models. After running the regression, we then tested the predictability of our model. This gave us some insight to how sufficient our model was. The resulting analysis allows us to better understand what is significant to irrigators when agreeing on energy contracts. From the regression we could also determine the successfulness of the energy contracts in meeting the MECC's goals.

1.2 Organization

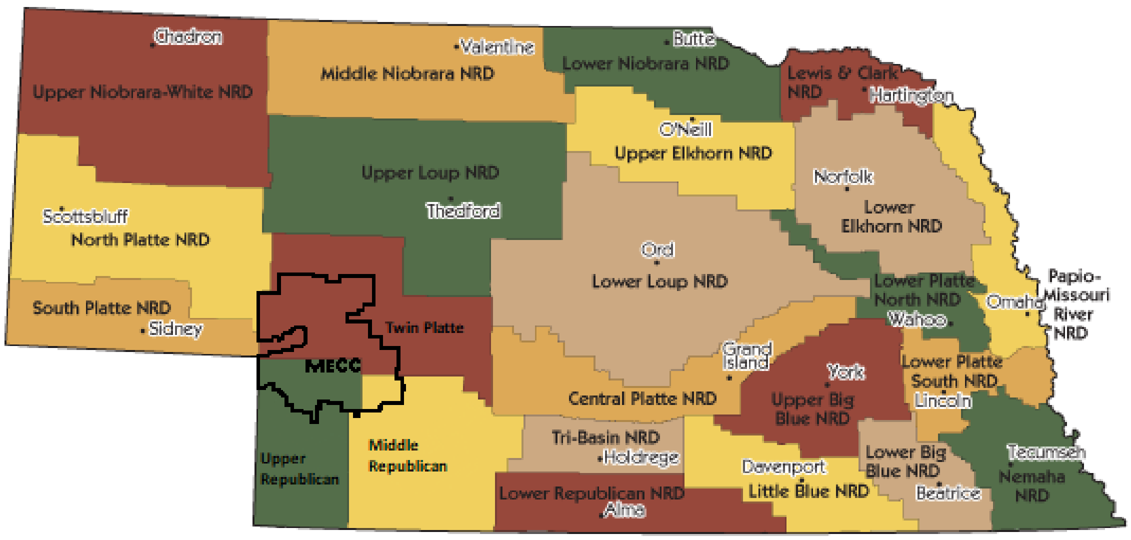
This thesis has been organized as follows: Chapter 1 establishes the objective of this thesis, presents the relevant background material, and certifies the significance of the study. Chapter 2 explores the previous literature on the subject. Chapter 3 presents the data, the model, and the methods to the thesis. Chapter 4 displays the results from the model, as well as the prediction capabilities. Chapter 5 discusses the implications of the results, and the improvements that could be made. Chapter 6 wraps up the thesis, and iterates conclusions that can be made.

1.3 Background

The area of focus for this study was the southwest region of Nebraska, bordering Colorado and Kansas. Specifically the cross sectional area shared by three NRDs, and one PPD. The dataset consists of parameters from the year 2009. The three NRDs include the Middle Republican Natural Resource District (MRNRD), the Twin Platte Natural Resource District (TPNRD), and the Upper Republican Natural Resource District (URNRD). The Midwest Electric Cooperative Corporation (MECC) is the PPD included.

The NRDs were established in 1972 to better manage groundwater in the state. Previously, groundwater was regulated by the counties, or not at all. This made it difficult for watersheds which crossed county lines to be managed properly. The NRD system, unique to Nebraska, originally established 24 districts to oversee the use and quality of groundwater in the state. The borders of each district were created using watershed boundaries, which is why many NRDs are named after major hydrological features in the area. Later in 1989, the Middle Missouri NRD merged with the Papio NRD to create the Papio-Missouri NRD (Jenkins, 2009), creating the current system of 23 NRDs.

Image 1: Locational Guide to All Four Districts



The NRDs oversee the use and quality of the groundwater in their respective district. Issues each NRD manages include run-off from irrigation, flood control, soil erosion, nutrient leeching, groundwater depletion, and many more. Each NRD has a board that determines any policy intervention that is needed. The board members are elected by those who reside in the NRD. The majority of NRD funding is raised through local taxes, with smaller portions of funding coming from the State or Federal level.

Middle Republican Natural Resource District (MRNRD)

The MRNRD is the furthest east NRD of the study area. The NRD borders Kansas to the south, the URNRD to the west, and the TPNRD covers its northern border.

The MRNRD is comprised of all of Hayes, Hitchcock, Red Willow, as well as portions of Frontier, and Lincoln Counties. The major river in the MRNRD is the Republican, which crosses west to the east. The average rainfall was 28 inches per year from 2007-2010 (Brown and Caldwell, 2013). Only 46% of the land is used for agriculture, while majority of it is considered rangeland (MRNRD, 2017).

For 2009, the MRNRD‘s portion of the study includes 97 irrigators, who operate 246 wells. Irrigators applied an average of 10.61 acre-inches (ai) per acre, with 33,769 total acres in production. The MRNRD has the lowest average water content of the three NRDs, with an average of 21.87%. This low water content means that access to water is more difficult compared to the other NRDs. Table 1 provides more summary statistics on the land and the well properties of the MRNRD.

Table 1: Characteristics of Irrigators in each of the Natural Resource Districts

		MRNRD	URNRD
Number of Irrigators		97	305
Number of Wells		246	629
Acreage	**Average:**	137.27	147.29
	Minimum:	54	64
	Maximum:	300	498.9
Water Use (ai)	**Average:**	10.61	9.70
	Minimum:	0.21	0.39
	Maximum:	34.57	30.66
Energy Use (kWh)	**Average:**	57,684.77	67,598
	Minimum:	1,520	4,000
	Maximum:	220,320	264,600
Horsepower	**Average:**	98.71	114.77
	Minimum:	41.50	51.70
	Maximum:	254.50	367.40
Well Yield (gpm)	**Average:**	874.59	798.80
	Minimum:	453.80	88.01
	Maximum:	1,891.90	2,317
Sand Composition	**Minimum:**	11.04%	12.36%
	Maximum:	95.52%	92.80%
Clay Composition	**Minimum:**	2.14%	3.09%
	Maximum:	24.63%	33.09%
Average Water Content	**Average:**	21.87%	32.80%
	Minimum:	7.27%	8.81%
	Maximum:	49.98%	54.70%

Note: The table includes soil, water, and energy characteristics in the study region; The table also excludes TPNRD, due to confidentiality concerns.

One policy approach to control groundwater use is to implement an allocation. An allocation sets a limit to how much water a producer can use over so many years. For example, in 2008 the MRNRD instituted a ground water allocation of up to 60 ai over the following five years. The resulting annualized allocation was 12 ai. Other policy restrictions in the MRNRD include restrictions on new well development, transfers, and pooling.

Twin Platte Natural Resource District (TPNRD)

The Twin Platte NRD covers the northern borders of both the MRNRD and the URNRD. The TPNRD includes portions of Arthur, Keith, Lincoln, and McPherson Counties. The TPNRD itself includes the largest body of water in Nebraska, Lake McConaughy. The North and South Platte River also merge together within the TPNRD. The average annual precipitation amount is 16 to 24 inches per year (NOAA). Majority of the land is agriculture and rangeland (TPNRD, 2016). Individual summary statistics for the TPNRD are not included due to confidentiality issues

Though the TPNRD has seen the depletion of groundwater through the years, groundwater restrictions have not been instituted. Since a large part of the TPNRD's area uses surface water, efforts are focused on protecting surface water instead. The TPNRD, like the other two NRDs, faces stream depletion issues. The Platte River basin contains a number of species included in the Endangered Species Act. As the use of irrigation expanded in the area, stream flows decreased creating problems for these species. For this reason water issues in the area are focused primarily on surface water policy.

Upper Republican Natural Resource District (URNRD)

The URNRD borders the TPNRD, MRNRD, Kansas, and Colorado, in the southwestern corner of Nebraska and includes Chase, Dundy, and Perkins counties. The major waterways include the Republican River in the south and its tributaries throughout the northern portion of the URNRD. The average amount of precipitation is about 17 to 20 inches a year (URNRD, 2017). Half of the land in the URNRD is rangeland, while a quarter of the land is irrigated crop land.

For the URNRD and MECC cross section, the URNRD oversaw the regulation of 629 wells, covering 92,648 total acres. 305 irrigators applied an average of 9.7 ai, which is the fewest of the three NRDs in the study. While producers in the Upper Republican applied less water than the other NRDs, they also operated larger field sizes. Table 1 includes complete summary statistics for the URNRD.

