THESIS

EFFECTS OF GROUNDWATER PUMPING FOR IRRIGATION ON STREAM PROPERTIES OF THE ARIKAREE RIVER ON THE COLORADO PLAINS

Submitted by
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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY LISA L. FARDAL ENTITLED EFFECTS OF GROUNDWATER PUMPING FOR IRRIGATION ON STREAM PROPERTIES OF THE ARIKAREE RIVER ON THE COLORADO PLAINS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

EFFECTS OF GROUNDWATER PUMPING FOR IRRIGATION ON STREAM PROPERTIES OF THE ARIKAREE RIVER ON THE COLORADO PLAINS

The Arikaree River lies in the Republican River Basin on the Northern High Plains of Colorado. This study was conducted on the portion of the Arikaree River that flows through the lower portion of Yuma County, Colorado. A groundwater dependent stream, it obtains its flow from springs and seeps. Discharge into the stream channel occurs wherever the aquifer head is higher than the elevation of the river bottom. On this river, there is a state-threatened species of minnow that is reportedly suffering due to lack of seasonal flow. It is assumed that groundwater pumping for irrigation is reducing the quantity of water within this river. However, the stream/aquifer relationships in this area are not well understood. Farmers in this area irrigate crops such as corn and alfalfa with groundwater that is pumped from the High Plains, or Ogallala aquifer. During the summer of 2002, the area experienced a severe drought that required farmers to irrigate continuously throughout the season. A mere 7.6 centimeters of precipitation fell on the land to supplement the irrigation water.

The irrigation practices of six representative farmers within the area were analyzed. Several parameters including the crop type and area, well pumping rates and duration of irrigation and evapotranspiration rates of the crops were examined for each field. The results show that a large quantity of water is withdrawn from the aquifer for irrigation purposes; however, most farmers were found to be in deficit irrigation for the majority of the 2002 season.

This study also observed the status of the river during the season. Stage height and connectivity of the river were recorded throughout the season. The volume of water extracted from the aquifer for irrigation purposes appears to have had a definite impact on the stage height and connectivity of the nearby Arikaree River. As groundwater pumping for irrigation increased, the stage height of the river decreased. Likewise, as the pumping concluded in the fall season, the water level of the river increased. While there are likely to be several factors influencing stage height of a stream, irrigation seems to be a major influence. A more accurate description of the groundwater hydrology and the surface/groundwater relationship of this area is necessary to verify this correlation and to make robust management suggestions to the irrigators in this area. Future research may entail more detailed descriptions of the river hydraulics, groundwater studies for stream/aquifer relationships, and modeling groundwater table depletions in conjunction with irrigation withdrawal.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Background

Brassy Minnow

In 1998, three plains fish species were listed in Colorado as threatened or endangered. Among them was the brassy minnow (*Hybognathus hankinsoni*). This species, once considered common in Colorado (Ellis, 1914), was found to be rare in a 1994 inventory (Nesler, 1997). In fact, it was shown that the frequency of brassy minnow occurrence in the South Platte River basin had decreased from 11 to 2 percent between inventories collected in 1980 (Propst, 1982) and those collected in 1994 (Nesler, 1997). Recently, the brassy minnow has been found in streams on the plains of northeast Colorado. It is found in both the Republican and the South Platte River basins, yet populations seem to still be declining (Scheurer, 2002).

A detailed study on habitat requirements for the brassy minnow by Scheurer (2002) was conducted on the Arikaree River in the Republican River basin near Idalia, Colorado. The Arikaree River is a groundwater dependent stream that cuts into the Ogallala Aquifer. Springs and seeps provide flow for the stream (Solek, 1996). In the absence of large piscivores, which is the case on the Arikaree, the adult brassy minnow tends to prefer dwelling in complex pools (Schlosser, 1988). Scheurer (2002) found that survival and persistence of the brassy minnow was strongly correlated with the extent of stream drying and pool depth. From mid-April to mid-May, this species spawns in the flooded vegetation on floodplains of small streams (Goldowitz and Whiles, 1999). The larvae emerge between mid-May and mid-June. Thus, the emergence of the species corresponds with the beginning of the irrigation season. It is believed that groundwater pumping for irrigation exacerbates the dewatering of the Arikaree River (Scheurer, 2002, Residents of the Arikaree Valley, 2002, personal communication). Subsequently, when the fish are at their most vulnerable stage, the stream segments begin to dry and the fish are forced to retreat to refuges or become stranded in isolated pools. Stranded fish are often preyed upon in shallow pools by terrestrial vertebrates, or eliminated as the pools eventually dry (Scheurer 2002).

Plains fishes, such as the brassy minnow, are highly tolerant of physiochemical extremes (Matthews and Maness, 1979). In fact, high temperatures and low dissolved oxygen, along with questionable water chemistry are not generally considered major causes of extirpation for plains fishes. Rather, the seasonably harsh conditions of plains streams help to exclude non-native fish such as the smallmouth bass that may serve as predators to native fishes (Strange and Foin, 1999). Scheurer (2002) found the brassy minnow to be able to withstand very low dissolved oxygen in the early morning (0.01 mg/L (ppm)) and very high stream temperatures in the afternoon 36°C (97°F). Other parameters such as pH, salinity and specific conductance were not found to vary much on the Arikaree (Scheurer, 2002). Thus, it is suspected that the rapid dewatering of this small stream is the most probable explanation for the brassy minnow's decline in this area.

Yuma County

Irrigation in Yuma County is extremely prevalent. About 43% of the total cropland are irrigated acreage (www.consideryumacounty.com). Furthermore, over 90% of all irrigation systems are supplied by groundwater pumping and almost 80% of those systems use center pivots as a means of conveying water to their crops (Frasier, et al. 1999). The main crops are corn, wheat and alfalfa. Sunflowers, sorghum, millet, beans, sugar beets and potatoes are also farmed.

Wells in this area are permitted according to the rule of the "three-mile circle" (Ground Water Commission, 2001). This rule is specific for wells in the Northern High Plains Ground Water Basin, which includes the White River and the Ogallala aquifers. According to this rule, the allowable annual appropriation within a three-mile (4.83-km) radius of a proposed well is determined by the equation:

$$A = \frac{640*(D)*(S.Y.)*3.1416*R^2*H}{(1.0-Ir)*t} + \frac{640*f*(\text{Pr})*3.1416*R^2}{12*(1.0-Ir)}$$

where,

A = Annual appropriation allowable within the circle being evaluated in acre-feet per year

D = Allowable depletion (expressed as a decimal, dimensionless)

S.Y. = Specific yield (dimensionless)

R = Radius of circle (miles)

H = Average saturated thickness within the circle (feet)

t = Time period during which depletion , D, occurs (years)

Pr = Precipitation recharge (inches/yr.)

f = Fraction of Pr that is available for appropriation in the circle (dimensionless)

Ir = Fraction of A that returns to the aquifer as deep percolation, i.e., irrigation return (dimensionless)

(Constants are: D=0.4, S.Y.=0.15, R=3miles, t=100years, f=0.2 and Ir=0.15)

(From Rule 5.2.2.3, Ground Water Commission, 2001)

Although Southern Yuma County, the study area, is not technically considered over-appropriated, new wells are not generally approved (Darrel Davis, Arikaree Groundwater Management District, 2002, personal communication). Replacement wells may be permitted if they are not to be located more than 0.8 kilometer (0.5 mi.) from the original well (7.3.5 Ground Water Commission, 2001).

1.2 Problem Statement

There has been no research conducted that describes how the irrigating community of Yuma County may be impacting the Arikaree River. It has been suggested that the dewatering of the stream is directly related to the lowering of the water table by irrigation (Residents of Lower Yuma County, personal communication). However, the stream/aquifer relationship in this specific area is poorly understood. Furthermore, the exact quantity of groundwater withdrawn from the area for irrigation purposes is unknown.

The annual quantities of water pumped from wells in Yuma County are not strictly monitored by government agencies. Only those who have requested an increase in permitted irrigated crop acreage are required to have a flow meter installed on their wells. True historic withdrawal can only be determined through power consumption records. When the power records are not available, the Ground Water Commission uses the average net crop irrigation. This is determined by the crop consumptive use, minus the effective precipitation (7.10.5 Ground Water Commission, 2001). This method is somewhat flawed, since not all farmers irrigate in the same manner to perfect efficiencies. Hence, the annual withdrawal from the aquifer due to irrigation pumping is not readily known.

In recent times, the connection between groundwater pumping and stream flow has been a major research topic in this area. The State of Kansas has recently settled a lawsuit with Colorado and Nebraska for violating the Republican River Compact (Dec 16th press release, www.nrc.state.ne.us/docs/RepublicanSettlement.html). The claim was that the groundwater pumped for irrigation in these states was affecting the flows they receive from the Republican River and its tributaries. Because this groundwater was not accounted for, it was felt that the Republican River Compact was being violated. In the settlement, it was agreed that some groundwater pumping for irrigation must be accounted in consumptive use calculations. However, neither state was ordered to pay damages to Kansas. The litigation caused many residents in the Republican River Basin to be very sensitive about their water usage.

Due to the necessity of defining stream/aquifer relationships for legal purposes and for fish habitat preservation, accurate withdrawal volumes need to be identified. The current system for quantifying irrigation groundwater pumping is not precise enough.

1.3 Objectives

The overall goal of this study was to research the impact of groundwater withdrawals for irrigation on river hydrology. The chosen study site was the Fox Ranch, owned by the Nature Conservancy, near Idalia, Colorado. Scheurer (2002) also used this site to research the habitat requirements of the brassy minnow. She found that extirpation of the minnow was strongly related to parameters of river hydrology such as pool drying and dewatering. For this study, our hypothesis is that the use of groundwater for irrigation in Lower Yuma County is adversely influencing the hydrology of the Arikaree River. The specific objectives of this study are as follows:

- To better understand the methodology and efficiencies of irrigating farmers in lower Yuma County.
- To estimate the quantity of water withdrawn for irrigated agriculture within the study area.
- To describe water quantity changes through time in the Arikaree River.
- To investigate the relationship between pool depth and the quantity of groundwater pumped for irrigation during the 2002 irrigation season.
- To recommend effective methodologies for longer term research.

The year this study was conducted was the driest on record (High Plains Climate Center, www.hprcc.unl.edu). Therefore, the results reflect an uncommon year, one in which there was extreme groundwater pumping for irrigation.

1.4 Scope

Describing the true dynamics of the stream/aquifer relations would require extensive groundwater modeling and aquifer testing. This project does not intend to provide definitive answers as to which pumps and pumping rates are affecting the stream. Nor does it attempt to obtain data for a groundwater model. Instead, the results of this study should provide insight into the irrigation practices of the area including the volume of water per season being drawn from the aquifer.

Furthermore, this study examines the temporal changes of water quantity in the Arikaree River. Scheurer (2002) suggests water quantity to be the most influential factor on minnow habitat. However, water quality may also affect fish and wildlife habitat on the Arikaree River. Some water quality issues have been addressed in previous studies (Scheurer, 2002), others may need to be considered in future studies. This study does not address any water quality issues. Nor does it attempt to define the habitat needs of the brassy minnow. Rather, the intention is to determine whether there is a general relationship between the timing of irrigation and the amount of water in the Arikaree River.

CHAPTER 2: LITERATURE REVIEW

2.1 The History of the High Plains

In 1931, Walter Prescott Webb defined the High Plains as a flat, treeless area with insufficient rainfall. With its harsh winters and hot windy summers, explorers such as John Wesley Powell, Stephen Long and Zebulon Pike deemed it uninhabitable and unfit for agriculture (Opie, 1993). However, that vast expanse of prairie between the 98th meridian and the Rocky Mountains, which was once called the "Great American Desert," has been home to struggling farmers and ranchers since the time of the Louisiana Purchase in 1803. Originally, "manifest destiny" sent people westward to settle the Great Plains. Homesteaders found acres and acres of flat, treeless, fertile soil without the big rocks and stumps they were used to running into in the east. Yet, the climate was mostly arid and dryland farming required a much bigger field to produce a decent crop. Fortunately, by the 1860s, new inventions such as John Deere's moldboard plow and Cyrus McCormick's mechanical reaper permitted the plains farmer to attempt quarter section (64.8 ha (160 acre)) farming (Opie, 1993).

Yet, even with technological advances, farming was difficult on the High Plains. The plains farmer continued to struggle through drought, grasshopper plagues, and hot, windy summers. That is, until the "climate anomaly" (Opie, 1993). Between 1878 and 1887, unusually high rainfall began to fall on the plains. Believing that farming was causing the beneficial climate change, homesteaders flocked to the plains with the slogan "rain follows the plow." They enjoyed the wet season for nearly ten years before the rains stopped and drought returned. Without the excess rain, farmers fell on hard times once again. It was then that the five years required for homesteading became known as "the period of starvation." Many farmers and ranchers were forced to move away.

In the early 1900s, gasoline tractors, combines and trucks brought new promise to the plains farmer, making it easier to farm large areas and to get harvests to far away markets. Drought tolerant strains of wheat and corn also found their way to the plains during this time. To further encourage farmers, the government reduced the homesteading time to three years with the Homestead Act of 1912. Once again, people came out to the West to try their hand at farming. In fact, at the end of World War I, homesteaders began plowing up vast acres of the Great Plains in an effort to produce crops to aid the European famine and enter international markets. In the last five years of the decade, wheat production rose 300 percent (Opie, 1993). However, by 1931, there was a severe wheat glut, and prices dropped significantly. Along with the glut came drought, dust and depression. What was needed was more water.

In the early 1930s over-cropping and over-grazing combined with a severe drought led to "the dust bowl." High winds eroded the overly dry soil and created huge dust storms throughout the area. The government attempted to provide relief funds for the struggling farmer. With the New Deal, the government helped many plains farmers stay on their land. However, by 1936, the government was beginning to reconsider the value of keeping farmers on the plains. The Great Plains Drought Area Committee was formed. They decided that the plains farmer should be moved off his sub-marginal land so that it may be returned to frontier status. In a report by the committee, it was stated "the government must do its full share in remedying the damaged caused by [1] a mistaken homesteading policy [and 2] by the stimulation of war-time demands which led to over-cropping and over-grazing" (Washington GPO, 1936). Unfortunately, the government did little to restore the area to its natural state. When all was said and done, it had purchased a mere 4,455,000 of the 30,375,000 hectares (11 million of the 75 million acres) it had intended. The program died in 1947.

The 1940s, once again, brought rain and wartime bumper crops. Hardworking farmers capitalized by reworking abandoned land. Once again, acres of land were being overturned. And once again, in 1948, the hot, dry winds returned to Eastern Colorado. With the wind, returned soil erosion and dust storms. The lessons learned in the "dirty thirties" had been forgotten and the plow-ups had once more put the region in jeopardy. However, this time, the effect on the farmers was different. America had a much more stable, post-war government. Generous government aid was available to farmers. Farmers were able to persevere during the hard times and the drive to farm the Great Plains did not diminish. Furthermore, there was an increased drive to reach the water below their land and the government provided the funds to support it.

2.2 Irrigation

In the late 1890s the centrifugal pump found its way to Garden City, Kansas. Coupled with the gasoline engine in the early 1900s, several large farming and ranching operations were able to irrigate their crops with the new technology. Yet, for most farmers, the economic strain was too great at the time of the first wells to make them advantageous. However, after the Second World War, in the late 1930s more and more irrigation systems began to appear on the plains. Technology had improved, pumps were more reliable and engines were cheaper. Yet, during this time, federal policies were encouraging better dryland farming rather than irrigation. Furthermore, farmers who had installed wells were not using irrigation to its potential and their profit margins were still minimal. Eventually, farmers stopped using irrigation as a back up for rain and began using it to meet the crop's needs. Irrigators began watering day and night and even on Sunday.

Groundwater now supports millions of acres of irrigated agriculture and the High Plains have been described as a "land of underground rain" (Green, 1973). This underground supply of "rain" comes from the giant Ogallala aquifer, which, besides Colorado, also nourishes Nebraska, Texas, Kansas, New Mexico and parts of Oklahoma, South Dakota and Wyoming. In 1952, a Colorado farmer named Frank Zybach invented the center-pivot (Figure 1). This giant sprinkler could water most of an entire quarter section "automatically." Furthermore, it could be used on uneven ground and was effective on sandy soils. The ease of this new irrigation system created a surge of well drilling requests on the Colorado Plains. Between 1961 and 1978, approximately 93% of the wells in the lower Yuma County study area were drilled (Appendix B). As a whole, the farmers on the High Plains Aquifer of Colorado increased their irrigated acreage by 211% to 360,548 hectares (890,241 acres) between 1959 and 1978 (Kromm and White, 1992). The new irrigation technology brought prosperity to the plains farmer despite the arid climate.

Figure 1. A Center Pivot Sprinkler with Drop Nozzles.

2.3 Groundwater Management Districts

Irrigation on the High Plains has been a mixed blessing. Since the mid-1970s, the depletion of the Ogallala Aquifer has been of national concern. The media has referred to groundwater irrigation as the "mining" of a non-renewable resource. In fact, during 1978, the volume of water pumped from the aquifer (28 billion m^3 (23 million acre-feet)) exceeded the flow of the Colorado River. This prompted states and counties to set restrictions on pumping and to form administrative units to manage groundwater depletion (Kromm and White, 1992). The Colorado Ground Water Commission has created 13 Ground Water Management Districts to monitor groundwater depletion in Yuma County. Each district takes a yearly census of water levels in thousands of observation wells throughout the county. They are also responsible for creating more "rules" regarding groundwater and the permitting of wells that are more specific to their area. The districts strive to allow economic development of the aquifer, while minimizing the lowering of the water table (Agricultural Water Conservation Task Force, 1996).

2.4 Yuma County

Economy

The people of Yuma County, Colorado, depend on irrigated agriculture for survival. In 1997, Yuma had 110,970 irrigated hectares (274,000 acres). The main irrigated crops are corn and alfalfa. These commodities generally go toward feeding the 250,000 head of cattle raised each year (www.consideryumacounty.com). Together, farming and ranching form the base of the economy in this area. Significant changes in the economy, environment and demographics of Yuma County could occur if there was a reduction in irrigation (Kromm and White, 1985).

Geohydrology

The geology and hydrology of the High Plains Aquifer has been studied in detail for the purpose of evaluating the potential impacts of declining groundwater supplies. The High Plains

RASA project, conducted by the U.S. Geological Survey, describes the area within Yuma County, including the Arikaree River and the study area. The geologic unit of the aquifer in this area is the Ogallala formation. Subsurface groundwater flow is from west to east and is estimated at a velocity of 30.48 centimeters (1 ft.) per day (Gutentag, et al. 1984). The quality of the water pumped in this area is very good with less than 250 milligrams per liter (ppm) of dissolved solids (Gutentag, et al. 1984).