Since 1979, all irrigation wells in the URNRD are required to have a flow meter installed to record water use. In 1980 the URNRD set allocation limits on irrigation wells. Over the years these allocations have varied from 22 to 13 ai. For the year of 2009, the allocation for the URNRD was set at 65 ai over five years starting in 2008 and concluding in 2012. In 1997 irrigated acres was capped by the URNRD, preventing the expansion of any new irrigated acres. This policy limits irrigator’s use of groundwater, and is the final cap on water usage.

Midwest Electric Cooperative Corporation (MECC)

The overlaying PPD in this analysis is the Midwest Electric Cooperative Corporation (MECC). The MECC covers portions of the three NRDs. Image 1 shows the approximate location of the MECC. For 2009 the MECC supplied electricity to 404 irrigators. These irrigators used this electricity to operate a total of 878 wells. 57.05 GWh was generated to supply these wells with electricity. Table 2 summarizes a few more statistics from 2009.

Table 2: PPD Summary Statistics for 2009

kWh Supplied to Ag	57,047,391 kWh
Average kWh Supplied to Ag	64,974.25 kWh
Average Well Horsepower	106.9276 hp
Average Well Yield	785.2581 gpm

One of the main issues PPDs face is the stress management on the electrical grid. Electricity powered wells consume a lot of energy due to the effort it takes to move water and the geographical distance from generation to well. In rural areas, this puts a large stress on electrical grids that, if not managed properly, could cause blackouts and other damages. Not only do wells require a lot of energy, but they require it for a long amount of time. This causes large influxes in electricity demand throughout the day for a PPD.

To combat these influxes, PPDs have created special contracts. These contracts, which are agreed upon by irrigators, allow the PPD to halt irrigator’s electricity supply. These types of contracts are known as interruptible contracts. In return for control, the PPD provides an economic incentive to irrigators. The PPD offers multiple contracts with varying days of control. The greater the number of control days, the lower the charge applied per horsepower. The contract structure offered by the MECC in 2009 is in Table 3.

Table 3: Midwest Electric Cooperative Corporation

On-Peak months are August and July, off-Peak months are all other months

Rate 28: No control off-peak months, one day per week control on-peak months			
Facility charge		$ 3.00	* hp
+	**Demand charge for use in off-peak**	$ 8.40	* hp
+	**Demand charge for use in on-peak**	$10.70	* hp
+	**For first 100 kWh/kW**	$ 0.059	* kWh
+	**Remaining over 100kWh/kW**	$ 0.045	* kWh
Rate 29: No control off-peak months, two day per week control on-peak months			
Facility charge		$ 3.00	* hp
+	**Demand charge for use in off-peak**	$ 8.40	* hp
+	**Demand charge for use in on-peak**	$ 8.80	* hp
+	**For first 100 kWh/kW**	$ 0.059	* kWh
+	**Remaining over 100kWh/kW**	$ 0.045	* kWh
Rate 30: No control			
Facility charge		$ 3.00	* hp
+	**Demand charge for use in off-peak**	$ 8.40	* hp
+	**Demand charge for use in on-peak**	$12.60	* hp
+	**For first 100 kWh/kW**	$ 0.059	* kWh
+	**Remaining over 100kWh/kW**	$ 0.045	* kWh
Rate 34: three day per week control off-peak months, No control on-peak months			
Facility charge		$ 3.00	* hp
+	**Demand charge for use in off-peak**	$ 4.65	* hp
+	**Demand charge for use in on-peak**	$12.60	* hp
+	**For first 100 kWh/kW**	$ 0.059	* kWh
+	**Remaining over 100kWh/kW**	$ 0.045	* kWh
Rate 35: three day per week control off-peak months, one day per week control on-peak months			
Facility charge		$ 3.00	* hp
+	**Demand charge for use in off-peak**	$ 4.65	* hp
+	**Demand charge for use in on-peak**	$10.70	* hp
+	**For first 100 kWh/kW**	$ 0.059	* kWh

+	**Remaining over 100kWh/kW**	$ 0.045	* kWh
Rate 36: three day per week control off-peak months, two day per week control on-peak months			
Facility charge		$ 3.00	* hp
+	**Demand charge for use in off-peak**	$ 4.65	* hp
+	**Demand charge for use in on-peak**	$ 8.80	* hp
+	**For first 100 kWh/kW**	$ 0.059	* kWh
+	**Remaining over 100kWh/kW**	$ 0.045	* kWh
Rate 37: Every day control off-peak months, no control on-peak months			
Facility charge		$ 3.00	* hp
+	**Demand charge for use in off-peak**	$ 0.90	* hp
+	**Demand charge for use in on-peak**	$12.60	* hp
+	**For first 100 kWh/kW**	$ 0.059	* kWh
+	**Remaining over 100kWh/kW**	$ 0.045	* kWh
Rate 38: Every day control off-peak months, one day per week control on-peak months			
Facility charge		$ 3.00	* hp
+	**Demand charge for use in off-peak**	$ 0.90	* hp
+	**Demand charge for use in on-peak**	$10.70	* hp
+	**For first 100 kWh/kW**	$ 0.059	* kWh
+	**Remaining over 100kWh/kW**	$ 0.045	* kWh
Rate 39: Every day control off-peak months, two day per week control on-peak months			
Facility charge		$ 3.00	* hp
+	**Demand charge for use in off-peak**	$ 0.90	* hp
+	**Demand charge for use in on-peak**	$ 8.80	* hp
+	**For first 100 kWh/kW**	$ 0.059	* kWh
+	**Remaining over 100kWh/kW**	$ 0.045	* kWh

* Rate structure from (MECC, 2016)
* Contracts 31, 32, and 33 were excluded because they use a different structure and there is only 12 observation

1.4 Significance

Almost everyone in Nebraska depends on groundwater in some capacity, and the current work will provide a better understanding of the interactions between groundwater irrigation and electricity usage. Annual precipitation in the region ranges from 16 to 28 inches. According to the University of Nebraska – Lincoln, corn in southwest Nebraska requires about 28 inches of water per year (rainfall or irrigation). This means that irrigation must provide crops with anywhere from 0 to 12 inches of water per year in an average year (Kranz, 2008). Since the crop cannot use 100 percent of applied water, more than this must be applied. With a consistent shortage of rainfall, a large depletion of the aquifer could result.

This issue is exacerbated with inconsistent weather, which creates uncertainty in the timing and quantity of precipitation. Uncertainty of drought can cause irrigators to over irrigate as well. However, one factor that may affect water application is the energy contract choice. A contract that limits electricity to manage demands on the grid may encourage irrigators to apply more water, when they can (Mieno, 2014). If this is the case, there may be benefit from the NRDs and PPD jointly determining contract structures.

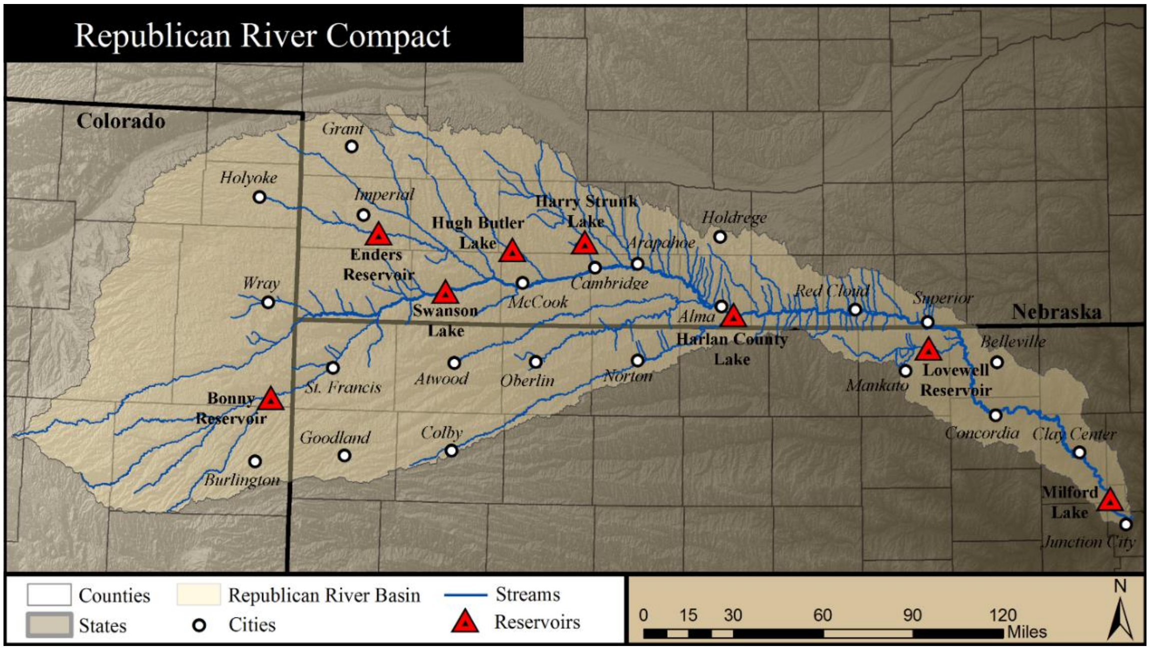
For example, an irrigator may agree to contract 39 (see Table 3). This contract allows the PPD to shut off electricity to the well for two days a week in the on-peak months and seven days a week in the off-peak months. Contract 39 also offers the greatest payoff for control, with a break of $3.80 per kWh in the off-peak season, and $7.50 per kWh in the on-peak season. In theory, the irrigator could still pump the same amount of water as with no control. In order to do this though, they will have fewer days to pump. This would result in irrigators applying water for longer periods of time.