Furthermore, most of the stream flow in this area is discharge from the aquifer (Luckey and Becker, 1998). Occasionally, the elevation of the water table in the aquifer rises above that of the land surface and water is discharged to the streams in the form of springs and seeps (Luckey, et al. 1986). The stream flow capture, defined as decreased stream flow caused by pumping from wells, was determined to be caused by pumpage within 16.1 kilometers (10 mi.) of the stream by Luckey, et al. (1988). In fact, their model of water table depletion predicted that the baseflow for parts of the Republican River and its tributaries would be depleted after 1990. Data collected by McLaughlin Water Engineers for The Nature Conservancy confirms that the area contributing groundwater flow to the Arikaree River in the vicinity of the Fox Ranch is 4.8 to 9.65 kilometers (3-6 mi.) from the stream (MWE, 1999). Thus, surface water/groundwater interactions are said to be very sensitive in the region of the Northern High Plains aquifer.

The Ogallala aquifer is said to be more like an "egg crate" than a "bathtub" (Beattie, 1981). Thus, localized effects of pumping may be more influential than pumping from the area as a whole. In fact, pumping near streams may change the natural flux of water to and from the aquifer. Therefore, reduction in groundwater withdrawals may result in increased stream flow (Alley and Schefter, 1987).

2.5 High Plains Studies

The High Plains Study

Due to the growing concerns for the vitality of the Ogallala Aquifer, the U.S. government funded a large study to investigate the extent of the groundwater depletion in the late 1970s. Six states participated in this study, which also looked at the economic impacts of changing policy concerning groundwater pumping. In Colorado, a report was published in 1982 that described the current and future state of the Ogallala on the High Plains under several different scenarios (Young, et al. 1982). The researchers developed a model that conceptualized how a rational, profit-oriented farmer would respond to changes in water availability, energy costs, crop prices, technological opportunities and government policies.

Under a "baseline" scenario, which assumes no changes in public policy toward groundwater use from 1979, it was projected that farmers would be able to produce 10,473 kilograms per hectare (167 Bu./Ac.) of corn in the year 2000. Irrigation water use was estimated to be 65.53 centimeters (25.8 in) for corn. The average decline during this period was projected to be approximately 0.366 meters (1.2 ft.) per year, leaving 56.7 billion cubic meters (46 million acre-feet) of recoverable water in the aquifer by the year 2000.

Under the "improved efficiency" scenario, farmers would voluntarily reduce their water use by improving efficiencies. This scenario is most like what actually happened in this area. The yield was expected to be the same as the baseline scenario at 10,473 kilograms per hectare (167 Bu./Ac.) of corn. However, the irrigation water use was only estimated at 55.12 centimeters (21.7 in.) for corn. In the model, the reduced amount of water pumped allowed more farmers to be able to pump. Thus, the reduction in the aquifer was slightly higher under this scenario. Again, 56.7 billion cubic meters (46 million acre-feet) of recoverable water were projected to remain in the aquifer by the year 2000. By the year 2020, the predicted recoverable water in storage would be 43.2 billion cubic meters (35 million acre-feet) under this scenario (Young, et al. 1982). In a 1999 study on irrigation practices, farmers in the same study area reported applying between 38.1 and 50.8 centimeters (15 and 20 in.) of water on their corn crops (Frasier, et al. 1999). The authors maintain that these estimates are low. Yet, the upper end value of 50.8 centimeters (20 in.) is comparable to the predicted value of 55.12 centimeters (21.7 in.) in the Young (1982) study.

These scenarios are somewhat comforting to today's farmer. The supply of economically recoverable water is not projected to be exhausted in the next 20 years. According to the High Plains Study (Young, et al. 1982), the majority of the area currently irrigating today will likely be irrigating in the future. Some areas will have to cease pumping due to the decreased saturated thickness of the aquifer. In these areas, pumps will not physically be able to extract water from the aquifer. Therefore, the water level declines are expected to slow as pumping decreases and reach a somewhat steady state with annual recharge. Economically, most areas should be able to afford to irrigate where water is hydraulically available, because energy prices are not expected to increase drastically. However, some critics feel the High Plains Study was flawed and that it was predisposed to portray the future of agriculture in favorable terms (Opie, 2000).

Finally, the High Plains study (Young, et al. 1982), found that implementing policies that restrict pumping would have little impact on aquifer life but significant adverse impact on farm income. While the study projects 17% more recoverable water in the aquifer under this scenario, it also predicts a considerable decrease in farm income and production. Thus, the authors recommended against such policies in 1982, and to date, they have not been implemented.

The question that remains is: where will the aquifer stop yielding hydraulically available water? How many irrigators will be forced to return to dryland farming? In 1985, 51% of Coloradoans in Yuma and Washington counties cited depletion of the resource as a very serious groundwater problem in the state (Kromm and White, 1985). Yet, most farmers supported improving their irrigation and well efficiencies over changing groundwater management policies. The High Plains Study predicted the township "3S 44W," just north of the town of Idalia, would cease to have hydraulically available water by 1985 whether there were restrictions made on pumping or not. The rest of the study site around the Arikaree River was projected to do well until the year 2020 under any scenario (Young, et al. 1982). Since several of our cooperating farmers currently irrigate land in township "3S 44W," this prediction was incorrect.

Aquifer Withdrawal Study

In 1980, there was a study conducted to determine the volume of water withdrawn from the High Plains Aquifer (Heimes and Luckey, 1983). This study outlines one approach to determining estimates of water use. Depth of applied water for the season was measured at several sites within certain counties of the Northern High Plains. This was accomplished by measuring the flow rate of the wells and the time each well ran during the season. This volume was then divided by the acreage being irrigated to result in a seasonal depth of applied irrigation water. The applied water from the sample sites was then related to the irrigation demand (calculated with the Blaney-Criddle equation). The relationship could then be used to extrapolate the depth of applied irrigation water for unsampled areas within the High Plains. Acreage and types of crops within unsampled areas were determined through Landsat imagery.

2.6 Efficiency Studies

Studies culminating in higher irrigation efficiencies are prevalent on the High Plains today. Researchers are evaluating several different management strategies that will result in maximizing yields while minimizing irrigation. Different crop rotations have been considered for reduced irrigation (Schneekloth, et al. 1991) and for minimizing soil water leaching between growing seasons (Klocke, et al. 1996). Also, the timing of water applications for the purpose of reducing irrigation without adversely affecting dollar per acre net returns has been investigated (UNL, 2000). It seems there are many things a farmer can do to decrease their irrigation applications without losing money. Some farmers are even using beef fat byproducts from processing plants to reduce the transpiration rates of their crops. Several crops are able to withstand a coating of fat without reducing photosynthesis or yield (Opie, 2000). High Plains farmers have great faith that technology will find a way to extend the aquifer life through improved efficiencies.

Farmers on the Eastern Plains were reported to have the greatest percentage of college graduates farming in Colorado (Frasier, et al 1999). They also reported having the highest gross farm sales in Colorado. They have the highest percent of farmers utilizing best management practices (BMP) for all irrigation practices in Colorado (Frasier, et al. 1999). They employ low-pressure sprinkler systems and many have drop nozzles on their center pivot systems to reduce losses to evaporation. The Eastern Plains farmer appears to be concerned with efficient irrigation practices and aquifer longevity.

2.7 Fish and Wildlife

Due to the modification of streams and rivers across the United States for human benefit (irrigation, power, etc.), fish and wildlife habitat has been compromised (Richter, et al. 1997). Therefore, many states are conducting studies to restore their streams (Barinaga, 1996). Yet, stream flow is a dynamic property when it comes to creating appropriate habitat. Merely maintaining a minimum flow will not reestablish the native characteristics of a stream that fish and wildlife have adapted to (Barinaga, 1996, Poff, et al. 1997, Strange, et al. 1999). In fact, Poff et al. (1997) outlines five critical components of the flow regime that regulate ecological processes: magnitude, frequency, duration, timing and flashiness. These must be considered in order to make proper management recommendations for stream flow. For example, on a small stream on the eastern Plains of Colorado, the minimum and maximum *magnitude* of flow must allow for enough water to provide stream connectivity, yet remain low enough for the small fish to readily move between habitat units. The *frequency* of occurrence of flow above a given magnitude must be considered to allow for the seasonal scouring of pools. The *duration* of specific flow conditions is also very important. For example, the floodplain must be inundated long enough for spawning and hatching of minnow larvae. The *timing* or seasonal regularity of flows must be considered as well. Finally, the *flashiness* or rate of flow change from one magnitude to another must be relatively stable for small fishes to persist (Schlosser, 1985).

Colorado Recovery Programs

The state of Colorado has several "recovery" programs in place concerning fish and wildlife habitat along the South Platte River. Specifically, whooping crane habitat in Nebraska and habitat for the pallid sturgeon are being targeted for recovery (Morgenweck, 2001). The South Platte has been greatly modified for irrigation purposes. With 15 interbasin diversions adding water from the Western Slope and about 1000 reservoirs (Dennehy, et al. 1993), the South Platte is frequently compared to a plumbing system (Strange, et al. 1999). Further modification may be the key to sustaining ecosystem services. For example, the Tamarak Project uses groundwater recharge to augment flows in low-flow time periods to sustain critical habitat. During times of no-call on the river, ten pumping wells located next to the river pump water into recharge basins several hundred meters away. The return flow reaches the river during times when flow augmentation is most needed (Flory and Halstead, 2001). This experimental project attempts to satisfy habitat requirements without adversely affecting water rights of irrigators.

New Mexico Recovery Program

Similarly, the silvery minnow (*H. amarus*) in New Mexico is listed as federally endangered due to altered flow regimes, sediment budgets and fragmented habitat. The long-term conservation goal includes managing stream flow so that it is sufficient for the silvery minnows' life cycle (USFWS, 1999). Annual dewatering of the river due to diversions for irrigated agriculture has been recognized as the major threat to the extant populations of the silvery minnow on the Rio Grande. Thus, alternate management practices for ditch companies, such as rotational water delivery, are being investigated (Barta, 2003).

CHAPTER 3: METHODOLOGY

To address the research objectives set out in this study, the study area was carefully defined and the irrigation practices and river parameters were described. First, to better understand the methodologies and efficiencies of the irrigating farmers within the study area, the cropping patterns, the irrigation water use and the overall water requirements of the crops were described. Next, to estimate the quantity of water withdrawn for agriculture, well discharge data and irrigation duration data were obtained from individual farmers. Data regarding well appropriation discharge were used to supplement this information. Water quantity changes throughout time on the Arikaree were described by traversing the stream and detailing its connectivity. Also, early season flow data, downstream flow data from a USGS gauge, and stage height of the river at four separate locations were identified. Finally, the stage height data were correlated with data depicting water quantity withdrawal from the aquifer, to investigate the relationship between pool depth and the quantity of groundwater that is pumped for irrigation throughout the summer.

3.1 Study Area

The Arikaree River lies in the Republican River Basin on the Northern High Plains of Colorado. A groundwater dependent stream, it cuts into the Ogallala aquifer, and obtains its flow from springs and seeps. Discharge into the stream channel occurs wherever the aquifer head is higher than the elevation of the river bottom. Pierre shale lies just below the channel bottom (MWE, 1999). The stream begins in Colorado near Lincoln and Washington counties and flows tend northeast through Yuma County and across the Nebraska border just north of Kansas (Figure 2).

Far out on the Eastern Plains of Colorado, this river obtains no runoff from mountain snowmelt. With improved farming techniques such as land leveling, and terracing, it also receives very little runoff from irrigation return flows (Solek, 1996). Geological formations that outcrop in the Arikaree basin include alluvium, dune sands, Peorian loess, the Ogallala formation and Pierre Shale.

The portion of the river studied was from county road M to highway 385, approximately 9.65 kilometers (6 mi.) north and 9.65 kilometers (6 mi.) south of the river. Data collected in 1999 for the Nature Conservancy by McLaughlin Water Engineers, Ltd., indicate that the area contributing groundwater to the river is only 4.83 to 9.65 kilometers (3-6 mi.) from each side of the river through the Fox Ranch (MWE, 1999). In some cases, boundaries were extended to include areas where representative farmers had land. The red line on the map in ArcView (Figure 2) represents the study area boundary. This area includes Fox Ranch (Figure 2), which is the lowest topographical area in the region and is owned by The Nature Conservancy. The stretch of river that flows through the ranch is one of the few perennial stretches along the entire river.

The hydraulic conductivity of the Ogallala formation generally yields 31.54 to 126.2 liters per second (500 to 2000 gal/min.) to wells. Specific yield ranges from 0.1 to 0.3. Transmissivity generally ranges from about 620.9 to 3725.4 m^2 per day (50,000 to 300,000 gpd/ft, MWE 1999).

The climate of the High Plains is semi-arid and the river appears as a sort of oasis among the dry, vast, openness of the Great Plains. The trees and riparian areas seem to arise out of nowhere as one enters the small valley, and disappear just as quickly. The average June temperature in Yuma County is 24°C (75.2° F) and the average yearly rainfall is 42.4 centimeters (16.7 in., www.consideryumacounty.com).

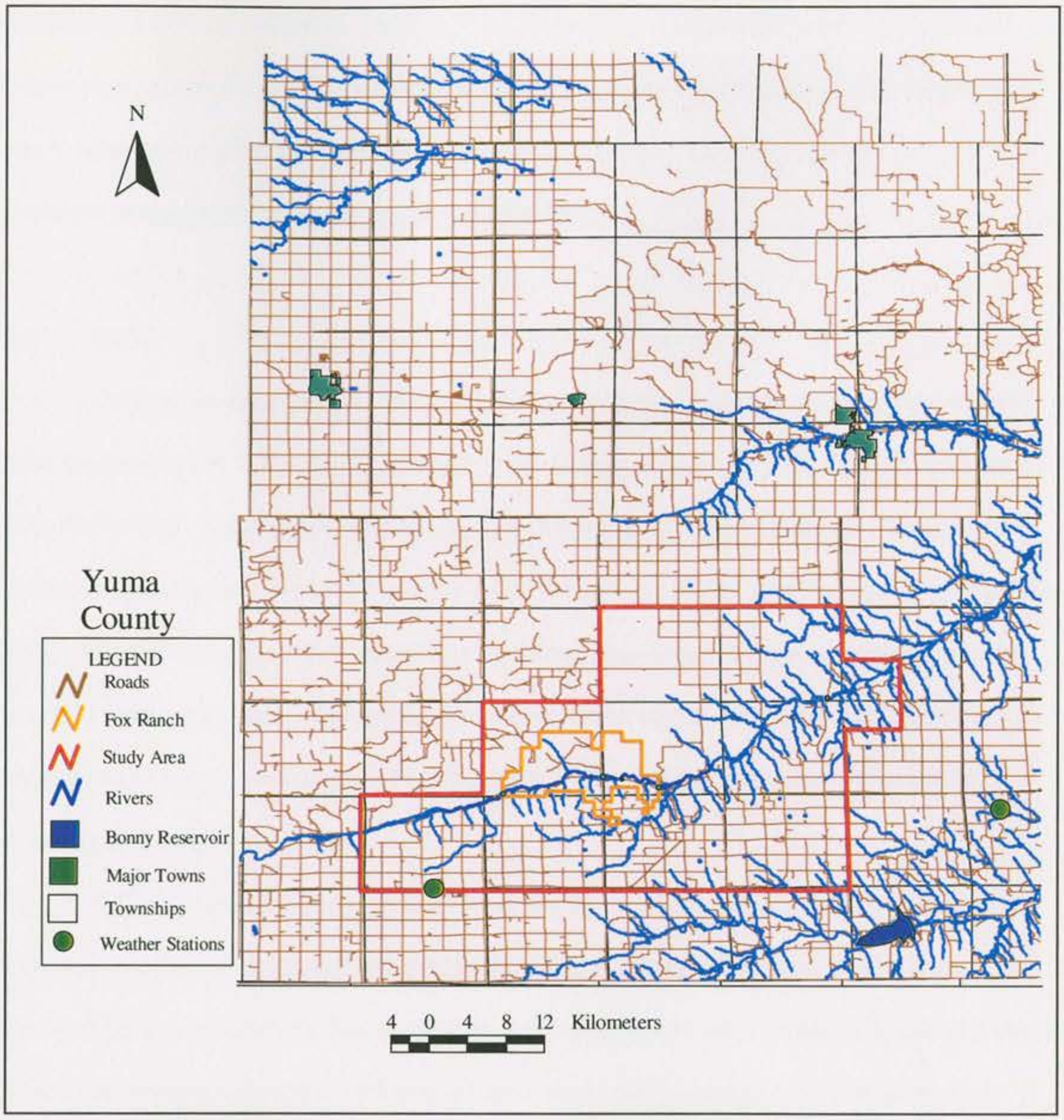


Figure 2. Map of Yuma County Including Fox Ranch and Study Boundary.

3.2 Farmer Interviews

Six farmers that live within this area were interviewed about their land and irrigation practices. These farmers were thought to be most cooperative and highly representative of farmers in the area by CSU cooperative extension and by The Nature Conservancy. These professionals previously notified all farmers who were contacted. Upon the recommendation of water managers in the area, these farmers were not explicitly told that this research involved any threatened or endangered species in their area. Rather, the section of the study that included farmer input merely focused on the irrigation practices of farmers in lower Yuma County and how irrigation was affecting water table levels in the aquifer. An example of the interview questions that were asked can be found in Appendix A.

3.3 GIS

To generate the GIS maps used to describe the river; shape file data were downloaded from the Internet for Yuma County. Roads, water bodies, towns and geological features came from the web site http://www.dola.state.co.us/oem/cartography/Tiger2000.htm. The shape file, which contains the township and range data, came from http://nationalatlas.gov/plssm.html. The PASIS lab (Pedology And Soil Information Systems Laboratory) at Colorado State University provided center pivot data. These data were generated by satellite imagery. Center Pivots were located on the imagery and digitized using ArcGIS. The data were then field checked for accuracy by PASIS employees.

Unfortunately, the center pivot file was not projected in the same grid as the other GIS data used in this project. Therefore, the file had to be re-projected using ArcGIS software. A former PASIS employee who had worked on the original center pivot project assisted with the re-projection. Somehow, because of the translation, the center pivot shape file did not line up exactly where the pivots are truly located (see figure 21 of Results). Thus, when interpreting the center pivot shape file, it should be noted that the pivots should be located a few feet south, or slightly down the page, so that they not cross over streets and rivers. This was confirmed with maps from the Yuma County Natural Resource Conservation Service office that contained center pivot locations in this area.

3.4 Weather

Climate can influence the decisions of the irrigating community within the study area as well as the quantity of water in the Arikaree River. Therefore, meteorological data for the years 2000-2002 were collected from the CoAgMet website, which is maintained by Colorado State University (ccc.atmos.colostate.edu/~coagmet/). The station contributing necessary data is located near Idalia, Colorado and is near the study area. This station was selected because it was said to be 3.2 kilometers (2 mi.) north of Idalia, which would have placed it within the study site. However, upon locating the station with ArcView, it was discovered that it is also several kilometers east of Idalia (Figure 2). The location is still very near the majority of the representative farmers, and therefore was considered the best station for meteorological data. Another more western station, near the town of Kirk, was considered for data collection. Although it is located within the study area boundary, more of the representative farms were closer to the initial station.

3.5 Crop Data

The cropping patterns of the study area were investigated to help understand the methodologies and efficiencies of the irrigating farmers. Cropping data were collected from individual farmers, the Farm Services Agency of Yuma County, and a USDA website. First, the six interviewed farmers detailed the crops they were growing during the 2002 season. The reported crop types and acreage were confirmed through Farm Services Agency by reviewing files, specific to each farmer, that list reported acreage by crop. These data were analyzed in terms of the percentage of each crop that was grown by the small group of farmers.

Next, data were obtained for the study area as a whole. Acreage and types of crops grown in 2001 within 6.4 kilometers (4 mi.) north and south of the river between the westernmost boundary of the Fox Ranch, and the CDOW site at Highway 385 were obtained from the Farm Services Agency. The Farm Services Agency did not have any comprehensive records of cropping acreage for areas of Yuma County. Therefore, these data were obtained by reviewing aerial photographs of the area and determining which areas were farmed. Geometry and coloration of the plots of land helped to identify farmed areas. These areas were then correlated to identification numbers, which identified files with the desired information. The acreage farmed for representative farmers was compared to the acreage farmed within the whole study site to determine how representative the farmers were of the study area.

Finally, due to the difficult nature of the data collection at the Farm Services Agency, the results of the cropping patterns within the study site were compared to the cropping patterns of Yuma County, for accuracy. Data for Yuma County crop acreage came from the website: http://www.nass.usda.gov:81/ipedb/.

3.6 Well Data

Data from the Office of the State Engineer

In order to estimate the quantity of water withdrawn for agriculture within the study area, the number of operating wells and their pumping capacities had to be determined. Well design depth and initial pumping capacity were obtained from the Office of the State Engineer for all wells within the study site area, approximately one township (9.65 kilometers (6 mi.)), on each side of the river (Appendix B). The initial permitted pumping capacities of wells owned by the interviewed farmers were compared to current pumping rates. Also, the well data from the State Engineers Office were used to determine the total number of irrigation wells within the study area. No stock wells or domestic wells were considered due to their minimum pumping capacities compared to irrigation usage. The number of wells within the area was used to compute the average volume of water being extracted from the aquifer within the study site. Three wells were omitted due to their exceptionally old age or low flow. These wells were also cross-referenced with the location of center pivots from the PASIS shape file in ArcView. It was determined unlikely that these wells are operating, as there is no crop circle near the wells' locations.

Data from Farmers

Also, interviewed farmers stated how many wells they used, the discharge of each well and how long each well was operated during the 2002 irrigation season (see Table 6, section 4.4). Names of farmers were omitted from these data to protect the individuals' anonymity. Where available, the discharge of each well was confirmed by comparison with records from a local well testing company (Y-W Well Test). An ultrasonic flow meter (Polysonics DCT7088) was used to confirm discharge for untested wells of cooperating farmers. In the case where the farmer would not allow a flow meter to be used on his wells and the local company had never tested the wells, the farmer's estimate of discharge was used.

When professionally testing a farmer's well, the local well testing company, Y-W Well Test uses a "Collins meter" to find the flow velocity. The pipe dimensions are used to translate the velocity into discharge. Y-W Well Test services many wells Yuma county, helping farmers to increase the efficiencies of their irrigation systems. For this study, unknown flows were tested with an ultrasonic flow meter made by Polysonics, model DC T7088 which measures the discharge of a well from the outside of the pipe (Figure 3). Y-W Well Test also assisted with these measurements. The flow meter sends an ultrasonic pulse into the pipe through one of two transducers. The instrument can measure the velocity of the water and thus the discharge flowing through the pipe by measuring the time for the pulse to return to the second transducer.

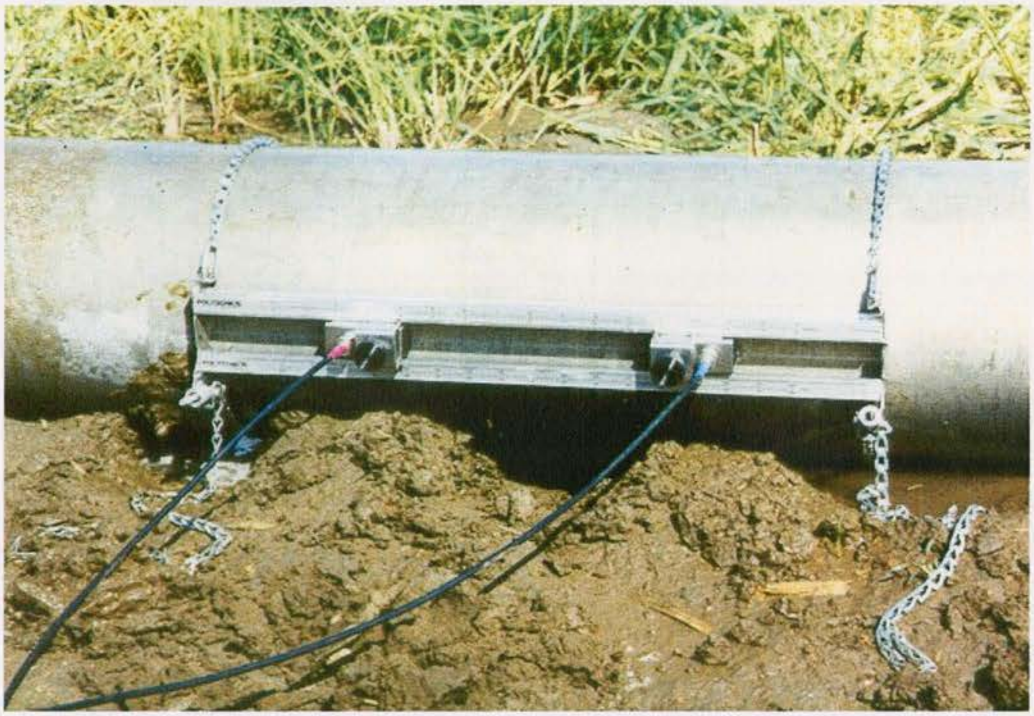


Figure 3. Ultrasonic Flow Meter on an Irrigation Pipe.

3.7 Crop Water Requirements

To describe the efficiencies of the irrigating farmers, evapotranspiration rates and meteorological data were obtained from Colorado State University's CoAgMet website (ccc.atmos.colostate.edu/~coagmet/). CoAgMet uses a modified Pennman equation to estimate ET rates for several commonly grown crops. Daily ET rates for corn, alfalfa, beans and small grains were taken directly from this website. For sorghum, daily evapotranspiration rates were calculated by computing a daily crop coefficient, according to the method outlined by Duke, et al. (1991). This coefficient was then multiplied by the daily reference ET calculated by CoAgMet. This method was designed for use with the Pennman equation and is specific for crops on the Eastern Colorado Plains. Evapotranspiration rates of millet were assumed to be similar to those of sorghum and were analyzed as thus. This assumption was made by comparing evapotranspiration calculation methods for both crops as outlined by Allen, et al. (1998).

Daily evapotranspiration was summed for the week and total weekly precipitation was subtracted to find the total weekly crop water requirements for each crop grown by the representative farmers. Then, the weekly total depth of water applied to each field was calculated and compared to the crop water requirements to estimate irrigation efficiency for each farmer (Appendix C). The weekly depth of water applied was calculated by multiplying the pumping rate by the time the well was run and dividing it by the area to which it was applied. An application efficiency factor of 0.9 was applied to equations for center pivot systems. Surface gravity systems were multiplied by an application efficiency factor of 0.7.

3.8 Stream Data

Several aspects of the Arikaree River were analyzed in order to describe the temporal water quantity changes. Connectivity, or areas of continuous flow, was analyzed for the stream throughout the Fox Ranch and compared with the Scheurer (2002) study. Early season flows and flow from a USGS gauging station were also assessed. Finally, stage height of the river at various locations was followed throughout the season.

Connectivity

A Magellan GPS 2000 XL Global Positioning Satellite receiving unit was used to identify points along the Arikaree River to determine stream connectivity. The points were located approximately 0.8 kilometers (0.5 mi.) from each other from the East to the West boundary of Fox Ranch. The location of each point was saved in the GPS unit and the "go to" function was utilized on subsequent data collection trips as a guide to each point. The locations of these points can be viewed on the GPS map in figure 11 of the "Results" section. Each point received a rating of connectivity at the end of each month (Table 1).

Ratings were as follows:

Table 1. Connectivity Codes

Dry	0
Marshy	1
Puddle/not connected	2
Deep Pool	2.5
Puddle/connected	3
Connected	4

Ratings were chosen based on a visual description of the stream and its likelihood to be utilized by the minnow as habitat (Figure 4). "Connected" areas were determined to be smooth channels of water, which may be flowing. Habitat units such as pools, runs and backwaters may be found in "connected" areas. In stream morphology, during low flow, a pool is an area of deeper, slower moving water usually located on a bend of a meandering stream. A run or a riffle is the area between the pools where the water may be shallower and flowing faster. A backwater is an area near tributaries or natural impediments where the water has been slightly backed up, but not to the extent of forming a true pool (Thorne, 1997). All three of these areas are considered habitat units in the study conducted by Scheurer (2002).

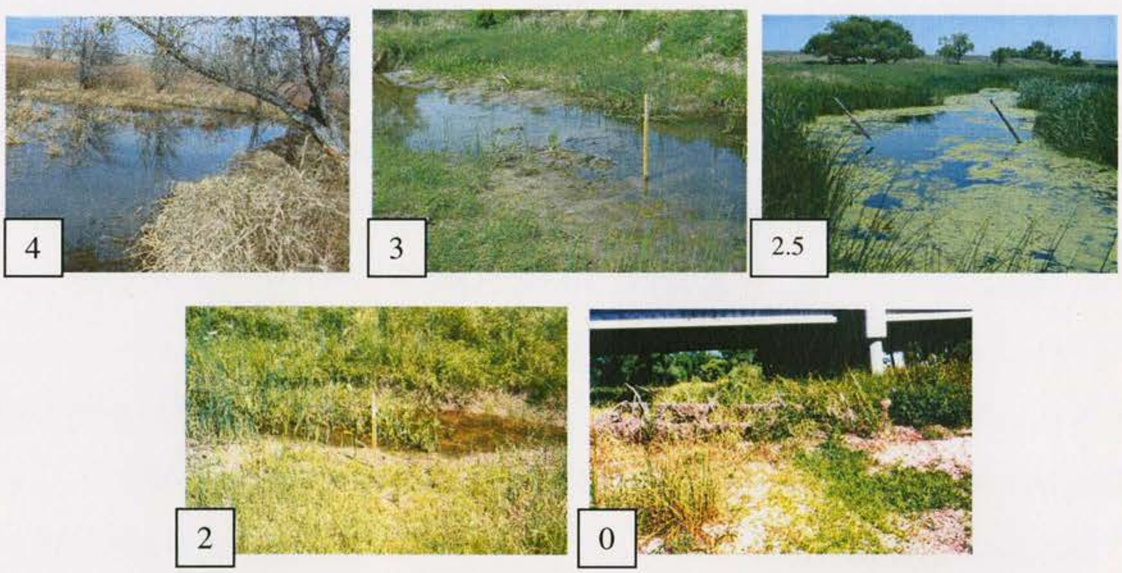


Figure 4. Examples of Connectivity Ratings.

"Puddle/connected" ratings were defined as a series of irregular puddles that are connected to each other and do not flow. "Puddle/connected" ratings differ from "connected" in the irregularity of their shape and the lack of flow between the puddles. A "deep pool" was considered an isolated segment of deep water that does not flow. A "deep pool" may be considered adequate habitat for aquatic life. Areas identified as "deep pools" were isolated pools and are not to be confused with normal pools found in connected areas. "Puddle/not connected" ratings were described as isolated pools of shallow. These puddles were not considered to have adequate quantities of water to support minnow persistence. Areas rated as "marshy" were muddy areas with saturated soils. No surface water was visible in these areas. These areas also frequently supported cattails (*Typha spp.*) and other riparian vegetation. Finally, areas that were rated as "dry" were areas with no visible surface water and soil that appeared unsaturated at the surface.

These data were translated into a Geographic Information System (GIS) using Arc View and compared to Scheurer's data from 2000 and 2001. Scheurer (2002) used low-altitude flights and observance by foot to approximate connectivity. Her results are shown as continuous, stippled and dashed lines along a map of the river in a GIS format. Connectivity data obtained in 2002 were translated into a similar format. However, since connectivity was evaluated on a point-by-point basis along the entire stretch of river flowing through the ranch, the connectivity of the area between points had to be approximated.

Early Season Flow

The Nature Conservancy collected flow data at various points along the river, throughout the study area, in early April 2002. These data are useful for describing the stream prior to the irrigation season and are presented in the results.

The Colorado Water Conservancy Board owns rights to the stream flow through the section of the river between 39 43.44N 102 36.46W and 39 46.13N 102 21.37W (Figure 5).

There should be 3.2 kilometers (2 mi.) of flow equaling 0.042 cubic meters per second (1.5 ft^3/sec), 11.26 kilometers (7 mi.) of 0.1 cubic meters per second (3.5 ft^3/sec) and 8 kilometers (5 mi.) of 0.2 cubic meters per second (7 ft^3/sec, http://cwcb.state.co.us/isf/database).

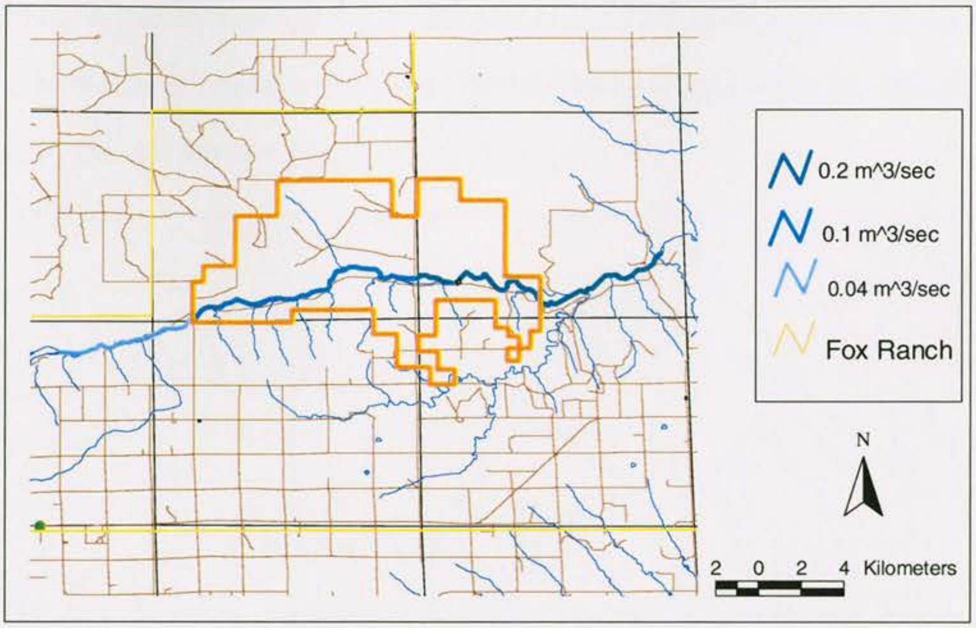


Figure 5. Instream Flow Rights.

Stream Gauge at Haiglar NE

Furthermore, stream flow data were collected from an on-line source that records data from a gauge at Haiglar Nebraska, 48 kilometers (30 mi.) downstream of the Highway 385 site. This gauge is also on a perennial stretch of the Arikaree River and has been observed since the 1930s by the USGS. These data were collected from the on-line site: http://waterdata.usgs.gov/ne/nwis/nwisman/?site_no=06821500&agency_cd=USGS.

While these data cannot be directly compared to flow rates within the study area, they are useful in describing the river as a whole, and the regional climatic effects on the stream.

Stage Height

Stream depth was collected at four points along the Arikaree River three times per week from early June until late August. From August to November, the data were collected once a week. Measuring sticks were inserted into the river bottom near the center of the stream and the depth of the river was recorded at this point. The four points were chosen as West Ranch, U road, East Ranch, and Highway 385 (Figure 6).

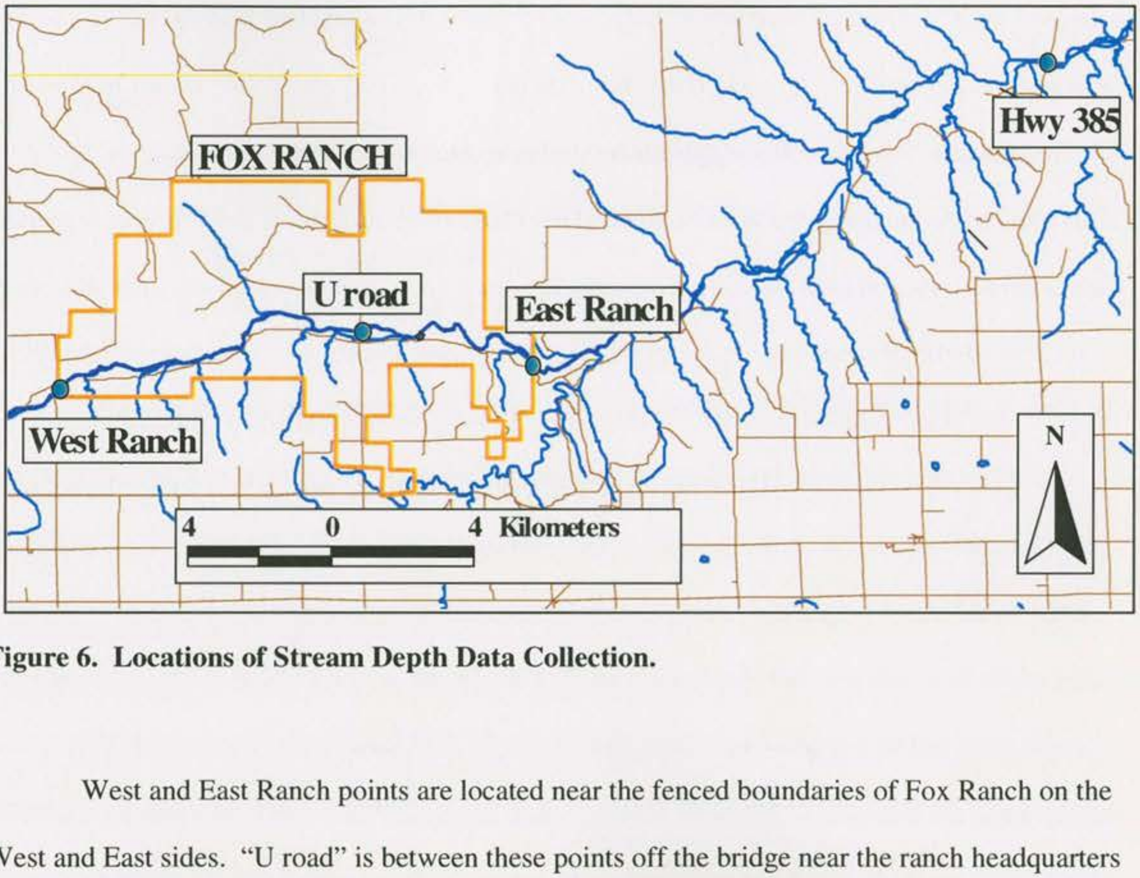


Figure 6. Locations of Stream Depth Data Collection.