The issue with this situation is that if rainfall occurs later in the week, an irrigator may have applied more water than necessary. The over application of water causes multiple problems such as eutrophication, nutrient leeching, and increased water loss to evapotranspiration. Further adding to the problem, the irrigator may try to compensate for the increased evapotranspiration and add more water. For areas that are not in allocation, such as the TPNRD, this increase in water consumption could cause further over application issues.

The other issue these contracts might create relates to the cost of water. The price of water, especially in agriculture, is essentially the cost to pump it out of the ground. Therefore by lowering the cost of electricity to pump the water, the irrigator has a lower input cost of water. If the marginal cost of water is reduced, the economically optimal decision is to pump more groundwater. This is more likely to be an issue in areas where there is no allocation, such as the TPNRD.

If the results indicate that the contract structure promotes an increase in water usage, policy changes may need to occur for the NRDs to achieve their goals. The other issue both Republican NRDs face is the legal obligation to preserve stream flows in the Republican River. The RRC is an agreement between the state of Colorado, Nebraska, and Kansas to fairly distribute water along the Republican Basin. Image 2 depicts the extent of the RCC.

Image 2: Republican River Compact

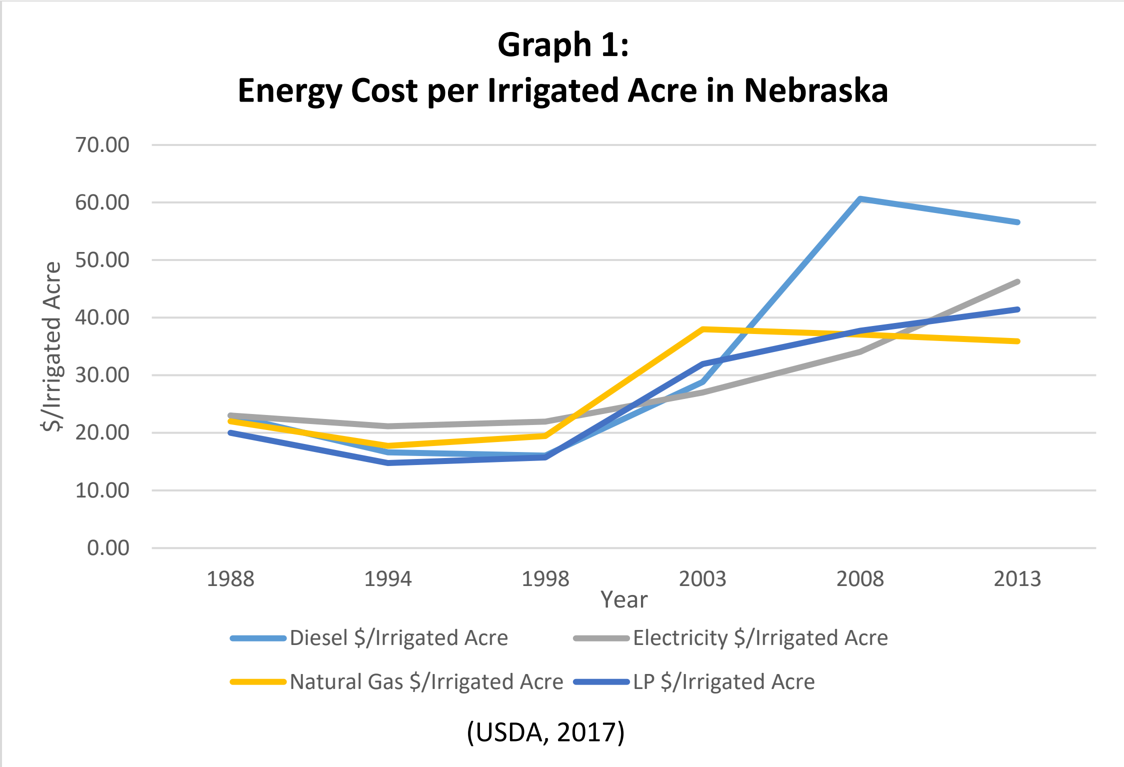


Though the Compact directly regulates surface water, groundwater use indirectly effects surface water levels. Therefore policies of the NRDs also effect the amount of water in this Basin. Because of the interstate compacts in the area of study, it is critical that the local entities manage their water appropriately. Without conservation the RRC may be violated, costing the state even more money than it already has.

The over application of water is also an overuse of electricity. This is an unnecessary stress to the grid which could be avoided with the proper management. As electricity demand increases in the PPD, the MECC may elect to build new generation facilities when all that is needed is better management of current supply. The other issue is if a significant amount of irrigators choose the same days for irrigation. If this occurs, the PPD may be stuck with certain days that have great amounts of demand, and others that have the opposite. The management of this demand could be get complicated, thus increasing costs. The overall idea is the more electricity unnecessarily used, the more the PPD has to spend on demand management. Since irrigators are a part of the tax base, they will also shoulder some of the burden.

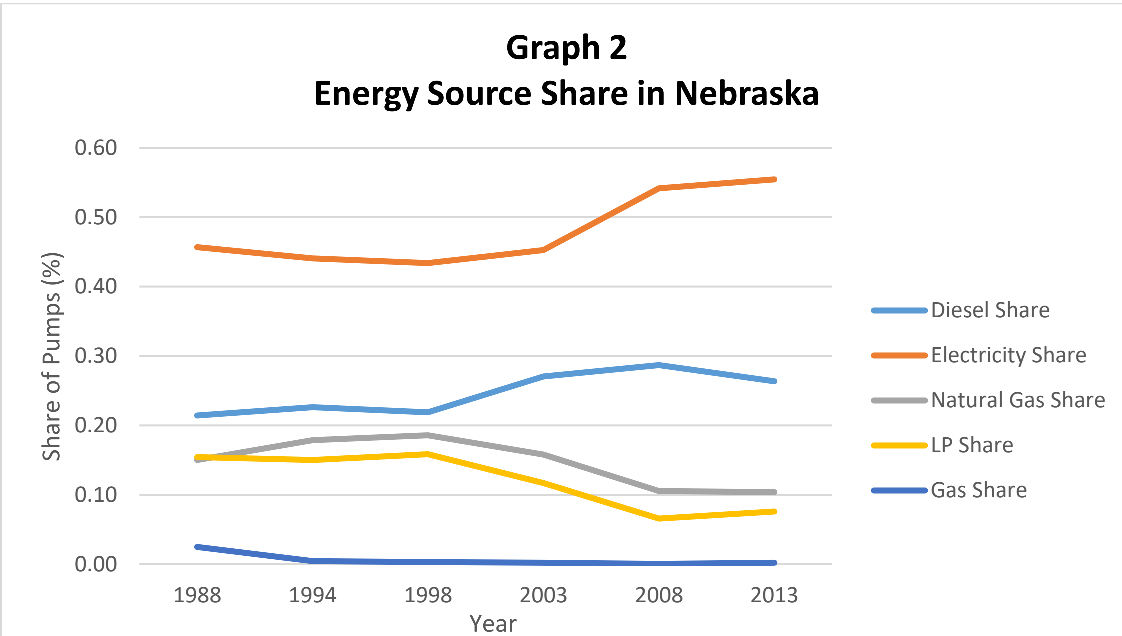
Many entities may find importance from this study, with the most obvious being the NRDs and PPD. The analysis may find that water and energy use increases depending on the electrical contract selected. This increase interferes with the goals of the NRDs, and could also violate the RRC.