West and East Ranch points are located near the fenced boundaries of Fox Ranch on the West and East sides. "U road" is between these points off the bridge near the ranch headquarters on U road. "Highway 385" point is located under the bridge where the Arikaree crosses Highway 385 on land owned by the Colorado Department of Wildlife.

An attempt to collect flow data was made in early June, yet the river had already ceased flowing. Flow rates remained unattainable throughout the study period. A final attempt to collect flow data was made in November. At this time, the river had still not attained measurable flow levels. Thus, stage height was the only parameter measured at these sites to describe the stream.

3.9 Irrigation vs. Stage Height

To correlate the stage height of the river with irrigation, the quantity of water pumped by each irrigator was calculated on a weekly basis. This was computed by multiplying the pumping rate by the duration of the irrigation. This quantity was converted to cubic meters and summed for all the wells for each week of the irrigation season.

$$V = G * t * d * \frac{m^3}{264.2gal}$$

where,

V= Volume of water extracted by a well in one week (m^3)

G= Pumping rate of the well in gallons per minute

t= Minutes in one day (1440)

d= Days pump was run in one week

This volume was summed for all farmers and divided by 33, the total number of wells to represent the average quantity of water being extracted by each well sampled. The result was multiplied by the total number of irrigation wells within the study area, 114 in all. Thus, an average, weekly volume of water pumped from the aquifer in the vicinity of the Arikaree River was calculated and compared to the stage height of the river within the boundaries of study area.

A Pearson correlation (SAS/STAT®, 2000) was used to determine whether there was a statistical correlation between the volume of water pumped from the aquifer and the stage height of the river at the various locations. First, irrigation and stage height were analyzed concurrently in time. Next, stage height data were lagged by 2.5 weeks in order to account for the response time of the river as it pertains to the stream/aquifer interactions. Finally, initial stream response and recovery response were analyzed separately to account for the different effects of stream depletion and recovery.

CHAPTER 4: RESULTS

4.1 Weather

The Eastern Plains of Colorado experienced a severe drought during the summer of 2002. It was the driest year in recorded history (High Plains Climate Center http://www.hprcc.unl.edu). Where the area usually reports around 33 centimeters (13 in.) of rain from March through August (MWE, 1999), the meteorological station located near Idalia, Colorado only reported 7.4 centimeters (2.9 in.) during the summer of 2002 (Table 2). The temperature was also very hot during this time period with 15 days of high temperatures reaching over 38 degrees Celsius (100° F) and 27 days over 37 degrees Celsius (98° F). This compares with only 5 and 7 days of high temperatures over 38 degrees Celsius (100° F) in 2001 and 2000 (Table 2).

Table 2. Meteorological Data from Idalia Station

	March – August		
	2002	2001	2000
Max Temp (C)	41.3	38.9	39.1
Max Temp (F)	106.4	102.1	102.4
Days > 37°C (98°F)	27	12	13
Days > 38°C (100°F)	15	5	7
Precip Sum (cm)	7.39	32.74	34.72
Precip Sum (in)	2.91	12.89	13.67

4.2 Cropping Data

Data obtained from Farm Services Agency regarding farmers' cropping acreage agreed well with the reported acreage obtained from the interviews. Therefore, it is assumed that the data reported in the interviews is accurate and truthful.

Furthermore, the data collected for the "study site" from the Farm Services Agency is assumed to be accurate because of its similarity to the results of Yuma County as a whole (Figure 7). This comparison is important due to the somewhat difficult nature of the data collection for the study site area. Irrigated corn constitutes 42% of the cropped acreage within the study area. This value is highly comparable to the 45% and 50% of irrigated corn acreage grown in Yuma County as a whole in 2000 and 2001, respectively. Dry corn data were even more similar. Farmers in the study area dedicate about 5% of their cropped land to dry corn. Yuma County reported 6% and 4% of their crops to be dry corn in 2000 and 2001, respectively. Hence, cropping patterns in the study area seem to be very comparable to those in the rest of Yuma County as a whole. Because of the smaller sample size, one would expect the cropping patterns of the representative farmers to be slightly different from that of the entire area surveyed.

It seems that fewer sugar beets and sunflowers are being farmed in Yuma County every year. One farmer explained that they were troublesome to sell in the market because they were sold in far away towns. Also, they are difficult to grow because they are somewhat sensitive to water stress.

Approximately 35% of the total acreage farmed by the representative farmers in 2002 was determined to be irrigated corn (Figure 7). The result compares to 42% of the acreage as corn for the study site determined from records in 2001. Corn percentage reported for interviewed farmers might be lower because of the drought year. One farmer had not planted any corn at all and instead was focusing on crops with lower water needs like sorghum and millet.

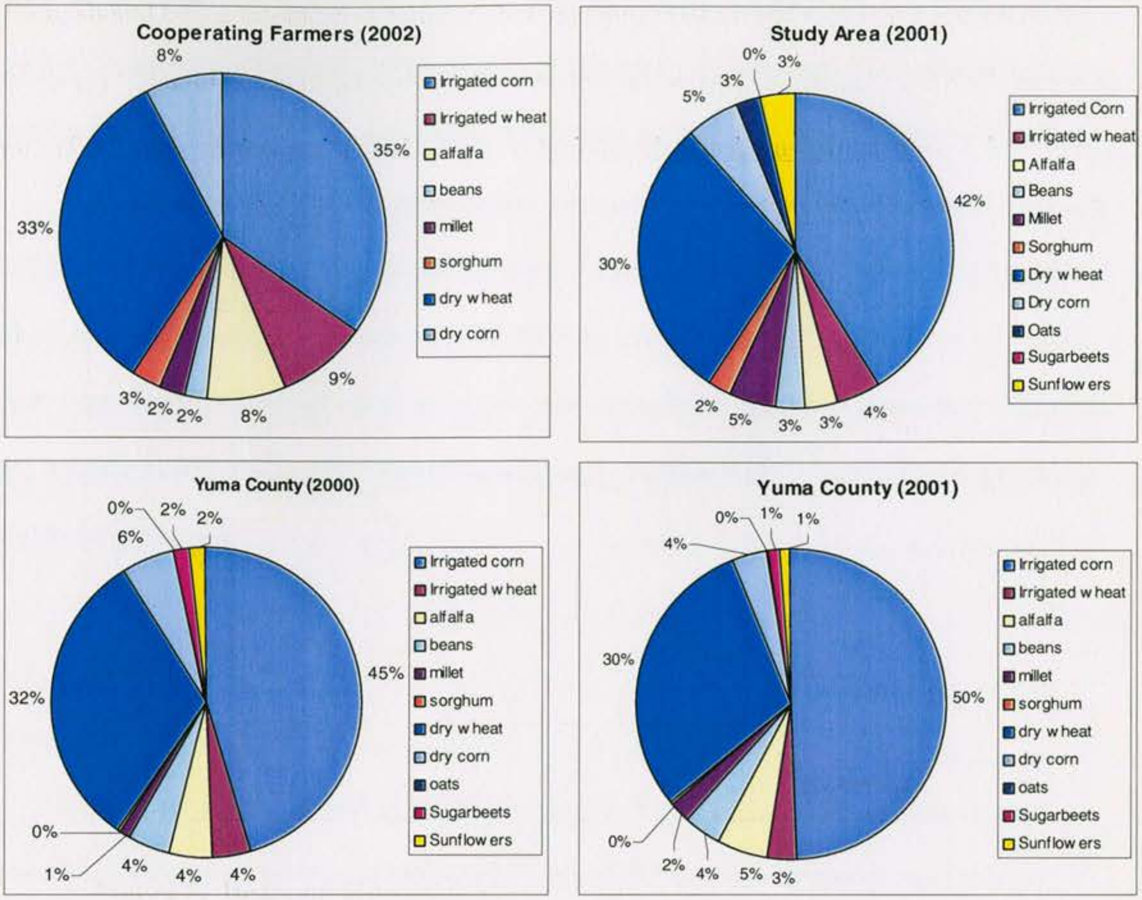


Figure 7. Cropping Patterns—Percent of Cropped Acreage.

Sorghum and millet comprise 5% of the crops grown by the representative farmers. This is similar to the 7% of sorghum and millet grown by farmers within the whole study area.

For the farmers interviewed, about 60% of all cropped acreage are irrigated acreage. However this does not include pasture or native grass acreage grown under the Conservation Reserve Program. None of the farmers interviewed could think of anyone who had switched to dryland farming from irrigated acreage. "Seems like pretty much everyone who has irrigation in this area uses it" claimed one farmer. Corn is the irrigated crop of choice because of the simplicity of selling it and the fair price it carries.

Several of the farmers interviewed also grow alfalfa. In a good year, one can get four cuttings of alfalfa. Although it is a water intensive crop, alfalfa's growing season starts earlier in the year than other irrigated crops. As one farmer explained, the water put on the crop during the earlier, cooler part of the year can be used more efficiently by the crop. Since alfalfa carries a good price, the water spent on the crop is easily made up from the harvest of the first cutting.

According to one farmer, more farmers seem to be planting forage crops like sorghum and millet this year compared to previous years. He explained that the need for cattle feed was likely to be great during the winter of 2002/2003 because the drought had taken its toll on the native grasslands. Although sorghum is somewhat drought tolerant, it is sometimes difficult to get started. In fact, the farmer interviewed who had planted sorghum was unable to produce a viable crop this year.

4.3 Irrigation Practices

Conservation Techniques

Due to the "dust bowls" of the 1930s and 50s, farmers of the Great Plains are very conscious of keeping moisture in their soils. Almost all farmers interviewed utilized soil conservation methods such as no-till farming, crop rotations and sweep, rather than disk plows. These methods help keep soils from blowing away and allow dryland crops to persist.

The decision of when to irrigate varied among farmers. Several farms had been in the family for generations, dating back to the early 1900s. These farmers generally based their irrigation decisions on field experience rather than academic expertise. Farmers who were somewhat newer to the land employed techniques such as gypsum blocks. The Y-W Well Test company in Yuma County, offers a gypsum block program that a few farmers were involved with. They provide the farmers with soil moisture reports and help them with irrigation scheduling. However, during the summer of 2002, none of the farmers utilized irrigation schedules. Because of the severe drought, all farmers interviewed irrigated continuously throughout the season. Occasionally, pumps were turned off for repairs or maintenance. These rare shutdowns lasted less than 48 hours. Strangely, only a few farmers reported beginning their irrigation seasons earlier this year than normal. Despite the lack of spring rains, most farmers admitted running irrigation systems harder (not shutting them off), but not earlier this season.

Most farmers interviewed irrigate with a center pivot system. Occasionally, one well is used to run two center pivots at the same time. Furthermore, nearly all the center pivots employ low-pressure, drop nozzles, or LEPA (Low Energy Precision Application) systems (Figure 8). However, the field on which a LEPA system is used must be very flat and not have hills or elevation changes within the sprinkler path. One farmer who had tried LEPA could not use it because his uneven ground kept pulling the hoses off the center pivot. The farmers who were still using a surface gravity flow irrigation system expressed a desire to change to center pivots as soon as they could afford to do so. Even with gated pipes and surge valves, the farmers feel that efficiencies with the center pivot systems are better than with the surface gravity systems. Increasing water application efficiencies decreases energy costs. One farmer claimed a 25% decrease in his electric bill after he had switched to low-pressure, drop nozzle sprinkler irrigation.

Figure 8. A LEPA Irrigation System.

Well Water Usage

Appendix B shows the initial flow rate for which each well within the study area was appropriated, the date which it was first used, and the depth to which it was drilled. On average, each well within the study area is permitted to pump 73 liters per second (1157 gal/min) to irrigate an average of 75 hectares (185 acres, Table 3). The locations of 22 out of 33 pumps utilized by the representative farmers were matched with the well data from the Office of the State Engineer, and the flow rates were compared. The farmers were initially permitted to pump an average of 74 liters per second (1169 gal/min) from their wells. However, the current flow rates of the same wells averaged only 45 liters per second (718 gal/min). Therefore, the farmers were are only pumping 61% of the water they were initially permitted to pump.

Table 3. Irrigation Data from SEO.

	Liters/sec	(Gallons/min)	Hectares	(Acres)
Average Initial Irrigation--Study Area	73	(1157)	75	(185)
Average Initial Irrigation--Farmers	74	(1169)	76	(189)
Average Current Irrigation--Farmers	45	(718)	76	(189)

Improved efficiencies and conservation techniques such as LEPA and low-pressure drop nozzle sprinkler systems are likely the cause of this efficient and conservative use of groundwater. Since most wells were installed around 1970, before these techniques were commonly utilized, they would have required higher flow rates to meet the needs of the crops.

While the main motivation for employing conservation techniques is economic, farmers also had concern for the longevity of the aquifer that serves them. The aquifer must have favorable hydraulic properties if it is to be useful for irrigation water extraction. For example, a reduced saturated thickness caused by a falling water table can affect the pumping rates of wells. The Arikaree Ground Water Management District reports an average annual water table decline of 9.8 cm (0.32 ft) in this area (Arikaree GWMD, 2002). However, localized decline during the irrigation season is generally much greater. Some farmers are required to pump at lower capacities to prevent the entrance of air into their systems. In groundwater pumping, a "cone of depression" forms around the discharging well. When the water table falls, water cannot enter the well as fast as it is being pumped out of the well and air enters the system. Subsequently, efficiencies are reduced as energy is spent pumping air rather than water. One of the ways Y-W well testing company helps irrigators to be more efficient is by changing some of the irrigation system dynamics to prevent air intake. Some of these changes include altering the pump pressures and changing the pumping rate.

4.4 Crop Water Requirements

Daily evapotranspiration rates for the six crops grown by the representative farmers were calculated and summed for the entire season (Table 4).

Table 4. Seasonal Evapotranspiration Rates.

	Corn	Alfalfa	Beans	Sorghum/millet	Wheat
Seasonal ET (cm)	90.7	120.1	85.6	56.1	37.3
Seasonal ET (in)	35.7	47.3	33.7	22.1	14.7

Due to high temperatures and strong winds, ET rates were very high for the season reaching more than 7.6 centimeters (3 in.) per week for corn at its peak (Appendix C-1). Between the months of March and August 2002, less than 7.6 centimeters (3 in.) of rain fell in this area. Crop water requirements were calculated as evapotranspiration minus precipitation. Therefore, weekly crop water requirements frequently equaled the evapotranspiration rates for the week. Seasonally, irrigation rates could not keep up with crop water requirements and the farmers were in deficit irrigation (Table 5).

Table 5. Crop Water Requirements.

	Corn	Alfalfa	Beans	Sorghum/ millet	Wheat
Seasonal Crop Water Requirements (cm)	83.6	112.9	79.6	49.1	35.4
Seasonal Crop Water Requirements (in)	32.9	44.5	31.3	19.3	13.9
Average Applied Irrigation (cm)	59.1	90.6	60.2	42.3	19.3
Average Applied Irrigation (in)	23.3	35.7	23.7	16.6	7.6
Percent CWR met	70.8%	80.2%	75.7%	86.0%	54.7%

Table 6 describes the irrigation practices of the representative farmers. Colors are used to represent each farmer without identifying him by name. Pumping capacities ranged from 28.4 liters per second (450 gal/min) to over 63.1 liters per second (1000 gal/min). Many of the higher capacity wells were used to run two center pivots at the same time, or were alternated between two circles. Occasionally, more than one type of crop was grown within the same circle under the same center pivot system (Table 6).

Crop water requirements for alfalfa reached over 7.6 centimeters (3 in) per week for the majority of June, July and the first half of August. They averaged 8.31 centimeters (3.27 in) per week in July (Table 6). During the peak summer months, farmers were unable to meet the crop water requirements for alfalfa. Alfalfa irrigation usually begins early in the season, during April or May. In a normal year, irrigated alfalfa can be cut up to four times during the season. A few alfalfa growers were only able to harvest two or three cuttings during 2002. Farmers with large wells and early irrigation onset seemed to produce the best yields.

Farmers growing corn had similar deficits during the 2002 season. Some began their irrigation in May. During this time the irrigation exceeded the crop water requirements. By mid-June, all farmers had begun irrigating corn. Despite the constant irrigation, none were able to exceed the calculated crop water requirements of the corn during the hottest parts of the summer.

Table 6. Irrigation Data from Interviewed Farmers.