Another issue that could arise relates to the irrigator's fuel choice. Energy supplied from a municipality has a number of benefits when compared to fossil fuels. The first benefit of municipal energy is cost volatility. Fossil fuel prices can spike as much as a few dollars a year. From January 29th 2007 to July 14th 2008, diesel prices increased from $2.41 per gallon to $4.76 per gallon (EIA, 2017). This difference of $2.35 per gallon occurred just over a year and a half. For irrigators using diesel, this time frame is too short for them to convert over to any other energy source. Graph 1 illustrates this sudden spike in diesel prices as dollars per irrigated acres.



Aside from avoiding the cost volatility of fossil fuels, energy from the municipals provide an ease of access to wells. Most pumps supplied with electricity from utilities offer the ability to remotely start and stop wells through the PPD. Electric pumps also have the ability to alter their yield, which alters energy consumption. Another benefit, is centralizing energy production can reduce greenhouse emissions. Due to economies of scale, large solar, wind, and hydro projects require a large input cost. This makes it nearly impossible for irrigators to construct their own energy supply. Since the Utilities in Nebraska are publicly owned, irrigators could persuade the PPDs to offset their increased use with renewable energy systems.

As the gap between the benefits of electricity and diesel increases, more irrigators are going to select energy from the utility. The issue at hand here is if this study finds that the energy contract structure is inducing a greater use of resources, then the substitution of diesel for electricity will exacerbate the issue. At this point both the NRD and PPD will want to revise their contract rate structure in order to manage the use of their respective resources. Every five years the census organizes the Farm and Ranch Irrigation Survey (FRIS), with the USDA. Using this survey the share of energy sources for wells can be determined. Graph 2 shows that this substitution effect is occurring.



(USDA, 2017)

From 2008 on, we can see that the share of electricity powered wells is increasing while the share of diesel powered wells is decreasing. The effect is small but with the next iteration of the FRIS, the magnitude of substitution would be better represented. Considering factors like technology, we would expect the gap to increase between the two shares.

CHAPTER 2: LITERATURE REVIEW

Most of the previous literature is focused on each resource individually. There has been extensive research on groundwater use, on many different levels of scale. Many studies have been done on the Republican River Basin, Ogallala aquifer, or the High Plains aquifer as well. Many of these studies have analyzed the impacts geophysical characteristics and or institutional groundwater policies have on water use. Few have included the interaction energy policies have on groundwater usage though.

2.1 Impacts of Electricity Interruption

As mentioned before, very few studies have been done on groundwater and energy usage together. Mieno and Brozović (2015) is one of the few pieces of work that does explore this relationship. In this study it was discovered that the more interruption days in an irrigator's contract, the more water they were using each time they irrigated. This lead to an increase in water usage, rather than a decrease. Irrigators were hedging against the possibility that they may not have access to water when they needed it. This phenomena of "use it or lose it" is rather prevalent throughout agriculture. This study though utilizes a different rate structure, which results in a different regression and outcomes.

2.2 Time of Use Rate Structure

As mentioned before, there are numerous types of rate structures. Train and Toyama (1989) highlight a rate structure where differing rates are applied depending on the time of day the use occurred. This rate structure happens to utilize three different periods throughout the day, off-peak, partial-peak, and on-peak. What Train and Toyama discovered is that as irrigators utilized the rate structure, irrigation shifted from the on-peak period to the off-peak period. This result is what they hypothesized, and aligned with the goal of the electrical municipality. Since the utility analyzed in their study is a private entity, an increase in revenue is also expected of the rate structure. This is the final part of their analysis, for which they found that the rate structure did increase the revenue earned. The daily time of use structure is what contrasts Train and Toyama's study from this one.

CHAPTER 3: DATA AND METHODS

3.1 Data

The cross sectional data for this analysis comes from a mixture of four sources. The data gathered started in 2006 and lasted until 2010. Water use in ai, energy use in kilowatt-hour (*kwh*), and hours the well ran was first collected from the United States Department of Agriculture (USDA) via the Soil and Water Resources Conservation Act (RCA). This act gives authority to the United States Department of Agriculture (USDA) to asses and protect soil, water, and agriculture related natural resources.

Soil characteristics such as the Average Water Content (*awc*), and the percentages of sand, silt, or clay present in the soil were then collected from the Soil Survey Geographic (SSURGO) database. This database is put together by the Natural Resources Conservation Service (NRCS), with the intention to track soil quality and type over time.

Well yield (*gpm*), and horsepower (*hp*) was gathered from the Nebraska Department of Natural Resources (DNR) in order to estimate the impact well yields have on contract choice. The DNR oversees the NRD system as well as handles surface water rights. The final piece of information gathered was the rate structure, which was gathered from the MECC. The MECC is a PPD located in southwestern Nebraska.

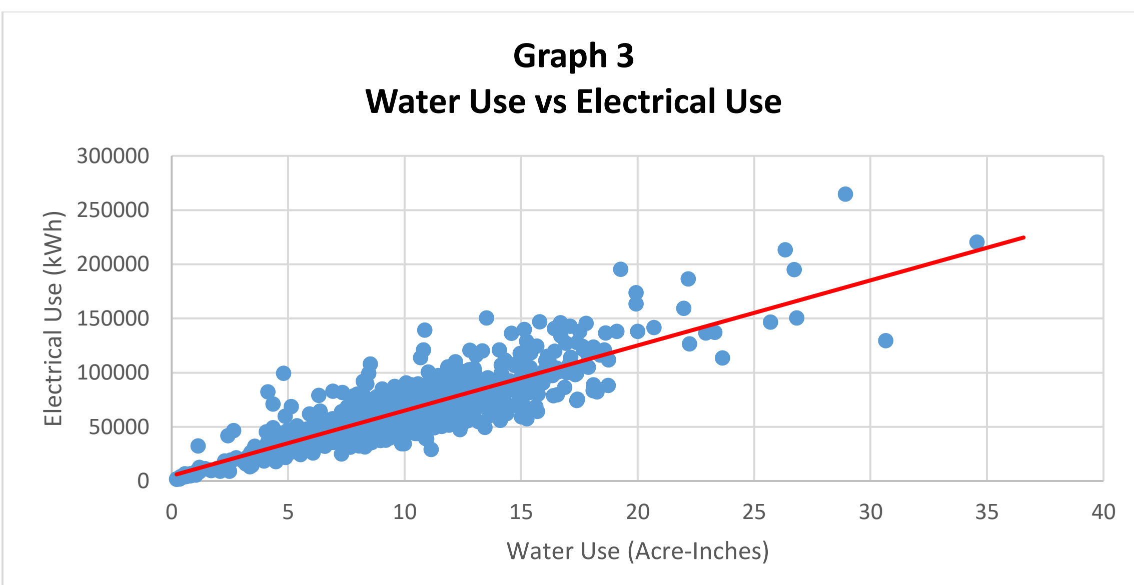
Within the data there are 878 wells managed by 404 irrigators. Each of the NRDs' descriptive statistics can be found again in Table 1. Since the goal is to examine these electricity contracts, the dataset only includes wells supplied with electricity. Therefore wells that are powered by natural gas, diesel, etc. are not included in the dataset. The dataset and code can be provided upon request. Table 4 compiles a list of variable definitions that are found throughout the regression.