Brown	Area		crop	irrigation		Max Irrigation		Avg CWR (July)		yield	
L/sec (gpm)	hectares	acres		begins	ends	cm/wk	in/wk	cm/wk	in/wk	metric	English
28.4 (450)	48.2	119	corn	24-Apr	24-Aug	3.20	1.26	6.48	2.55	0	0
56.8 (900)	42.1	104	corn	30-Jun	30-Aug	7.34	2.89	6.48	2.55	12855 kg/ha	205bu/acre
41 (650)	50.6	125	corn	28-Apr	30-Aug	2.21	0.869	6.48	2.55	0	0
	47.0	116	alfalfa	28-Apr	25-Sep	2.39	0.94	8.31	3.27	10080 kg/ha	4.5 ton
50.5/63.1 (800/1000)	37.2	91.9	corn	28-Apr	1-Sep	3.23	1.27	6.48	2.55	0	0
	61.5	151.9	corn	28-Apr	1-Sep			6.48	2.55	4703 kg/ha	75 bu/acre
41 (650)	40.5	100	corn	28-Apr	30-Aug	3.18	1.25	6.48	2.55	100 kg/ha	195 bu/acre
	30.0	74	alfalfa	28-Apr	25-Sep			8.31	3.27	10080 kg/ha	4.5 ton
69.4 (1100)	48.6	120	alfalfa	13-Apr	25-Sep	7.77	3.06	8.31	3.27	14559 kg/ha	6.5 ton
44.2 (700)	47.0	116	alfalfa	13-Apr	25-Sep	5.11	2.01	8.31	3.27	14560 kg/ha	6.5 ton
Pink	Area		crop	irrigation		Max Irrigation		CWR (June-July)		yield	
L/sec (gpm)	hectares	acres		begins	ends	cm/wk	in/wk	cm/wk	in/wk	metric	English
56.8 (900)	94.0	232	corn	14-Jun	30-Aug	2.57	1.01	6.48	2.55	21952 kg/ha	9.8 ton/acre
58.3 (925)	49.8	123	corn	14-Jun	30-Aug	3.20	1.26	6.48	2.55	8541 kg/ha	136.2 bu/ac
	32.6	80.5	corn	14-Jun	30-Aug	4.88	1.92	6.48	2.55	6114 kg/ha	97.5 bu/ac
28.6 (454)	50.2	124	corn	14-Jun	31-Aug	3.10	1.22	6.48	2.55	27462 kg/ha	12.26 ton/acre
47 (745)	39.7	98	corn	14-Jun	31-Aug	5.03	1.98	6.48	2.55	8253 kg/ha	131.6 bu/ac
84.1 (1334)	45.8	113	corn	14-Jun	31-Aug	4.22	1.66	6.48	2.55	10604 kg/ha	169.1 bu/ac
	38.5	95	pintos	14-Jun	31-Aug			8.31	3.27	72.3 bags/ha	29.3 bags/acre
73.8 (1170)	2.8	7	corn	14-Jun	31-Aug	6.43	2.53	6.48	2.55	9162 kg/ha	146.1 bu/ac
	45.8	113	pintos	14-Jun	31-Aug			8.31	3.27	61.7 bags/ha	25 bags/acre
Blue	Area		crop	irrig		Max Irrigation		CWR (June-July)		yield	
L/sec (gpm)	hectares	acres		begin	ends	cm/wk	in/wk	cm/wk	in/wk	metric	English
41.8 (662)	50.6	125	corn	5-May	28-Aug	4.50	1.770	6.48	2.55	13169 kg/ha	210bu/acre
48.6 (771)	50.6	125	corn	5-May	28-Aug	5.23	2.060	6.48	2.55	13671 kg/ha	218bu/acre
36.5 (578)	49.8	123	corn	5-May	28-Aug	3.99	1.570	6.48	2.55	13044 kg/ha	208bu/acre
42.5 (673)	48.6	120	corn	5-May	28-Aug	4.75	1.870	6.48	2.55	13483 kg/ha	215bu/acre
36.6 (581)	48.6	120	corn	5-May	28-Aug	4.11	1.620	6.48	2.55	13169 kg/ha	210bu/acre

Table 6. (cont.)											
Red	**Area**		**crop**	**irrigation**		**Max Irrigation**		**CWR (June-July)**		**yield**	
L/sec (gpm)	**hectares**	**acres**		**begins**	**ends**	**cm/wk**	**in/wk**	**cm/wk**	**in/wk**	**metric**	**English**
25.2 (400)	51.2	126.3	wheat	14-Apr	15-Jun	2.69	1.06			---	---
	50.6	125	sorghum	15-Jun	26-Aug	2.69	1.06	4.85	1.91	0	0
25.2 (400)	48.6	120	wheat	14-Apr	15-Jun	2.82	1.11			---	---
	24.3	60	millet	7-Jul	26-Aug	5.66	2.23	4.85	1.91	2240 kg/ha	1ton/acre
25.2 (400) (2 circles)	36.5	90	wheat	14-Apr	15-Jun	1.42/2.82	0.56/1.11			---	---
	12.2	30	sorghum	14-Apr	15-Jun			4.85	1.91	0	0
	26.3	65	sorghum	14-Apr	26-Aug			4.85	1.91	0	0
	22.3	55	millet	14-Apr	26-Aug			4.85	1.91	2240 kg/ha	1ton/acre
18.9 (300)	45.0	111.2	millet	14-Apr	26-Aug	2.29	0.901	4.85	1.91	2240 kg/ha	1ton/acre
Green	**Area**		**crop**	**irrigation**		**Max Irrigation**		**CWR (June-July)**		**yield**	
L/sec (gpm)	**hectares**	**acres**		**begins**	**ends**	**cm/wk**	**in/wk**	**cm/wk**	**in/wk**	**metric**	**English**
50.5 (800)	52.7	130	corn	2-Jun	26-Aug	5.21	2.050	6.48	2.55	9406 kg/ha	150 bu/ac
50.5 (800)	52.4	129.3	corn	2-Jun	26-Aug	5.23	2.060	6.48	2.55	11288 kg/ha	180 bu/ac
50.5 (800)	57.5	142	corn	2-Jun	26-Aug	4.78	1.880	6.48	2.55	7525 kg/ha	120 bu/ac
37.8 (600)	54.7	135	corn	2-Jun	27-Aug	3.76	1.480	6.48	2.55	1254 kg/ha	20 bu/ac
31.5 (500)	51.8	128	alfalfa	2-Jun	30-Jun	3.33	1.31	8.31	3.27	3360 kg/ha	1.5 ton (2 cuttings)
Turquoise	**Area**		**crop**	**irrigation**		**Max Irrigation**		**CWR (June-July)**		**yield**	
L/sec (gpm)	**hectares**	**acres**		**begin**	**ends**	**cm/wk**	**in/wk**	**cm/wk**	**in/wk**	**metric**	**English**
56.8 (900)	81.0	200	wheat	5-May	15-Jun	3.40	1.34			---	---
50.5 (800)	23.8	58.8	corn	2-Jun	28-Aug	5.77	2.27	6.48	2.55	3951 kg/ha	63 bu/acre
	23.8	58.8	sorghum	2-Jun	28-Aug			4.85	1.91	8960 kg/ha	4 ton/acre
	47.8	118	wheat	5-May	2-Jun	5.74	2.26			---	---
50.5 (800)	64.0	158	corn	2-Jun	28-Aug	4.29	1.69	6.48	2.55	8403 kg/ha	134 bu/acre
	63.8	157.5	wheat	5-May	2-Jun	4.32	1.7			---	---
56.8 (900)	32.4	80	corn	26-May	28-Aug	4.78	1.88	6.48	2.55	10034 kg/ha	160 bu/acre
	32.4	80	alfalfa	26-May	28-Aug			8.31	3.27	11200 kg/ha	5 ton/acre

In fact, in July the smallest wells were only 40-50% efficient (Table 6). On average, farmers were approximately 29% short of the crop water requirements during the entire season (Table 5).

Several farmers had fields on which they were not able to harvest any corn. Those with small wells (less than 50.5 liters/sec (800 gal/min)) did not generally have good yields unless they began watering very early in the season (Table 6). Those who attempted to divide their wells between two or more center pivots also did not seem to have good yields. Besides the earlier watering schedule, higher yields may be attributed to better soils or fertilization methods. However, water quantity and irrigation timing were the only parameters measured in this study. Some farmers were able to harvest their corn for silage. Most dryland corn also went for silage. Corn harvested for this purpose can have fewer ears than corn that is harvested for grain. Thus, it appears that constant irrigation that began early in the year and continued throughout August was beneficial for obtaining profitable crops during the 2002 season. Despite the efforts to irrigate in efficient ways, farmers were unable to meet the needs of crops commonly grown in this area.

4.5 Stream Data

Connectivity—East Ranch Segment

Scheurer (2002) observed stream connectivity in the portion of the Arikaree River that runs through the eastern part of the ranch. The observed segment of the stream spans approximately 5.63 kilometers (3.5 mi.) from the eastern boarder of Fox Ranch, westward. Scheurer traversed this distance during her observations, marking points where the river became intermittent and dry on a Global Positioning Satellite receiver (GPS). The data were then translated into ArcView (Figure 9). To compare the condition of the stream in 2002 to that of previous years, the same segment of stream was observed on a monthly basis between June and November 2002 (Figure 10).

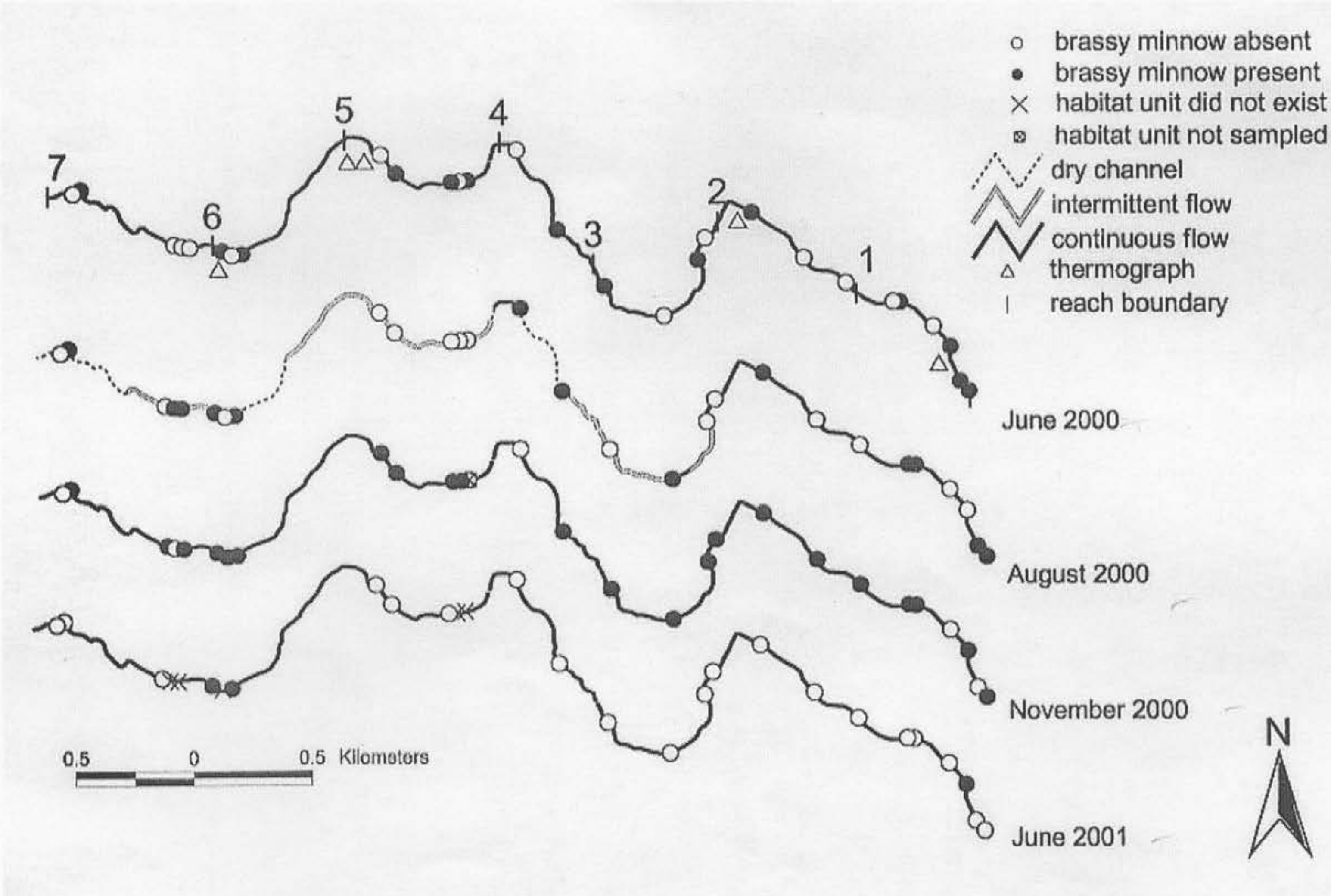


Figure 9. Connectivity of a Portion of the Arikaree River. (From Scheurer 2002).

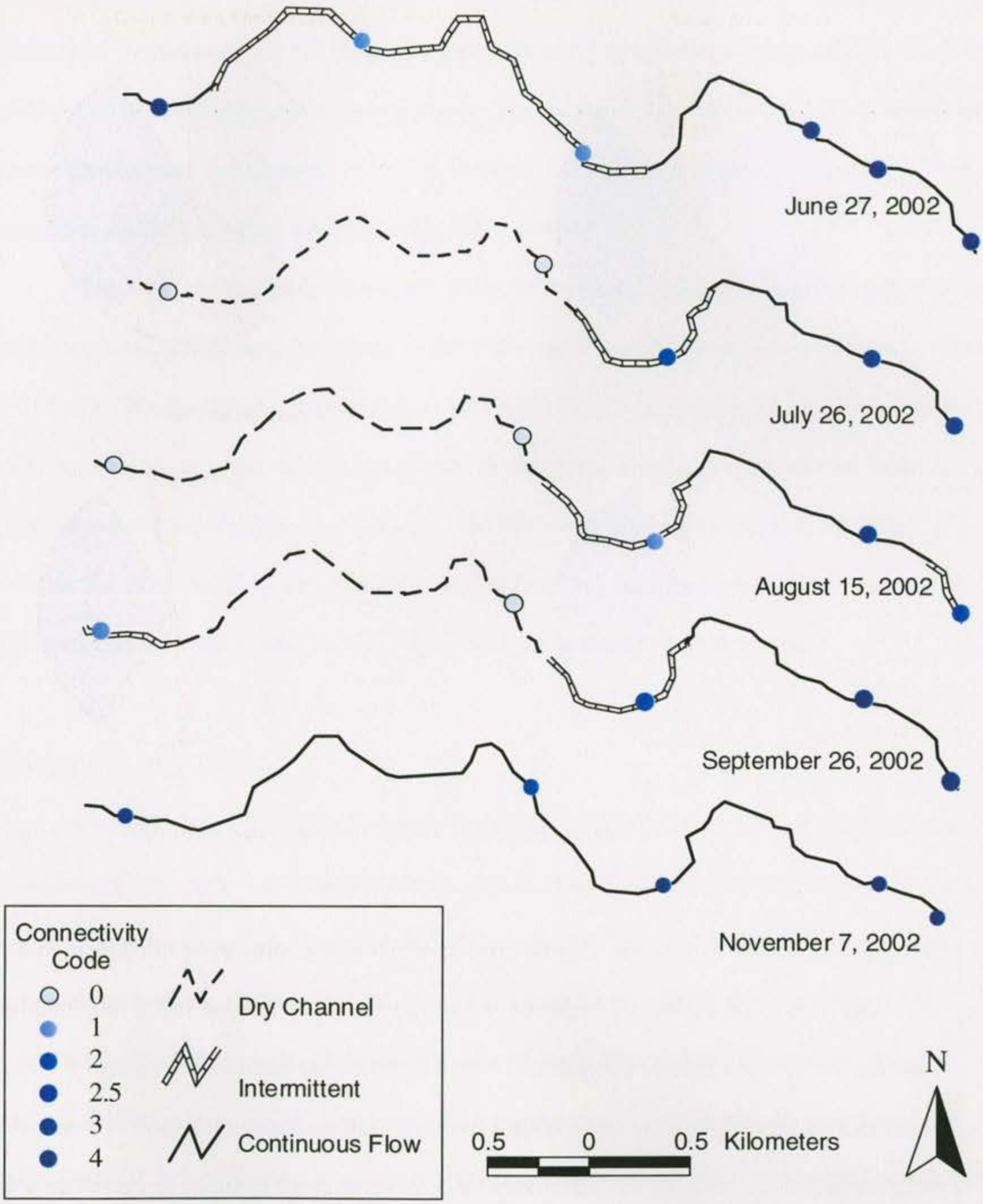


Figure 10. Connectivity of a Portion of the Arikaree River.

Sections of the stream were described at approximately 0.8 kilometer (0.5-mile) intervals. The area of the stream between observed points was assessed by extrapolating the data collected at the points and estimating flow intermittency. The connectivity results of this study resembled the results obtained by Scheurer. However, it seems that some areas of the stream became drier during the 2002 season than they did during 2000 or 2001.

The streams depicted in Scheurer's study during June 2000 and June 2001, appear to be fully connected, where the June stream in this study had areas of intermittent connectivity. This can be explained by the severe drought experienced in 2002. There were fewer spring rains and some farmers began irrigating full-time earlier in the season than usual (Interviewed farmers, 2002, personal communication). Furthermore, there was no rainfall throughout the season to recharge the river and irrigation return flow to the river was assumed to be minimal due to the high transpiration rates of the crops and the efficiency of center pivot irrigation.

Connectivity--Entire Ranch

Descriptions of the entire 16-kilometer (10-mi) study segment of the stream were noted throughout the study area on a monthly basis. Areas located at 0.8-kilometer (0.5-mi.) intervals were coded according to the characteristics of the water levels (see Table 1). The connectivity code corresponds with the shade of colored dot depicted on the map of the river (Figure 11). Symbols that are darkest represent areas that were flowing and connected. Lighter colored symbols depict drier conditions with the lightest representing a completely dry stretch of river. Throughout the 2002 season, connectivity of the stream decreased. Areas of the stream that were fully connected became pools, then shallow puddles and eventually became completely dry. At the end of the summer, the stream began to recover, becoming more and more connected at the various observed spots.

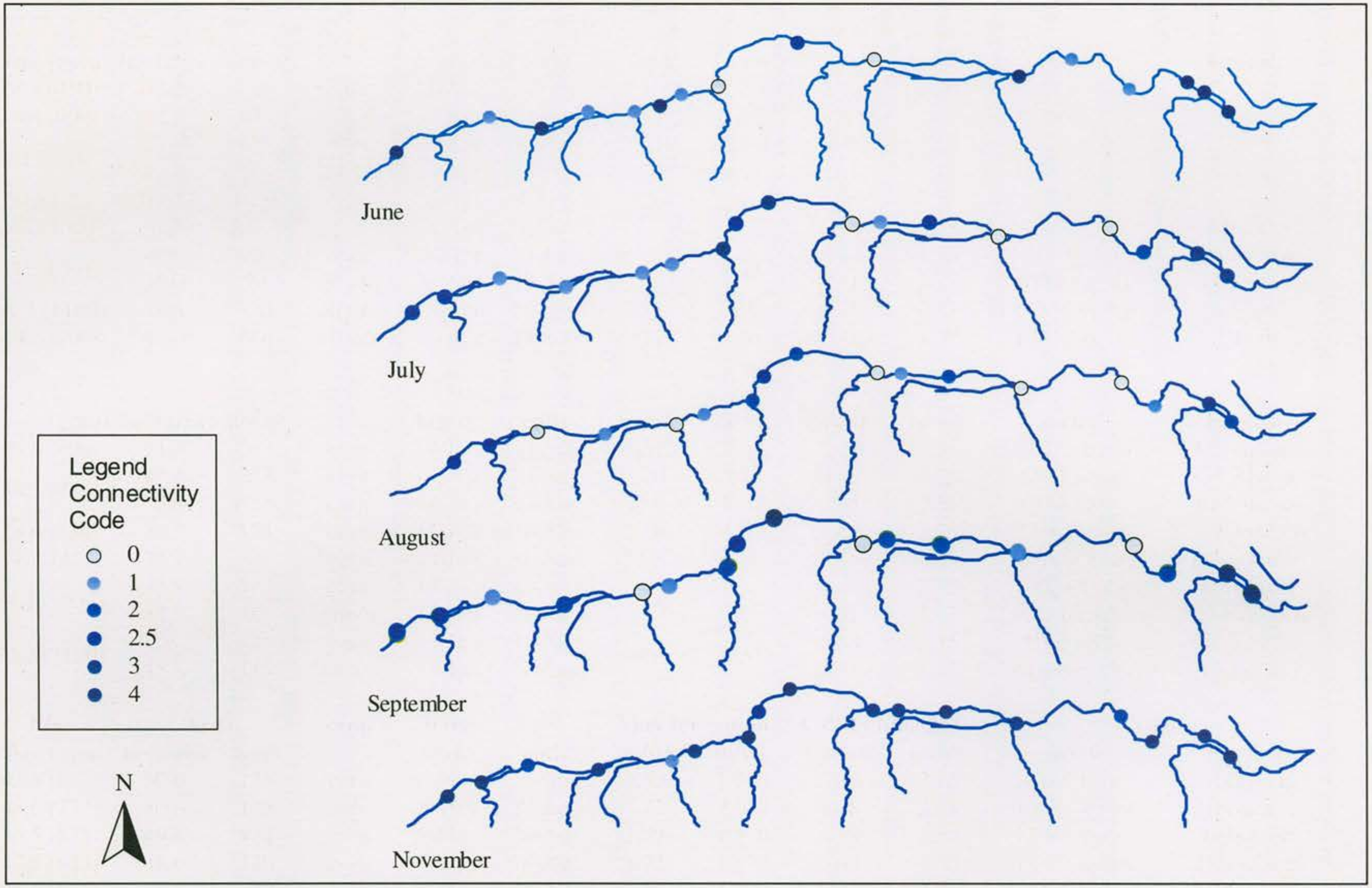


Figure 11. Connectivity of the Arikaree River through Fox Ranch.

The status of the river according to the connectivity codes may reflect its ability to provide good habitat for the brassy minnow. Scheurer (2002) showed that shallow pools or puddles and intermittent flows were not conducive to minnow persistence. In fact, the more shallow a pool was found to be early in the season, the more likely it was to dry and the more likely it was to extirpate brassy minnow.

Disconnected puddles were thought to be unlikely to support minnows because there is no corridor for escape from aquatic predators and shallow water makes small fishes more vulnerable to terrestrial vertebrates. Isolated "deep pools" may support minnows if they are found to be deep enough. Schlosser (1988) showed that when not in the presence of predators, brassy minnows seem to prefer complex pools for habitats. Unlike the pools in this study however, Schlosser's (1988) pools contained corridors for emigration. Also, connected puddles are less likely to support minnows than fully connected areas, because of their lack of depth. Finally, a connected, flowing river was determined to be most conducive to brassy minnow persistence (Scheurer, 2002).

The months with the most areas receiving a connectivity rating of 4, were June and November. A rating of 4 represents a fully connected segment of the stream. There were no segments rated as 4 during the months of July and August. In fact, over half of the segments observed during the month of August had no water in them at all and received ratings of 0 and 1 representing dry and marshy soils where river should have been.

Finally, the connectivity codes for the areas were averaged for each date of data collection in order to obtain a relative status of the river within the study area, over the course of the season. It is apparent that the river dried and became disconnected, then recovered during 2002 season (Figure 12).

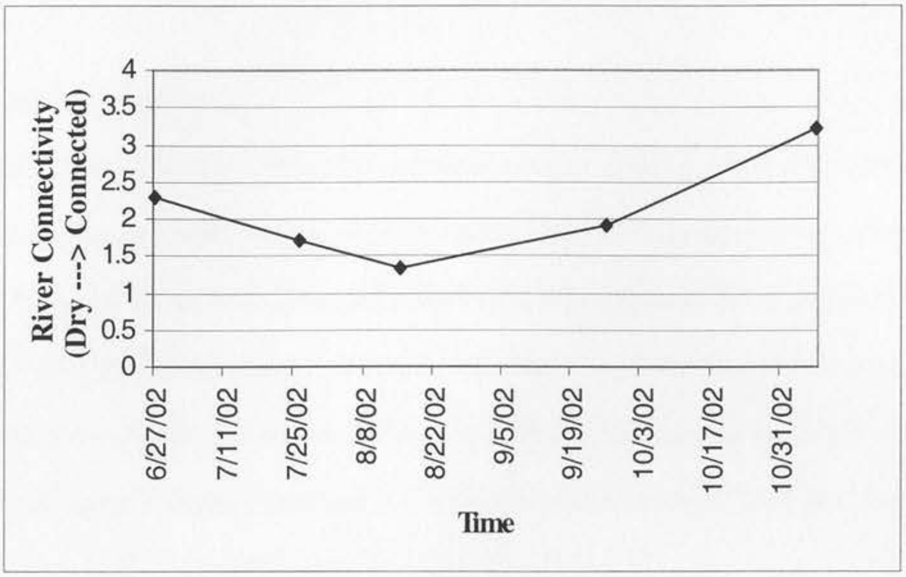


Figure 12. Average Connectivity Rating.

Early Season Flows

In early April 2002, The Nature Conservancy measured flow in the portion of the Arikaree River that runs through Fox Ranch. Flow at the site on the westernmost boundary of the ranch, near P road, measured 0.005 cubic meters per second (0.2 ft^3/sec). Flow rates gradually increased up to the Nature Conservancy Ranch Headquarters at U road. There, the flow was measured at 0.05 m^3/sec (2.1 ft^3/sec). The flows continued to increase as the stream flowed east and measured at 0.1 m^3/sec (4.36 ft^3/sec) at the eastern boundary of the ranch (Tom Iseman, The Nature Conservancy, 2002, personal communication). The early season stream flow was less than the instream flow rights of the Colorado Water Conservancy Board (CWCB). The CWCB owns stream flow rights of 0.1 cubic meters per second (3.5 ft^3/sec) between P road and U road and 0.2 m^3/sec (7 ft^3/sec) between U road and the eastern boundary of the ranch (http://cwcb.state.co.us/isf/database, see figure 5). Thus, the early season flows, which are likely to represent peak flows, were a few cubic meters per second short of minimum CWCB standards in 2002.

Stream Gauge at Haiglar NE

During the summer of 2002, other perennial reaches of the Arikaree River experienced extreme dewatering, possibly because of the drought. The USGS gauge at Haiglar Nebraska has monitored flows on the Arikaree River since the 1930s. The gauge is 49 kilometers (30 mi.) downstream from the eastern boarder of Fox Ranch. The flow of the river near the gauge was greatly reduced during 2002. Between the months of March and November in 1999, excluding big floods, the gauge at Haiglar averaged 0.21 cubic meters per second (7.5 ft^3/sec, Figure 13).

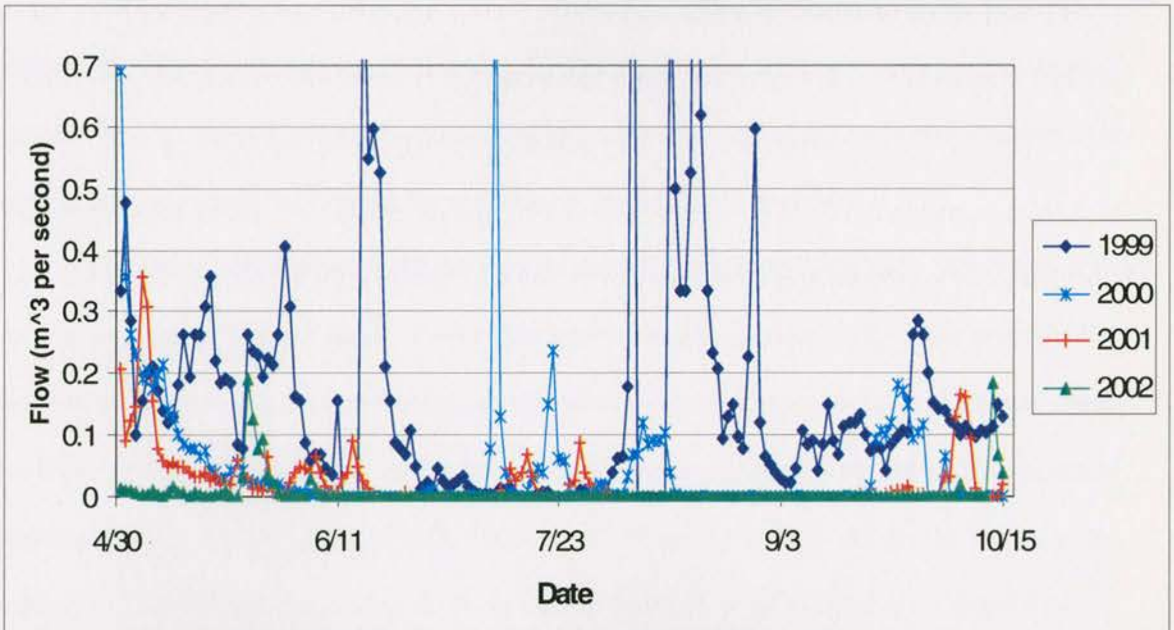


Figure 13. Summer Flow of the Arikaree River at Haiglar Nebraska.

During 2000, that flow had reduced to an average of 0.125 cubic meters per second (4.4 ft^3/sec). During 2002, the flow for the gauge at Haiglar Nebraska only averaged 0.01 cubic meters per second (0.35 ft^3/sec). Between June 9 and October 6 of 2002, no flow was recorded at all (Figure 13).

The past several years have been increasingly drier with the summer of 2002 being the driest. The effects of the drought are very apparent in the USGS stream flow records for the

Arikaree River at Haiglar Nebraska. It can be assumed that the drought is also affecting the flow in the river 49 kilometers (30 mi.) upstream near the study site.

Stage Height

During a visit in May of 2002, the river was flowing fairly steadily at U road (personal observation). However, by the first part of June, the flow in the river was too small to be gauged with an Ott-Kempten propeller velocity meter. By early November, the flow had still not returned to a strength that could be gauged with the available equipment.

Since flow rates were unobtainable, stream depth was evaluated throughout the season (Figure 14). The stream rapidly dried during the month of June. In many areas, the stream was completely dry, void of puddles or marshy ground. Other areas had pools of water that may have been suitable for small fish like the brassy minnow (personal observation).

The site at "West Ranch" did not vary much in depth during the season. The water at this site was stagnant and full of algae. The bottom was thick with organic matter. It is possible that this pool is disconnected from the water table because of a non-permeable layer of organic matter. Pools like this are not unusual in small streams with low flow (Deanna Durnford, 2002, personal communication). The vertical hydraulic conductivity of the streambed controls the flux of water between the aquifer and the stream. In this case, the hydraulic conductivity of the streambed would be close to zero due to a non-permeable layer of organic matter lining the canal. This lining could effectively disconnect the pool from the water table. Thus, changes in water levels would have to be attributed to evaporation and the minimal precipitation received.

The site at "U road" had the deepest water. The water level of the stream was gradually declining during the latter part of May and the early part of June. Then the stream experienced a rapid dewatering. Between June 19 and June 27, the stream fell 40.6 centimeters (16 in.). The stream continued to drop until it was merely a puddle and the gauge was no longer submerged.

Figure 14. Stream Depths at Monitored Stations.

The stream remained dry throughout the majority of the summer. At the end of the season, the stream seemed to recover almost as quickly as it disappeared. Between October 21 and November 7, the stream depth increased 50.8 centimeters (20 in.).

The site at the eastern boarder of the ranch, "East Ranch," showed similar patterns to that at U road. Although it was not as deep as the site at U road, the pool depth at this site also decreased rapidly during the middle part of June and increased at the end of October. Some of the fluctuation at this site may be attributed to a small beaver dam that appeared sometime in September. The dam was removed by Nature Conservancy staff, but reappeared a few weeks later.

Finally, the stream at site "Highway 385" also remained dry for the majority of the summer (Figure 15). This site, which is normally an ephemeral stretch of the river, had a small trickle of water running through it at the start of the observation period. Small minnows were

Figure 15. Site at Highway 385.

seen swimming in the shallow water at this location (personal observation). Within a few weeks, it was also completely dry (Figure 14). At the end of the season, around the beginning of November, the water returned. However, it was very shallow, less than an inch in depth.

4.6 Irrigation vs. Stage Height

The approximate volume of water pumped for irrigation by the representative farmers was computed on a weekly basis during the season of 2002 (Appendix D). The volume, in cubic meters was averaged per pump surveyed and multiplied by the total number of pumps within the study area (Figure 16). Since the cropping practices of the cooperating farmers were determined to be representative of farmers within the study area, their irrigation practices were also assumed to be representative of the study area.

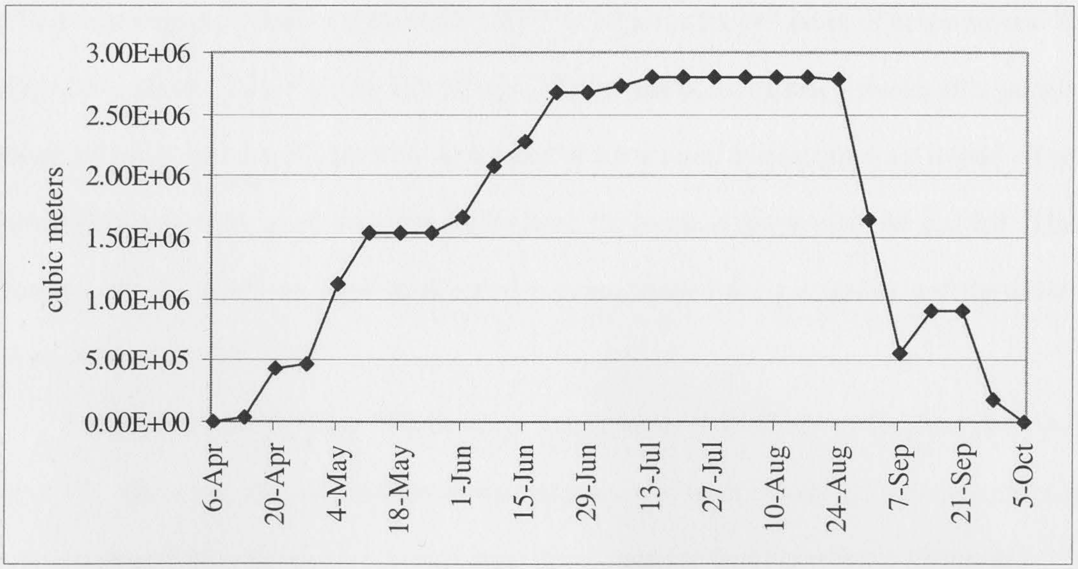


Figure 16. Water Pumped from Study Area for Irrigation.

All farmers interviewed were running their wells full-time by the beginning of July. The major increases of water use were during the middle of May and the middle of June. These times coincide with the start of the corn irrigation season. The major decrease in water use came at the end of August when a few strong rainstorms occurred in the area. Most pumps were not restarted after these rainstorms subsided. However, a few pumps were turned back on in early September in an attempt to store moisture in the soil profile for the planting of winter wheat.

Although this study found that farmers might be using as much as 1/3 less flow than they were originally appropriated for (see Table 3, section 4.3), the fact that they ran their wells full-time may have significantly affected the aquifer. For example, one farmer in this study reported that electric bill tripled his this season. Assuming that the farmer tripled the time his well was running, even if he pumped at 2/3 the rate permitted for, he still used twice the volume of water from the aquifer than he was appropriated for. Such a demand on the aquifer could dramatically impact the level of the groundwater water table and perhaps the river.

In fact, the decrease and increase of the water levels within the stream seem to strongly reflect the onset and subsidence of irrigation within the study area. The data collected at U road and East ranch appear to have a 2 to 3-week lag time between the full onset of irrigation and the drying of the stream. Likewise, the re-wetting of the stream occurs about 3 weeks after pumps are shut off for the season (Figure 17). At the end of the season, when pumps are turned off and restarted for the planting of wheat a few weeks later, the levels of the stream rise and fall. Thus, there appears to be a definite connection between groundwater use for irrigation and the water level of the Arikaree River.

Furthermore, at Highway 385, the stage height behaved similarly to the other study points (Figure 17). However, this site is on an ephemeral stretch of river. There are no trees or riparian vegetation around this site, and it normally goes dry during the summer months. Therefore, it is uncertain whether this specific area is responding to water table fluctuations to the degree of the other study sites.