Table 4: Variable Definitions

ai	Acre-inches applied from well
kwh	The kWh used by the well
acres	Acres the well services
hp	Horsepower of well
gpm	Well yield
hrs	Hours the well ran
awc	Average Water Content of the soil
MRNRD	Dummy variable for well NRD location; 1 in MRNRD, 0 not in MRNRD
TPNRD	Dummy variable for well NRD location; 1 in TPNRD, 0 not in TPNRD
URNRD	Dummy variable for well NRD location; 1 in URNRD, 0 not in URNRD
hp_charge_1	Charge applied per horsepower in the off-peak months
hp_charge_2	Charge applied per horsepower in the on-peak months
offpeak.control	Number of control days for contract in the off-peak months
onpeak.control	Number of control days for contract in the on-peak months
sand_pct	Percentage of sand in the soil
clay_pct	Percentage of clay in the soil
silt_pct	Percentage of silt in the soil
kv	Hydrologic conductivity of the soil

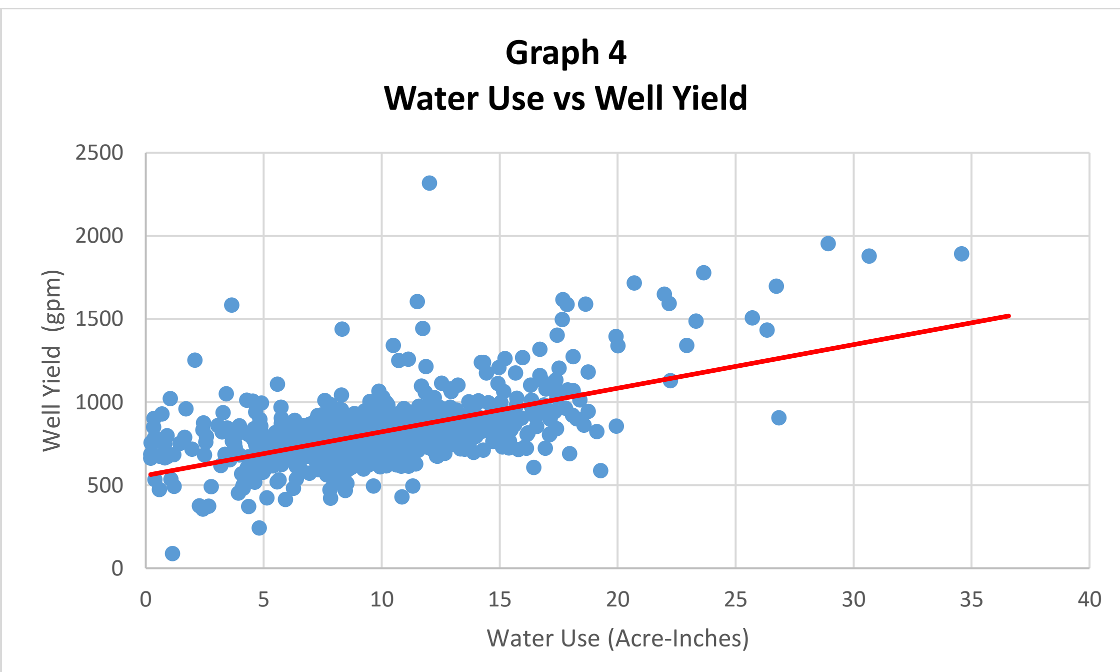
After the data was gathered, the individual datasets were merged based on the well id of the individual wells. If the irrigator was making decisions rationally, they know their well yield, energy usage, and water use over the years. Therefore after merging the datasets, the variables *gpm*, *kwh*, and ai were averaged individually from 2006 through 2008. The dataset then needed to be transformed in order to accompany the many different contract sources. This included the creation of the *hp_charge_1* and *hp_charge_2* terms, which were used to evaluate the effect the hp charge had in the on-peak and off-peak season.

One of our expectations is that energy use and water use should have a positive correlation. Therefore we expect an irrigator to only invest in more electricity if they foresee a return on their investment, such as more water. If this assumption does not hold, there would be a weak relation. This would cause issues within the regression, since the relation would be almost random between two variables important to the regression. Graph 3 presents water use in ai versus the energy use in kWh.



As you can see from Graph 3 the correlation among these two variables is rather linear. As mentioned before, we expect this result and was welcomed as it would cause issues otherwise. This means an irrigator does get a return on their investment. The other noteworthy point is that both water and energy use were within reasonable limits; as most of the water use ranged from 0 to 20 ai and energy use from 0 to 150,000 kWh.

Another expectation is that there should also be a relation between water use and well yield. Well yield increases are not accomplished by simply supplying the well with more energy, a new pump must be installed in order to accomplish this. An investment on the well is required for this, and in return there should be a payoff. The payoff for this investment is an increase in availability of water for irrigation. If there is no reward (water availability) for the risk (well investment), there is no economic reason an irrigator would take the risk. Graph 4 plots the water use of irrigators versus their well yield.



From Graph 4 we can see that there is a positive correlation between well yield and water use. Therefore, irrigators are receiving a reward for their investment into improving the well yield. This result leads us to examine the correlations between each of the other variables in greater depth. The correlation coefficient matrix between the variables in this study can be found in Table 5.

Table 5: Correlation Coefficients Matrix

	Water Use (ai)	Well Yield (gpm)	HP	Energy Use (kWh)	AWC (%)	Hours	Historical Water Use (ai)	Historical Energy Use (kWh)
Water Use (ai)	1	0.572	0.338	0.848	-0.154	0.806	0.864	0.628
Well Yield (gpm)	0.572	1	0.647	0.429	-0.066	0.023	0.628	0.440
HP	0.338	0.647	1	0.625	0.124	-0.021	0.476	0.763
Energy Use (kWh)	0.848	0.429	0.625	1	-0.030	0.739	0.777	0.868
AWC (%)	-0.154	-0.066	0.124	-0.030	1	-0.139	-0.118	0.031
Hours	0.806	0.023	-0.021	0.739	-0.139	1	0.597	0.468
Historical Water Use (ai)	0.864	0.649	0.476	0.777	-0.118	0.597	1	0.786
Historical Energy Use (kWh)	0.628	0.440	0.763	0.868	0.031	0.468	0.786	1

From past experience we established that 80% correlation would be the cutoff point where we could not rely on these variables to cause issues. From this table we could see that water use, energy use, and the hours are highly correlated with a correlation above 80%. This would create issues with the regressions. Because of this the regressions were adjusted to compensate for these high correlations. Other than these correlation issues, the rest of the variables have reasonable correlations.

The final pre-regression piece to be noted is the percentage of contracts chosen by the irrigators. The majority of irrigators selected contract 35, which made up 36.75% of contract selections. Looking at Table 5, this contract allows the MECC to interrupt the irrigator's electricity supply three days a week in the off-peak months and one day in the on-peak months. Contract 36 was selected the next frequently with 24.46% of irrigators. Table 6 summarizes the contract choice outcomes:

Table 6: Energy Contract Choice Outcomes

28	29	30	34	35	36	37	38	39
4.06%	0.60%	14.56%	2.03%	36.75%	24.46%	0.36%	3.22%	13.96%

As you can see the top two contract selections included 61.21% of the irrigators. The top four contracts made up almost 90% of the contracts selected. This creates some issues, especially when it comes to predictions.

3.2 Methodology

This analysis utilizes three regressions in order to model the contract choice irrigators' face. The first two regressions analyze the impact certain characteristics have on water use and energy use. These two regressions utilize the following linear models:

(1) $ai = \beta_0 + \beta_1 gpm + \beta_2 hp + \beta_3 awc + \beta_4 offpeak.control + \beta 5 onpeak.control + \beta_6 MRNRD + \beta_7 URNRD$

(2) $kwh = \beta_0 + \beta_1 gpm + \beta_2 hp + \beta_3 awc + \beta_4 offpeak.control + \beta_5 onpeak.control + \beta_6 MRNRD + \beta_7 URNRD$

Originally historical water and energy usage were included in the model, but with a correlation above 80% this causes the results to be insignificant. Because of this these two variables are not included in the regressions. The remaining variables were included because they are utilized later in the contract choice regression.

The choice analysis model utilizes a multinomial logistic regression to analyze how irrigators select their electricity contracts for irrigation. Multinomial logistic (mlogit) models use parameters to model how discrete choices are made. Mlogit regressions allow the choice of non-binary choices to be modeled. This model estimates the probability of selecting a contract based on each variable. Mogit regressions assume that the probability to select a single contract choice is irrelevant to the other contract types. This can cause some issues, as this means that irrigators do not hold personal preference to one contract or the other.

The final parameters used for the model were the on-peak season hp charge, the off-peak season hp charge, the logged yield per acre, the awc, and the average kWh usage. Parameters such as sand, silt, and clay percentages were included originally in the regression. These soil percentage parameters were later excluded because they were insignificant and may have led to multicollinearity issues in the model. Because of this we eliminated the soil types from the regression. Hydraulic conductivity (kv) was also one of these parameters included originally. With the *awc* already included, the addition of the kv resulted in both the *awc* and kv being insignificant. This could be due to a multicollinearity issue as well. When the historical energy and water usage were added, we encountered a multicollinearity issue when both were added to the same regression. For this reason only the historical energy use was used. For the mlogit regression we assume the model to be linear with a structure of:

(3) $V_{ik} = \beta_1\, hp\_charge\_1_{ij} + \beta_2\, hp\_charge\_2_{ij} + \beta_3\, log\_gpm\_per\_acre_{ij} + \beta_4\, awc_{ij} + \beta_5\, avg\_kwh_{ij} + u_{ij}$

Where,

$$\Pr(\text{choose } j)_i = \frac{\exp(V_{ij})}{\sum_{k=1}^{9} \exp(V_{ik})}$$

Here V_{ik} is the utility of individual *i* for selecting contract *j*. The *hp_charge_1* is the individual irrigator's hp charge in the off-peak season, while the *hp_charge_2* is their hp charge in the on-peak season. The *log_gpm_per_acre* is the log of the individual's well yield per acre. The *awc* is the average water content, and the *avg_kwh* is the historical average electricity usage. The betas are the constants associated with each term. Each observation is based solely on individual well to section pairings. In other words, though an irrigator may have more than one section of land, each observation was analyzed individually.