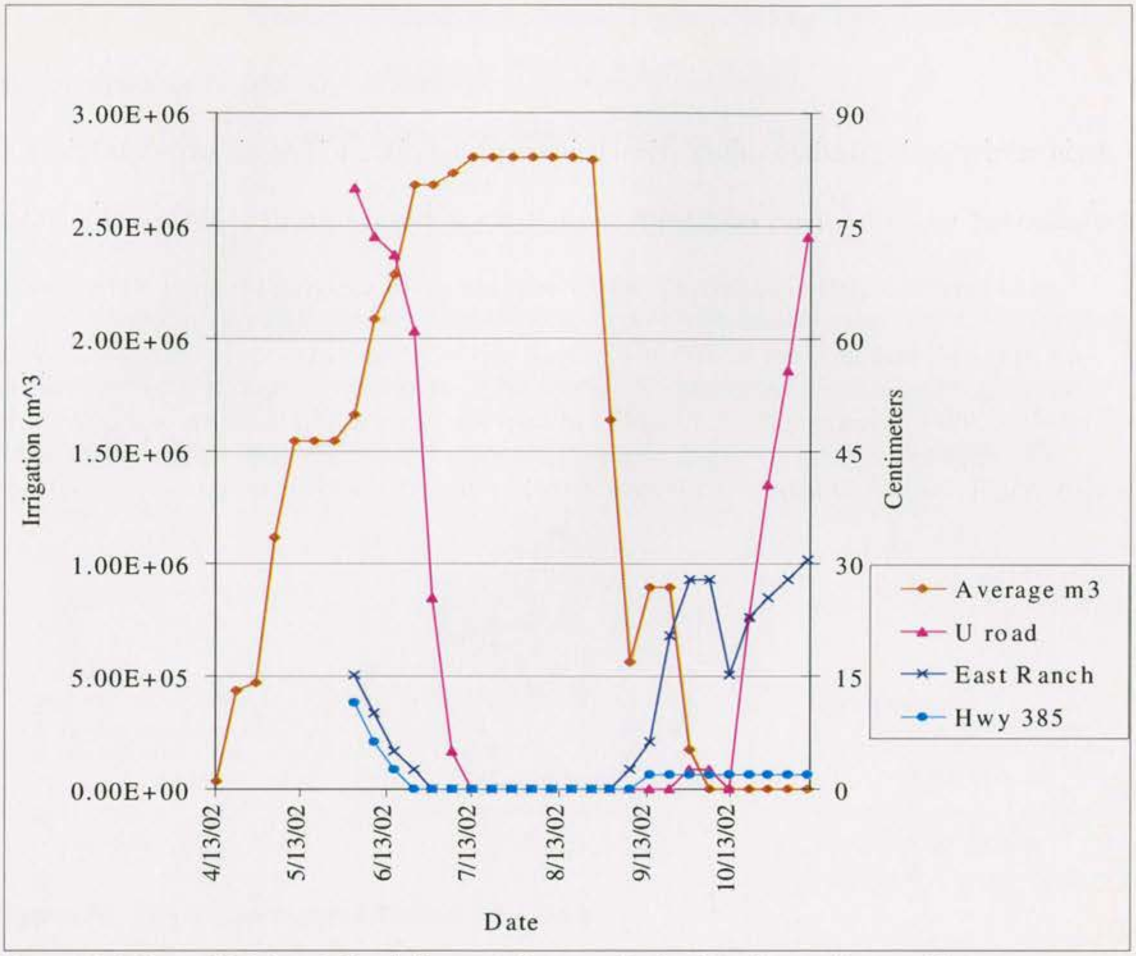


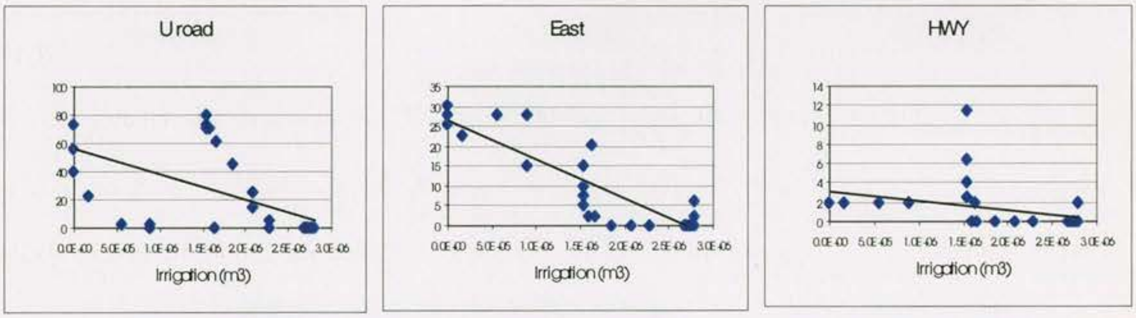
Figure 17. Stage Height of the Arikaree River vs. Irrigation Groundwater Usage.

A Pearson correlation test (SAS/STAT®, 2000) was used to determine if there was a temporal relationship between the amount of water being pumped from the aquifer for irrigation and the stage height of the river. These data were analyzed without considering a lag time. Data collected at U road, East ranch and Highway 385 were tested separately. Each area showed a trend of negative correlation (as one value increases, the other decreases), which implies that increasing irrigation pumping decreases river stage height and vice versa. Yet, for most areas, the correlation coefficient (r) was not robust (close to one, Table 7).

Table 7. Irrigation vs. Stage Height—No Lag Time

X*irrigation	Pearson correlation coefficient (r)
U road	-0.237385
East ranch	-0.903674
HWY	-0.362175

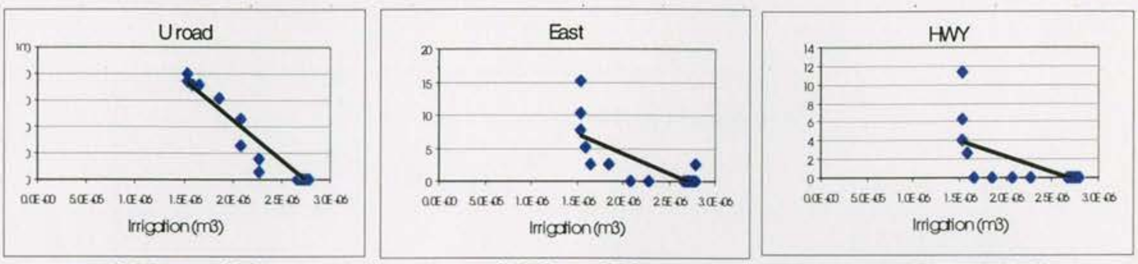
Therefore, the data were re-analyzed to account for the apparent lag time in the response of the river to the changes in irrigation. A lag time of 2.5 weeks was chosen as the optimum relationship. Again, each site showed a trending toward a negative correlation (Figure 18).



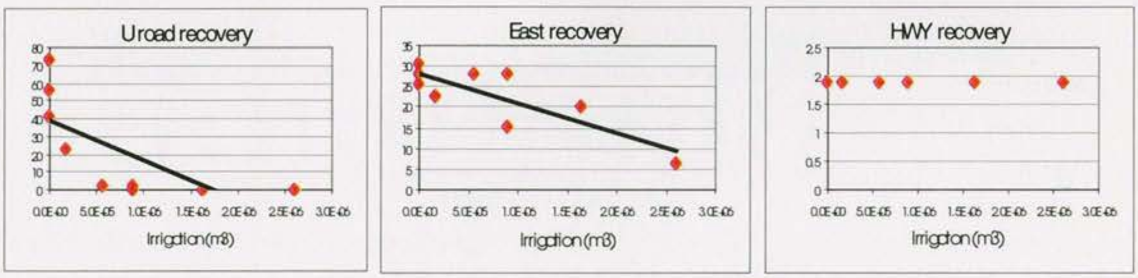
r= -0.581, p= 0.0002 r= -0.901, p< 0.0001 r= -0.425, p= 0.0088

Figure 18. Correlation with 2.5 Week Lag Time.

Finally, the stage height/irrigation correlation was analyzed with the stream response of depletion and recovery separated in time. Stream depletion and recovery are considered two separate phenomena and do not necessarily respond to changes in aquifer withdrawal in the same manner. In fact, the recovery of the stream did appear to take longer than the dewatering (Figure 17). The stage height for each site was analyze with changes in irrigation water withdrawal for the dewatering stage, with a lag time of 2.5 weeks and for the recovery stage, with a lag time of 3 weeks. A negative correlation is depicted in all cases with a more robust Pearson correlation coefficient (r) than was seen without the temporal correlation (Figure 19). The recovery of the site at Highway 385 did not show a correlation. Although water returned to this section of stream, it did not increase with time. Since this segment is an ephemeral segment, it is expected to behave differently than the perennial segments.



r= -0.974, p<.0001 r= -0.758, p<.0001 r= -0.655, p=0.0002



r= -0.704, p=0.0341 r= -0.829, p=0.005 No correlation

Figure 19. Initial Response Correlation, 2.5-week Lag Time and Recovery Correlation, 3 Week Lag Time.

It is important to note here that defining a correlation does not necessarily imply causation. Several factors may be influencing stage height in the river. The data presented here merely depicts the trend in negative correlation between groundwater withdrawal from the aquifer for irrigation and the stage height of the river. Also, it suggests the importance of considering the lag time of the river's response to the changes occurring within the aquifer.

Finally, data collected at the "West Ranch" site do not seem to correspond with the changes in irrigation. As previously postulated, the pool observed at "West Ranch" may not have been hydraulically connected to the groundwater table. Therefore, fluctuations in this area would not be a function of the water table response to irrigation pumping. Rather, fluctuations in the stage height at "West Ranch" seem to be a response to evaporation and the precipitation at the end of August (Figure 20). Throughout the hot, windy summer months, the water level in the pool decreases. After the August rains, it increases. Hence, the large pool of water at "West Ranch" may simply reflect the weather patterns of the area.

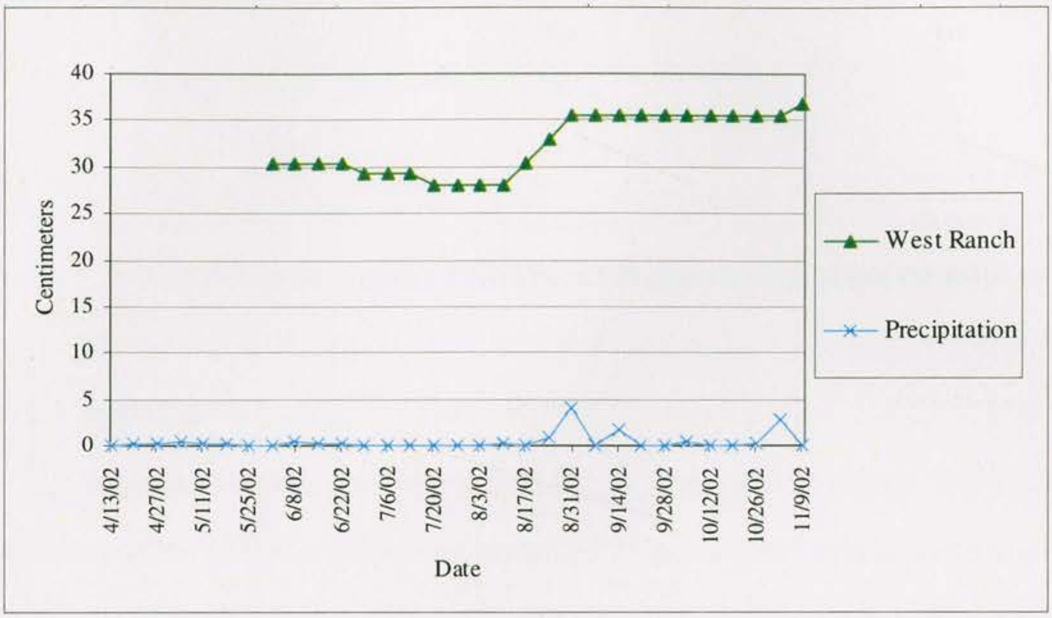


Figure 20. Stage Height at West Ranch vs. Precipitation.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

Irrigated agriculture is an integral part of Eastern Colorado's economy. Yet, irrigators have come under criticism for high water consumption that reduces flow in streams and rivers. Under legal interstate compacts, certain flows must be maintained in streams that cross borders into other States to be available for other water users. Also, flows must be maintained to conserve the ecological balance and to preserve good habitat for fish and wildlife. Much research has been conducted on behalf of fish and wildlife regarding acceptable flows for effective habitat. However, few researchers have looked closely at how irrigators can accommodate the needs of their crops without adversely affecting these critical river habitats.

On the Arikaree River there is a state-threatened species of minnow that is reportedly suffering due to lack of seasonal flow. It is assumed that groundwater pumping for irrigation exacerbates the seasonal dewatering of the Arikaree River (Residence of the Arikaree Valley, personal communication, 2002). However, little is known about the relationship between irrigation and seasonal stream flow in this area. Thus, this research set out to determine whether the use of groundwater for irrigation is influencing the hydrology of the Arikaree River. This was accomplished by describing the methodology and efficiencies of irrigating farmers in lower Yuma County, estimating the quantity of water withdrawn for agriculture within the area, describing the water quantity changes in the river throughout the season and investigating the relationship between pool depth and irrigation withdrawal from the aquifer. Also, this research suggests future studies that might enable managers to provide for the needs of water users as well as the needs of the minnow.

5.2 Summary of Results

This research was conducted during the very dry summer of 2002 in Lower Yuma County. In this area, farmers irrigate crops such as corn and alfalfa with groundwater that is pumped from the High Plains, or Ogallala aquifer. Due to improved efficiency techniques, wells in this area may have flow rates that are 1/3 less than they are appropriated for. However, because of the severe drought, farmers ran their irrigation wells much longer than is typical, during the summer of 2002. In fact, most wells pumped non-stop throughout the season. Even with increased pumping, many farmers experienced reduced yields and some had crops that were determined to be a total loss (see table 6, section 4.4).

Furthermore, this study examined the state of the Arikaree River, which flows through the middle of Lower Yuma County. This river, which contains the brassy minnow, had reduced flow during the summer of 2002 at the USGS gauging station in Haiglar Nebraska. Also, the river became dry and disconnected in many areas within the normally perennial reach of the study site. Stage height within the river also dropped. There was a definite temporal trend in the correlation between groundwater pumping for irrigation and the stage height of the river. As groundwater pumping for irrigation increased, the stage height of the river decreased. Likewise, as the pumping concluded, the water level of the river increased. This could be seen in the Pearson correlation. The most robust correlation was shown when the dewatering response of the river is considered separately from the recovery response and when lag times were considered. While there are likely to be several factors influencing stage height of a stream, irrigation seems to be a major influence. However, it is recognized that correlation does not necessarily imply causation.

5.3 Water Conservation in Irrigation

The farmers in Yuma County seem to be very conscious of their water use. Because the Ogallala aquifer is a non-renewable resource, there is much concern about its longevity. The water table of the aquifer is dropping and has been for many years now (Arikaree GWMD, 2002). Farmers are striving to improve their irrigation efficiencies and prolong the life of the aquifer under their farms. Yet, with the unpredictable weather and the frequency of droughts on the High Plains it is difficult to achieve consistent, efficient irrigation. During drought years, many irrigators are forced to run their irrigation systems to the maximum in order to produce viable crops. Any conservation measures employed are done so for the sake of the crop only. Water conservation for the sake of the aquifer may only be feasible during seasons of moderate rain.

When wells are permitted, the State of Colorado Ground Water Commission appropriates them for a maximum annual depletion that will maintain an aquifer life of 100 years. This volume is translated into a flow rate to be used on a fixed amount of land area. However, after the wells are installed, little is done by the government to monitor the water usage from these wells. In a drought year like 2002, the length of time a well is run can be much greater than that of a typical year. Therefore, even if a farmer adheres to the appropriated flow rate and acreage for pumping, the amount of water being extracted from the aquifer might be more than what is determined by the appropriation.

Moreover, the volume of water appropriated for removal from the aquifer does not take into account any groundwater/surface flow interactions. Appropriations were originally based on the allowable aquifer depletion rate of 40% in 25 years in this basin. In 1990, the basin designation was amended to allow a depletion of 40% in 100 years (Arikaree GWMD 2002, Groundwater Commission 2001). However, having hydraulically available water in the aquifer for 100 years may not translate into having adequate flow in the streams and rivers of the area. Thus, the allowable rate of depletion may still be too great.

From the data collected at Haiglar, Nebraska, it is apparent that stream flow in the Arikaree has been reducing over the years. Furthermore, even the early season flow rates on the Arikaree within the study area do not measure up to the instream flow rights of the Colorado Water Conservation Board (see figure 5, section 3.8).

5.4 Future Research

If having a wet river that is capable of sustaining small fishes like the brassy minnow is determined to be of value to the people of the Eastern Plains, more research must be conducted. First, the relationship between the stream and the aquifer must be defined. This can be determined by better defining the water budget of the river and by conducting aquifer tests. Next, it may be necessary to further consider the needs of the minnow and other organisms that use the river for habitat. Timing of flows and minimum baseflows should be considered. Finally, re-examining the parameters of this study, such as stream connectivity and irrigation water extraction, can help water managers make beneficial recommendations to water users for prolonging the life of the river.

Hydraulic Analyses

The water balance for the aquifer system identifies inflows and outflows from the area. Inflows are identified as precipitation, groundwater inflow, seepage from tributary flows, seepage from irrigation return water, recharge from the sandy areas north of the river, and direct runoff to the stream. Outflows are evapotranspiration, groundwater outflow, discharge to the stream and groundwater extraction (The Nature Conservancy, personal communication). Quantifying these parameters will be necessary to understand the physical relationship of the stream/aquifer connection. In this study, precipitation, irrigation returns, recharge and overland flow were negligible due to the severe drought. Parameters such as evapotranspiration and groundwater extractions were augmented.

The groundwater hydrology of this area must be better understood before management regulations are enacted. Currently, transmissivity is said to range from about 620.9 to 3725.4 m^2 per day (50,000 to 300,000 gpd/ft) and specific yield from 0.1 to 0.3 (MWE 1999). Hydraulic properties such as transmissivity, specific yield, as well as vertical and horizontal hydraulic conductivity can be found for the study area by conducting an aquifer test. Unconfined aquifers can be difficult to test due to delayed yield effects, borehole storage, and unreliable early-time data. However, these parameters must be determined for studies that incorporate three-dimensional groundwater flow and stream-aquifer relations. An inverse computational method for analyzing pumping and recovery tests for unconfined alluvial aquifers, such is found around the Arikaree River, has been shown to be effective for other areas in the Republican River Basin (Chen et al. 1999). Conductivity values may also help to determine if there is a maximum flow rate or a minimum radius from the river for a well.

Furthermore, it may be useful to examine the proximity of pumping wells to the river. Figure 21 shows the center pivot circles within lower Yuma County. With other hydraulic components such as transmissivity and hydraulic conductivity known, the relative influence of well pumping can be related to the draw down of the water table in the vicinity of the river. Groundwater tests that employ the Theis equation and stream depletion factors can help determine which wells may be affecting the stream the most (Charbeneau, 2000). These tests can help define a groundwater model for the area.

The use of piezometers might also be helpful for determining the groundwater/stream interactions. By inserting piezometers next to the stream, any differences in stage height and water table can be accounted for. This will help determine stream/aquifer relationships for individual stretches of the river. Also, a piezometer would help to identify the optimum lag time between the changes in the aquifer and the response in the river. For this study, some areas of the stream appeared to have pools that were disconnected from the water table (see figure 14, section 4.5). The use of a piezometer would verify this observation. Monitoring wells can also be used to show water levels around the stream throughout the season. Such observations would verify the correlation observed in this study between irrigation and stage height of the river. Furthermore, a more detailed description of the river elevations may be useful. Use of an altimeter to identify water level elevations can be compared to water table contours to determine flow direction and gradient of the river (The Nature Conservancy, personal communication).