After running the mlogit regression, the marginal effects will be determined to better illustrate the impacts each of the variables have on choice. Finally, the regression results will be placed in a prediction function in order to test the quality of the original regression. The prediction is tested against the original outcomes for each individual. If the results of the prediction closely match the original outcomes, this will be supporting evidence to the ability of our regression. This is important because of the ability to predict the real world.

CHAPTER 4: RESULTS

4.1 Water and Energy Model

As mentioned before, the first two regressions attempt to model water use and energy use in the area. This regression uses two linear models to analyze the effect yield, horsepower, average water content, the number of control days, and associated NRD has on both water use and energy use. Reviewing Table 5, we can see that the water use, energy use, and hours operated are highly correlated. For this reason they are not included in the regressions with each other. This also means that in the model irrigators can only adjust the included variables. The inclusion of the two NRD terms is due to the fact that all three NRDs have differing allocation limits. The objective of these terms is to analyze the relative impact each NRD has on the usage.

Prior to running the regression, we expect well yield and horsepower to have a positive coefficient. If an irrigator wanted to use more water they could only achieve this by increasing their well horsepower, well yield, or run the well longer. As the hours irrigated is not included in the regression, they are assumed to be constant. Therefore only the horsepower, and yield could be adjusted. We also expect that the coefficients on the *awc* would be negative. The more access to water the plant has from the ground (awc), the less water from irrigation is needed. Since the goal of these contracts is to reduce grid stress, essentially reducing water usage, the number of control days should be negative as well. The TPNRD has the fewest controls for groundwater, with no allocations, therefore we would expect that the coefficient on the TPNRD dummy variable would be positive (relative to MRNRD) and greater in magnitude than the URNRD dummy variable. Since the MRNRD has a lower allocation than the URNRD, the *URNRD* variable should have a positive coefficient as well. Table 7 displays the output provided by the regression.

Table 7: Water Use

Intercept	1.6348	*
	(0.6677)	
Well Yield (gpm)	0.0135	***
	(0.0009)	
HP	-0.0089	•
	(0.0052)	
AWC (%)	-0.0503	***
	(0.0102)	
Off-peak control	-0.1768	*
	(0.0720)	
On-peak control	-0.2368	
	(0.2140)	
TPNRD	5.7477	*
	(2.4727)	
URNRD	0.8113	*
	(0.3165)	
R-squared: 0.3626		
Observations: 831		
Significant codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1		

Analyzing Table 7, the well yield is very significant and positive, which is what we expected prior to the regression. The awc is also very significant, and is negative, which matches our assumptions for this term. The impact the very significant terms have on water use is very small though. The off-peak control days, and the two NRD terms were significant at the 99% level. The expectation we had of the off-peak control days was also correct. From the regression, we can see that an increase of one day of control in the off-peak period leads to the use of 0.177 ai less water.

When analyzing the NRD dummy variables, we can see that our assumption on the TPNRD variable holds. The TPNRD coefficient is positive and is large in magnitude as well. The URNRD variable is positive as expected. The MRNRD, has stricter controls on water usage than the URNRD, and therefore should have a positive coefficient. The final term that is significant, albeit only at the 95% level, is the *hp* term. The term though returns negative, which is not what we expected. Even though the term defies our expectation, the effect itself is rather insignificant. A one hp increase results in the use of 0.0089 ai less. When the average irrigator applies about 12 ai, a decrease of 0.0089 is very irrelevant. Even a moderate change of fifty hp only results in about a half of ai change. The on-peak control returned insignificant, which could be associated with the size of the dataset, or the lack of included variables. Also note, the regression individually is not very good at explaining all the variation with an r-squared value of 0.3626. For this analysis though, we were not attempting to perfectly model this system. All we are looking for is that the direction and significance were consistent with our assumptions.

Following the water use regression, we focus on the other resource in the analysis. Going into the second regression, our assumptions for the variables shared with the first remain the same. In other words the coefficients on well yield, hp, TPNRD, and URNRD should be positive; the coefficients on awc and the two control day variables should be negative; and that the coefficient on TPNRD should be greater than the coefficient on URNRD. The reasoning behind these assumptions are the same as Regression 1, since water use and energy use are strongly related. Table 8 presents the regression results from the energy use regression.

Table 8: Energy Use

Intercept	11,023.55	*
	(4,499.29)	
Well Yield (gpm)	8.51	
	(5.91)	
HP	531.06	***
	(35.278)	
AWC (%)	-340.57	***
	(69.13)	
Off-peak control	-1,265.60	**
	(485.40)	
On-peak control	-1,519.47	
	(1,441.90)	
TPNRD	40,389.44	*
	(16,662)	
URNRD	5,756.87	**
	(2,132.652)	
R-squared: 0.424		
Observations: 831		
Significant codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1		

As you can see, for the variables that are significant our assumptions did hold. The hp and awc variables have the strongest significance in this regression. From the regression, a one hp increase leads to an increase of 531.065 kwh. Again this is a rather small effect since the average irrigator consumes 27,000 kwh. The awc has a small impact on energy usage as well, with a one percent increase in awc resulting in a decrease of 340.568 kwh used. The off-peak control, URNRD, and TPNRD variables were also significant, though not as great. Along with their significance, the direction of the coefficients matched our assumptions as well.

The only issue with the regression is that well yield and the number of control days in the on-peak season is insignificant. The issue with well yield is rather surprising though. Intuition would say that irrigators know how much water they need to use, thus what yield they need and how much energy it takes to irrigate with that yield. This insignificance may come from lack of variation in the data. With an r-squared of 42%, the regression can only explain under half of the variation in the data. This provides evidence that more variables are needed to fully explain this relationship. Again, explaining the entirety of this relationship is not the purpose of this analysis though. It's merely meant to explain the relationship of the variables included in the choice models.

4.2 Contract Choice Model

The analysis in this section utilizes an mlogit regression to model how irrigators determine their energy contract choice. With this regression, we can only tell which way each term influences the irrigators choice (more likely vs. less likely). The first assumption we have is that the on-peak hp term will be at least equal in significance to the off-peak hp charge term, but more than likely will have a greater significance. This is because the on-peak hp charge term has to do with the water usage in the on-peak season, where water is more critical to plant development. Therefore this difference should be visible when comparing the two variables.

The next assumption is that an irrigator with a higher historical energy use, would be less likely to select a contract with a greater number of interruption days. This means that the coefficients for contracts with a high number of control days should be negative, and they should be positive for contracts with a low number of control days. Since energy and water usage go hand in hand, the same could be said for the historical water usage. The reasoning here is the more water an irrigator needs to irrigate, the more time they will need electricity for their well. This means the irrigator has a smaller surplus of time than an irrigator with low historical energy use. If the energy contract structure is working properly, the irrigator will not trade this surplus of time for the economic incentive created by the energy contract structure. The opposite could be said for irrigators with a large surplus of time.

The third assumption we have is that as the awc increases for an irrigator, they are then expected to select a contract with a higher number of control days. In other words the awc terms should be positive for contracts with greater number of control days. This is due to the inverse relationship between awc and how much water is needed from irrigation. The greater the awc is, the more water the soil can hold. This means more water available to crops in the soil itself, therefore less water is needed from irrigation.

The final assumption we have is that the greater the well yield, the more control days an irrigator would select. A high well yield pump will move water quicker than a low well yield pump. This again creates a surplus of time for the high well yield irrigator. Because of this the irrigator will trade the unused time for control and its associated economic payoff. So the coefficient should be positive for contracts with greater amounts of control days. Since contracts 39 and 36 have the most control days, we expect the coefficients to be positive. For contracts 34 and 37, we expect the opposite. If we assume that the electricity rate structure is operating correctly, then these assumptions should hold. The result of this regression will give us some insight as to the successfulness of the rate structure. Table 9 contains the regression results from this mlogit regression.

Table 9: Contract Choice Regression Results

Off-peak HP Charge	-0.00123 (0.000980)		28: Historical Energy Use	-0.00000493 (0.00000507)	
On-peak HP Charge	-0.00298 (0.00165)	•	29: Historical Energy Use	-0.0000143 (0.0000130)	
28: Logged Yield per Acre	-1.15 (0.347)	***	34: Historical Energy Use	-0.0000113 (0.00000789)	
29: Logged Yield per Acre	-1.19 (0.688)	•	35: Historical Energy Use	-0.0000209 (0.00000432)	***
34: Logged Yield per Acre	-0.853 (0.458)	•	36: Historical Energy Use	-0.0000215 (0.00000576)	
35: Logged Yield per Acre	1.14 (0.204)	***	37: Historical Energy Use	-0.0000257 (0.0000191)	
36: Logged Yield per Acre	0.765 (0.225)	***	38: Historical Energy Use	-0.0000250 (0.00000860)	***
37: Logged Yield per Acre	-1.87 (1.01)	•	39: Historical Energy Use	-0.0000395 (0.00000747)	***
38: Logged Yield per Acre	-0.896 (0.412)	*			
39: Logged Yield per Acre	0.654 (0.274)	*			
28: AWC	0.0134 (0.0158)				
29: AWC	-0.0468 (0.0342)				
34: AWC	-0.00650 (0.0207)				
35: AWC	-0.0213 (0.00856)	*			
36: AWC	-0.0318 (0.00910)	***			
37: AWC	0.00868 (0.0468)				
38: AWC	0.00707 (0.0175)				
39: AWC	-0.0206 (0.0104)	*			

Significant codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

From the results we can see that our assumptions about the regression hold true. When looking at our first assumption we can see how much significance level disparity there is. The significance level of the *hp_charge_*2 term is significant at the 90% level, while the *hp_charge_1* term is insignificant. The intuition behind this is that the irrigators are placing more weight on the choices made in the on-peak season as opposed to the off-peak season. This makes sense because during the on-peak season the crop is stressed the greatest, and thus irrigator's choices are more critical.

When analyzing the historical energy use, only contract 35, 36, 38, and 39 are significant. Contract 39 is the least likely contract to be selected by irrigators with high historical usage. This is what we expect as contract 39 has the greatest number of control days in both periods. Contract 38 is the least significant of the four, but it is the next least likely contract chosen by high use irrigators. If we combine our first two assumptions, it makes sense that contract 38 is the next least likely contract to be selected. This is because contract 38 has more control days in the on-peak season than contracts 36 or 35, but less than contract 39. Continuing this logic contract 36 would be the next least likely, followed by contract 35. When reviewing the results, this logic does in fact hold true.

For our second assumption only three of the nine contracts were significant. The most significant was contract 36, at the 99.99% level. Not only was this contract the most significant, it was the least likely contract to be chosen by irrigators with high awc. Contracts 39 and 35 were also significant, though only at the 95% level. These results differ from what we assumed, as the coefficients on these contracts is negative. The surprising part of the regression is that our assumptions relating to on-peak vs off-peak significance for awc is not noticeable. This could be related to the weak overall significance of this variable to the contracts.

The most surprising result of this regression relates to the well yield and contract choice. Well yield has the greatest amount of significance for all variables. We originally assumed that for high well yield irrigators; the more control days, the less likely an irrigator is to select that contract. This assumption did not hold completely though, as no pattern existed. Some of the contracts with a high number of control days increased the likeliness to be selected. In contrast some contracts with just a day or two less, decreased the likeliness.

The other missing piece from these results is the reoccurring situation where the on-peak season is more significant than the off-peak season. Looking at contract 39 and 36, we can see that not only are they both the opposite sign of our hypothesis, but contract 36 is greater in magnitude than 39. This violates our assumption that choices are more critical (greater significance) in the on-peak season, than in the off-peak season. The disappointing results of this regression is that no clear pattern can be determined due to well yields.

A common reoccurrence in these regressions is which contracts were significant. The contracts that are continually significant are the contracts most of the irrigators selected. This should be expected as contracts 30, 35, 36, and 39 make up almost 90% of the observations.

With this regression we are not able to make many interpretations, as the results of this regression are just a likeliness to select a contract. So all we can gather from this regression is whether or not the variable makes a choice more or less likely to occur for a given contract. The relative magnitude within each variable can also be determined as well, which is still not very useful. In order to infer the specific effects each variable has on contract choice, the marginal effects must be determined.

Marginal Effects

In order to better understand the results of our regression, we will need to create the marginal effects. These effects will allow inferences to be made on the likeliness to select each contract. Table 10 contains the results of the marginal effects.

Table 10: Marginal Effects

Contract	logYield (gpm)	Sig	AWC (%)	Sig	Energy Use (MWh)	Sig
28	-8.4268 %	***	0.1367 %		0.0416 %	
29	-0.6959 %	•	-0.0155 %		-0.0077 %	
30	-15.1603 %		0.4441 %		0.4822 %	
34	-4.0034 %	•	0.0162 %		0.0039%	
35	25.5555 %	***	-0.3332 %	*	-0.2842%	***
36	4.5819 %	***	-0.2502 %	***	-0.1107%	***
37	-0.7028 %	•	0.0063 %		-0.0041%	
38	-2.1746 %	**	0.0314 %		-0.0211%	**
39	1.0264 %	**	-0.0358 %	*	-0.1068%	***

Significant codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

When looking at the results the first noticeable information is how different the three variables effect the probability of selecting a contract. Each marginal effect is represented as a percentage impact on the contract choice given an increase in one unit of each variable. For example, an increase in the logged well yield by one, results in a 8.4268% lower chance of selecting contract 28.

If we look at the three variables we can see that there is a large difference in the size of effects. The well yield's effect in magnitude ranges from 0.6959% to as large as

25.5555%. In comparison, the awc term only has an effect between 0.0063% and 0.4441%. This is all relative, as the scale differs among the three variables. The effect historical energy use has on contract choice ranges between 0.0041% and 0.4822%. The largest effect historical energy use has on a contract choice is contract 30. This result can be inferred as a one MWh increase in energy use, increases the chances of selecting contract 30 by 0.4822%. In our data set the largest fluctuation in energy use was about 20 MWh. This change results in about a 9.64% increased chance of selecting contract 30, which is not a very large effect.

For well yield, all of the contracts had at least some significance. There are only three contracts whose probabilities increase as well yield increases. Contracts 35, 36, and 39 all have probabilities that increase when the well yield increases. Contract 35 increases the greatest at 25.56%, while contract 36 and 39 increase by 4.58% and 1.02% respectively. The increase of 25.56% is rather surprising as a less than three gpm increase has that large of effect on 400 plus gpm. The largest decrease in probability occurs with contract 30, with a decrease in probability of 15.16% per added log(gpm). The well yield has a relatively small effect on contracts 29 and 37 with an effect of less than 1%.

The result for contract 30 was expected, since there is no control days with this contract. We would expect that an irrigator that selects this contract has a lower well yield, and thus are less likely to trade for control days. Contracts 34, 35, and 36 each have three control days in the off-peak months. This is the middle amount of control days for the off-peak period. The yield effects these contracts the greatest. This, along with the fact that contract 35 and 36 are the two most selected contracts, is a good indication that irrigator’s are trading their surplus time for control days.

The awc, while less impactful than the yield, still has an effect on the contract choices. Though contract 30 has the greatest impact, with an increase in probability of 0.44%, the effect is insignificant from our regression. Contract 35 has the largest effect that is also significant. With an increase of one percent in awc, the probability of selecting contract 35 decreases by 0.33%. Each of the three significant effects decreases the likeliness of the contract being chosen. Contracts 36 and 39 were also significant, with effects of 0.25% and 0.03% respectively. The direction of the effects was as expected, but any change in awc takes a long time to do so.

Predictions

After the regression analysis, we wanted to see how good the model is at explaining irrigator's choice. The purpose of any study is to analyze the outcomes of the past, so that it can be used in the future. One justification of a study's purpose is how well it is able to predict possible outcomes. In order to do this we created a prediction utilizing the original parameters. Then used these parameters to predict which contract the irrigators would have chosen. We can then compare the actual results to the predicted results. The higher the frequency of correctness, the better our model was at predicting. Table 11 includes a summary of the successfulness of the prediction.

Table 11: Prediction Success

Overall Success	35.68%
Contract 28	0.35%
Contract 35	34.01%
Contract 36	1.31%

We can see that our prediction overall was successful 35.68% of the time. This may not seem like much, but given only five variables were used to model the choice, this number isn't terrible. When analyzing the individual contracts though, our prediction does not look so stellar. Of the 35.68% success rate, 34.01% resides with contract 35. Contract 35 also happens to be selected by irrigators 37% of the time. So the prediction is doing a good job predicting contract 35, but not much more than that. This is likely due to the lack of variation between contract selections made by irrigators, and lack of variables in the regression.

In order to improve on this prediction, we combined the four most common contract selections into one group. This group included contracts 30, 35, 36, and 39. We then ran this through the prediction again. Table 12 includes the results from after the combination of the four contracts.

Table 12: Prediction Success in Combination of Four Contracts

Overall Success	85.08%
Contract 28	0.36%
Contract 34	0.24%
Contract 37	0.12%
Contracts 30, 35, 36, and 39 Combined	84.37%

After grouping the contracts, our prediction overall correctly predicted 85.08% of the time. The resulting overall prediction did improve upon the previous one, though the same issue with individual contracts is still prevalent. We want to see the prediction be able to predict more evenly across the different contract choices, not just the most popular contract choices. More than likely the only way to overcome these shortcomings would be to gather more data.

CHAPTER 5: IMPLICATIONS AND IMPROVEMENTS

Reviewing our regression, did it produce the answers we set out to find? Our analysis could not go as far to say the contract structure is failing, but if well groundwater depletion continues it is likely to happen. What we can say is that, with the available data, if water levels start declining there is a good probability irrigators will start utilizing contracts with fewer control days. This is problematic as water levels in the area have been declining for years. To avoid resource depletion in the future the MECC should either reform their contract structure, or take policy action elsewhere.

Reforms could possibly include a greater economic payoff for each of the control days. An increase in the rate payoff could lead to irrigators selecting a greater number of control days. Another option could be to remove contracts with a fewer number of control days in the on-peak season. Of course this contract would have to carry a greater economic incentive than contract 39. The other route the MECC could go is focus on well yield improvements. Cost share programs are commonly used within the NRDs to reduce water usage, and improve resource allocation. A cost share program could be established by the MECC in order to help irrigators improve their well yields. The improved well yield means the irrigators would have at least the same surplus of time that then could be traded for control days.

We would have liked to find more significant results from the regression, but with a small data set issues were expected. One of the reoccurring issues we noticed was that the hp charges regularly returned insignificant. This means that when irrigators make their contract decisions, the hp charge currently is not structured to effect these decisions. The main issue we noticed is how small the charge is. It is greater in the off-peak season than it is in the on-peak season. This does nothing to decrease usage in the on-peak season.

The one thing the structure does achieve is that as energy prices increase, irrigators are more likely to select contracts that have a greater number of control days. As energy prices increase, irrigators would be expected to decrease their usage. From our regression's marginal effects we can see that an increase of energy use, results in a decreased probability to select contract 39. With this, the opposite can be said as well; decrease in energy use results in a greater probability to select contract 39.

Many of the issues encountered in this study could be solved with a larger data set. With this larger data set we would expect the significance in our regression to increase. Along with the larger data set, extra variables may be added. With more resources we could add variables such as irrigation technology. We would hope this data set would also lead to more variation. This may allow variables eliminated in this regression, due to multicollinearity, to be utilized in future regressions.

CHAPTER 6: CONCLUSIONS

The original goal of this study was to try to model and identify the effects the MECC's electrical rate structure had on energy and water resources in 2009. To achieve this, a multinomial logistic regression was utilized. Data was first gathered from the USDA, NRCS, DNR, and MECC. This data contained information on water and electricity usage, as well as soil properties, electrical rate contract agreements, and the rate structure itself.

Preliminary regressions were run in order to analyze the impact each of the variables had on water and energy use. This not only gave us insight on the interactions with these systems, but legitimized the use of the mlogit regression. With these regressions we found that the NRD the irrigator resided in, was a big significance in the usage of resources. This was expected since the Upper Republican has a water allocation limit in effect. The other significant factor was the number of control days agreed upon between the irrigator and the MECC. As the MECC's rate structure was so significant to the irrigator's resource decisions, the legitimacy of our mlogit regression was accomplished.

After analyzing the resource use variables, we moved forward with our mlogit regression. This regression utilized the hp charge, average water content, well yield, and historical energy usage to try to model irrigator's contract choices. From this regression we noticed that the on-peak season vs off-peak season decisions were important to irrigators. The on-peak variables were continually significant, whereas the off-peak variables were less significant. This result seemed reasonable as the on-peak season is when resource allocation is most critical. The mlogit regression provided us insight as to the direction and relative magnitude of the effects each variable had.

In order for us to make better conclusions, we needed to determine the marginal effects each variable had on contract choice. From these marginal effects we were able to identify the extent of these effects. The first noticeable effect was how much the yield effected irrigator's decisions. The magnitude of the yield effects ranged from 0.69% to 25.55%. In contrast the historical energy use had effects less than 10% for a 20 MWh change. So as the historical energy use did have an effect on irrigators' contract choices, they were not very large. The awc did have a moderate effect on contract choice, but individually at best the effects were equal to the yield effects. Apart from the effects altering the awc is no easy task.

After creating our model and analyzing it, we wanted to test the usefulness of this model. To do this we used the parameters from each irrigator in order to predict which contract an irrigator would have selected. This prediction was then compared to the original contract selections. Our prediction turned out to not be very accurate, as the prediction was only correct 35.68% of the time. Within these correct predictions about 95% of the correct selections occurred with contract 35. This was disheartening because the prediction did not do a very good job predicting anything other than contract 35.

To improve upon this analysis, greater amounts of data must be gathered. This will improve upon the variation issues we discovered. With this additional variation, more variables can be added in order to better explain the system. When it's all said and done, the study has done the best possible with the data that was available. The analysis has found that although there may not be issues currently with the contract structure, changes in the future with groundwater levels and energy prices may disrupt the structure.

References

Brown, and Caldwell. “Medicine Creek Basin Groundwater Model: Status Check 1.” Middle Republican Natural Resources District, 30 Jan. 2013.

EIA. “Weekly U.S. No 2 Diesel Retail Prices.” *Weekly U.S. No 2 Diesel Retail Prices (Dollars per Gallon),* U.S. Energy Information Administration, 16 Oct. 2017, www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=emd_epd2d_pte_nus_dpg&f=w.

Ganzel, Bill. “Center Pivots Take Over.” *Center Pivot Irrigation Systems Take Over During the 1950s*, Living History Farm, 2006, www.livinghistoryfarm.org/farminginthe50s/water_03.html.

Jenkins, Hazel M. “A History of Nebraska's Natural Resource Districts.” Edited by Robert B. Hyer, July 2009, p. 2.

Kranz, William L., et al. “Irrigation Management for Corn.” University of Nebraska - Lincoln, May 2008.

MECC. “MIDWEST ELECTRIC COOP CORP 2016 IRRIGATION RATE 28 THROUGH 39.” Midwest Electric Cooperative Corporation, Jan. 2016.

Mieno, Taro. “ESSAYS IN WATER RESOURCE ECONOMICS.” University of Illinois at Urbana-Champaign, 16 Sept. 2014.

Mieno, Taro, and Nicholas Brozovic. “Energy-Water nexus in Agriculture: The Impact of Energy Supply Interruption on Groundwater Use.” University of Nebraska - Lincoln, Sept. 2015.

MRNRD. “About the MRNRD.” *About the MRNRD | Middle Republican Natural Resource District, Curtis Nebraska*, Middle Republican Natural Resource District, 1 Jan. 2017, www.mrnrd.org/about-mrnrd.

NOAA, and NRCS. *Average Annual Precipitation*.

Perlman, Howard. “Irrigation Water Use: Surface irrigation.” *Water pictures: Furrow irrigation*, USGS, 9 Dec. 2016, water.usgs.gov/edu/irfurrow.html.

TPNRD. “Know Your NRD.” Twin Platte Natural Resource District, July 2016.

Train, Kenneth E., and Nate Toyama. “Pareto Dominance Through Self-Selecting Tariffs: The Case of TOU Electricity Rates for Agricultural Customers.” International Association for Energy Economics, Jan. 1989.

URNRD. “District Overview.” *District Overview | Upper Republican Natural Resources District*, Upper Republican NRD, Oct. 2017, www.urnrd.org/about/district-overview.

USDA. “Census of Agriculture Publications.” *USDA - NASS, Census of Agriculture - Publications*, USDA, 15 June 2017, www.agcensus.usda.gov/Publications/.