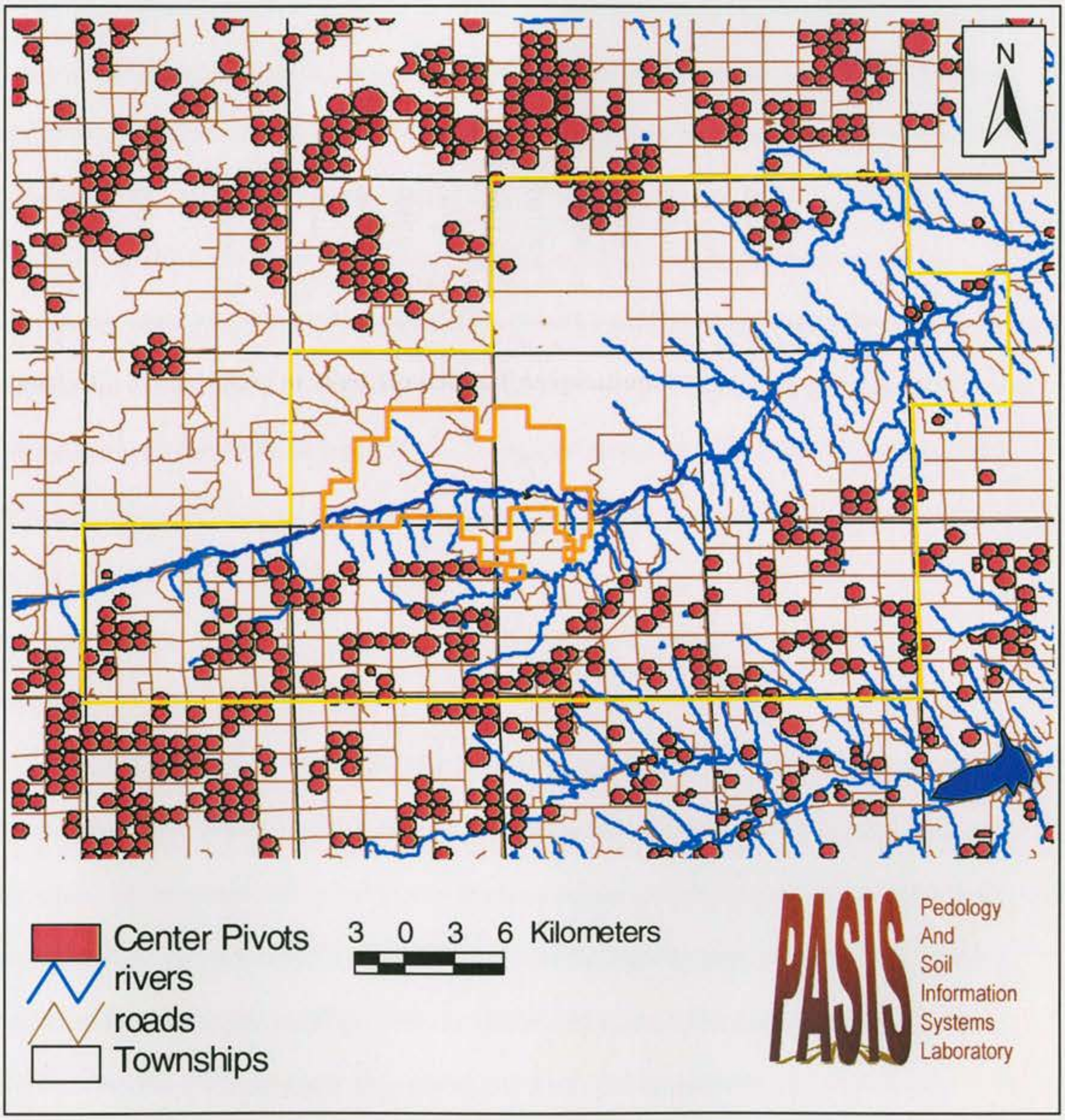


Figure 21. Center Pivots in Lower Yuma County.

Habitat Requirements for the Brassy Minnow.

The brassy minnow is adapted for harsh conditions and does not necessarily require high flow throughout the summer season. However, Scheurer (2002) found that the larval and juvenile life stages of the brassy minnow might be the life stages responsible for dispersal and colonization. Therefore, it is imperative that a well-defined stream flow is maintained in the river during the early months of the season. Young minnows must be able to retreat to larger pools and permanent habitats if they are to persist to older ages. It is possible that the postponement of irrigation could allow the minnow time to disperse and bolster the populations. An adequate time frame for minnow dispersal must be identified.

Using the hydraulic parameters of the area, research can model the effect of the groundwater pumping on the baseflow of the perennial stretches of the river. The river would not be treated as a constant head boundary (as is usually the case), and the stream stage would vary with time (Tabidian and Pederson, 1995). The model should be able to identify which, if any, wells should be regulated to maintain certain baseflows during the critical life stages of the minnow.

Recommendations

Finally, there are a few recommendations to be made for the future investigation of the parameters discussed in this study. First, a more accurate representation of stream connectivity throughout the season would be helpful in determining the seasonal extent of perennial flow. Access to the stream is limited if a person must walk through the poison ivy and tick-infested vegetation that borders most of the Arikaree River in this area. The four-wheel drive vehicle driven on the two-track road near the river in this study did not allow the researcher to continuously view the river. The two-track road follows the river, but can be almost two kilometers away from the river at times. Driving off the road is not recommended because it can cause severe damage to the natural vegetation and terrestrial habitat in the area. A continuous view of the river is important because the Arikaree River is very dynamic and changes are likely between the observation points surveyed in this study.

Second, stage height and river flow at the "East Ranch" site can now be monitored remotely. The Nature Conservancy installed a USGS stream gauging station at this site in August 2002. This gauge records the stage height of the river at 15-minute intervals and can be accessed in "real-time" on-line. These data will provide another more accurate description of the river.

Furthermore, it may be necessary to determine the quantity of groundwater extracted from the area in an average year. The data collected in this study was for a drought year. A more accurate estimate of water extraction may be calculated from power records of electrical consumption. Many pumps in this area are serviced by electrical power. These records may be obtainable from the Y-W Electric Company, which services the area. Also, the Y-W Well Test company was very helpful and very knowledgeable about well efficiencies pumping rates, water levels and other irrigation related issues.

Also, The Office of the State engineer sent out a survey to landowners in the area in 2002 requesting annual acre-feet diverted from their wells for irrigation purposes. The survey also requested information about the type of crop and the acres irrigated. In the future, this survey may be useful for estimating total water usage. However, during this study period the survey was being used in the litigation over the Republican River Compact (Megan Sullivan, Office of the State Engineer, 2002, written communication), and was not available to the public.

5.5 Conclusion

The farmers of Yuma County are very interested in preserving the life of the Ogallala Aquifer (Kromm and White 1985). Since the mid 1970s they have been improving their irrigation efficiencies by switching to drop nozzle, low-pressure sprinkler systems and minimum tillage practices. Furthermore, this area has great potential for future water savings because the on-farm changes made in water use do not impact other users within the basin. Also, prolonging the aquifer life is essential to the economic viability of the region (Smith, et al. 1996).

Convincing water conscious people to preserve stream flow for ecosystem services such as fish habitat may not be difficult in this area. A study on the South Platte demonstrates that many Coloradoans are willing to pay for species preservation in streams and rivers (Loomis, 2000). In fact, people surveyed in the Loomis study were willing to pay higher water bills to provide money to pay irrigators to decrease water usage in order to increase stream flow. This may be an acceptable strategy for irrigators in the Lower Yuma County area. Also, for a $90 per acre payment, irrigators in Texas were convinced to suspend groundwater pumping in dry years for the sake of maintaining flows in a nearby stream (Keplinger et al. 1998). This program encompassed groundwater usage, endangered species and spring flows. These are similar to the issues faced by water users in Yuma County. Water managers may be able to implement successful programs such as these in Eastern Colorado.

If timing of irrigation is proven to be a major factor in preserving critical minnow habitat, a change in cropping patterns might be helpful. For example, the irrigation season for sorghum and dry beans doesn't start until the middle of June, where the irrigation season for alfalfa begins in April. Irrigation of corn crops may begin as early as May. Therefore, it is important to determine the time at which brassy minnow are mature enough to disperse into refugia. An incentive that encourages farmers to switch to crops that do not require much water early in the season could help the minnow persist.

Hydraulically defining the groundwater and surface water interactions is important. Until it is clear how the irrigators affect the stream flow, no robust management suggestions can be made. Finally, determining an economic incentive for irrigators to adopt any future management suggestions will be necessary.

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APPENDIX A

1. General farm information

   What is your total farm area?

   Of that, how much are irrigated crops? Dryland crops? CRP?

   What kinds of crops are grown?

   Do you own or rent your farm? Area rented? Area farmed?

   How long have you been farming?

2. Farm management practices

   What kinds of changes or trends in cropping patterns have you seen over the years? Irrigated crops? Dryland crops?

   What kinds of changes in soil and crop management practices have you seen?

   How effective do you think dryland farming is at utilizing rainwater?

   Have you seen changes in water management/irrigation practices over the years?

   Have you seen an increase or decrease in irrigated areas? Why do you think that is?

3. Irrigation water use

   How do you irrigate? What kind of system do you use? Center pivots, furrows and ridges with surge valve…

   Have you changed any of your practices over the years? Why? Have you benefited from these changes?

   How do you decide when to irrigate? Experience, info from scheduling experts, NRCS, Extension…

   Have you altered your irrigation practices this year because of the drought? How?

   Are you a part of the YW well test program? The moisture block program?

   Has your well been tested in recent years?

   How much water do you use in a season? How do you know? Meter installed, from well test, from electric bills, log of well operation hours…

   What are the details of your well (head, static water level, etc)?

4. Groundwater and its effect on the stream

   Overall, do you think the use of groundwater has increased?

   Has the groundwater discharge to the stream increased, decreased or stayed the same?

   Why?

   Do you think the groundwater table in this area is going up or down?

   Why?

Appendix B

Well depth	Water level	GPM	Irr. Acres	Year 1st used	Known Current flow Rates
295	196	500	136		300
330	221	1200			400
321	219	1200			400
310	192	1250	320		400
290	191	800	146	1963	450
329	205	1250		1967	454
274	180	1200	160	1973	578
324	220	1000	160	1976	581
296	175	1100	160	1975	673
345	214	1200		1968	745
258	177	1200	160		771
252	124	800	130	1978	800
255	125	800	160	1978	800
225	124	800	160	1978	800
320	196	1000		1971	800
345	202	1400	240		800
324	203	1400		1970	900
324		1500	320	1949	925
26	8	1500	180	1961	1000
340	211	1750	240	1965	1170
354	220	1700	160		1334
205	85	550	440	1973	
280	145	600	130	1978	
1120	13	600	30	1961	
146	47	600	160	1978	
319	600	600	160	1973	
85	9	600	80	1969	
190	41	620	360	1984	
204	81	650		1967	
85	6	700	80	1966	
351	237	750		1999	
260	107	800	160	1978	
264	105	800	160	1975	
96	6	900	160	1978	
146	60	900	160	1965	
129	50	900	160	1968	
330	218	950		1968	
70	15	1000		1971	
343	215	1000	125	1965	
292	191	1000	253	1965	
342	180	1000	160	1964	
340		1000	160	1972	
325	178	1000		1968	
320	187	1000		1969	
320	176	1000		1969	
320	186	1000	200	1964	
300	189	1000	160	1964	

Appendix B

	310	197	1000		1965	
	226	108	1000	160	1975	
	212	79	1000	140	1973	
	216	70	1000	160	1968	
	252	100	1000	160	1968	
	274	147	1000		1969	
	279	105	1000			
	253	108	1000		1968	
	216	78	1000	160	1968	
	215	112	1000	220	1976	
	198	97	1000		1968	
	234	85	1000		1969	
	259	84	1000	240	1973	
	222	96	1000	160	1973	
	244	75	1000		1968	
	264	95	1000		1968	
	299	158	1100	200	1978	
	79	10	1200	160	1965	
	130		1200	160	1965	
	116	39	1200	160	1965	
	146	45	1200		1967	
	136	3	1200	160	1965	
	314	217	1200	160	1955	
	339		1200	160		
	334	190	1200		1970	
	300	169	1200	160	1970	
	300	172	1200	160	1970	
	225	72	1200		1968	
	218	72	1200		1967	
	329	193	1200	160	1973	
	211	93	1200		1968	
	240	97	1200	160	1968	
	243		1200			
	270	84	1200		1967	
	242	80	1200		1968	
	260		1200	160	1972	
	285	90	1200		1968	
	330		1250		1967	
	310	209	1250		1965	
	308	192	1250	160	1968	
	340	190	1300		1970	
	243	95	1300	160	1973	
	270	151	1320	130	1980	
	340	210	1350	320	1965	
	316	196	1350	200	1964	
	333	200	1400	170	1965	
	339	203	1400	200	1973	
	310	200	1400			
	315	199	1400	160	1972	
	345	216	1500	240	1968	

Appendix B

	310	186	1500	160	1963	
	339	188	1500	160	1973	
	228	98	1500	160	1973	
	187	78	1500	150	1949	
	264	95	1500		1967	
	280	130	1600	130	1978	
	127	36	1600	160	1964	
	345	260	1600	160	1973	
	350	262	1600	320	1973	
	330	258	1600	320	1973	
	235	95	1600	480	1976	
	348	180	1600	180	1972	
	332	183	1600		1969	
	245	92	1600		1967	
	340	222	1700	240	1972	
	334	228	1812			
	300	190	1850		1966	
Average			1157.035	184.6667	1969.598039	718.1428571
Std Dev			299.2232	72.64433	6.33747272	267.9948294
Average Farmers Allotted			1169.048			
% allocated used			0.6142			

Appendix C-1
Corn

	GPM*(60min/hr)*(24hr/day)*(acre-ft/325851gal)*(12in/ft)*(1/acres)*(.9)													
			Blue					Orange						
								462.5	462.5					
		GPM	662	771	578	673	581	925	925	900	745	1334	1170	454
		Acres	125	125	123	120	120	123	80.5	232	98	113	7	124
			0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
Date	**ET corn**	**Precip.**												
14-Apr		0	0	0	0	0	0	0	0	0	0	0	0	0
15-Apr		0	0	0	0	0	0	0	0	0	0	0	0	0
16-Apr		0.02	0	0	0	0	0	0	0	0	0	0	0	0
17-Apr		0.01	0	0	0	0	0	0	0	0	0	0	0	0
18-Apr		0	0	0	0	0	0	0	0	0	0	0	0	0
19-Apr		0	0	0	0	0	0	0	0	0	0	0	0	0
20-Apr	0.01	0.03	0	0	0	0	0	0	0	0	0	0	0	0
SUM	0.01	0.06	0	0	0	0	0	0	0	0	0	0	0	0
21-Apr	0.02	0	0	0	0	0	0	0	0	0	0	0	0	0
22-Apr	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0
23-Apr	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0
24-Apr	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0
25-Apr	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0
26-Apr	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0
27-Apr	0.03	0.05	0	0	0	0	0	0	0	0	0	0	0	0
SUM	0.31	0.05	0	0	0	0	0	0	0	0	0	0	0	0
28-Apr	0.03	0.08	0	0	0	0	0	0	0	0	0	0	0	0
29-Apr	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0
30-Apr	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0
1-May	0.03	0.03	0	0	0	0	0	0	0	0	0	0	0	0
2-May	0.03	0.02	0	0	0	0	0	0	0	0	0	0	0	0
3-May	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0
4-May	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0
SUM	0.25	0.13	0	0	0	0	0	0	0	0	0	0	0	0
5-May	0.05	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
6-May	0.05	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
7-May	0.04	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
8-May	0.05	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
9-May	0.05	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0

Appendix C-1
Corn

10-May	0.07	0.03	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
11-May	0.06	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
SUM	0.37	0.05	1.769348	2.060675	1.569958	1.873696	1.617559	0	0	0	0	0	0	0
12-May	0.06	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
13-May	0.05	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
14-May	0.08	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
15-May	0.08	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
16-May	0.08	0.06	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
17-May	0.06	0.05	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
18-May	0.07	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
SUM	0.48	0.12	1.769348	2.060675	1.569958	1.873696	1.617559	0	0	0	0	0	0	0
19-May	0.09	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
20-May	0.12	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
21-May	0.1	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
22-May	0.12	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
23-May	0.12	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
24-May	0.11	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
25-May	0.1	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
SUM	0.76	0	1.769348	2.060675	1.569958	1.873696	1.617559	0	0	0	0	0	0	0
26-May	0.1	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
27-May	0.13	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
28-May	0.15	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
29-May	0.16	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
30-May	0.19	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
31-May	0.21	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
1-Jun	0.23	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
SUM	1.17	0	1.769348	2.060675	1.569958	1.873696	1.617559	0	0	0	0	0	0	0
2-Jun	0.25	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
3-Jun	0.22	0.03	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
4-Jun	0.16	0.1	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
5-Jun	0.13	0.03	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
6-Jun	0.17	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
7-Jun	0.27	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
8-Jun	0.35	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
SUM	1.55	0.17	1.769348	2.060675	1.569958	1.873696	1.617559	0	0	0	0	0	0	0
9-Jun	0.45	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0

Appendix C-1
Corn

10-Jun	0.45	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
11-Jun	0.4	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
12-Jun	0.32	0.05	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
13-Jun	0.28	0	0.252764	0.294382	0.22428	0.267671	0.23108	0	0	0	0	0	0	0
14-Jun	0.28	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
15-Jun	0.28	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	2.46	0.06	1.769348	2.060675	1.569958	1.873696	1.617559	0.358925	0.54842	0.28801	0.564395	0.476143	0.72386	0.349487
16-Jun	0.3	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
17-Jun	0.34	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
18-Jun	0.4	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
19-Jun	0.44	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
20-Jun	0.41	0.07	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
21-Jun	0.44	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
22-Jun	0.5	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	2.83	0.08	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
23-Jun	0.51	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
24-Jun	0.46	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
25-Jun	0.41	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
26-Jun	0.354926	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
27-Jun	0.417414	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
28-Jun	0.538228	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
29-Jun	0.65623	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	3.346798	0.02	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
30-Jun	0.51264	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
1-Jul	0.58	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
2-Jul	0.5	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
3-Jul	0.48	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
4-Jul	0.44	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
5-Jul	0.39	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
6-Jul	0.37	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	3.27264	0	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
7-Jul	0.37	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
8-Jul	0.4	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
9-Jul	0.4	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
10-Jul	0.38	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
11-Jul	0.36	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744

Appendix C-1
Corn

12-Jul	0.34	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
13-Jul	0.33	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	2.58	0	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
14-Jul	0.37	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
15-Jul	0.42	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
16-Jul	0.46	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
17-Jul	0.45	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
18-Jul	0.42	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
19-Jul	0.39	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
20-Jul	0.39	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	2.9	0	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
21-Jul	0.36	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
22-Jul	0.31	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
23-Jul	0.26	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
24-Jul	0.24	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
25-Jul	0.23	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
26-Jul	0.2	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
27-Jul	0.18	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	1.78	0	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
28-Jul	0.15	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
29-Jul	0.15	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
30-Jul	0.27	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
31-Jul	0.29	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
1-Aug	0.4	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
2-Aug	0.5	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
3-Aug	0.48	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	2.24	0.01	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
4-Aug	0.43	0.08	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
5-Aug	0.4	0.01	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
6-Aug	0.43	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
7-Aug	0.52	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
8-Aug	0.53	0.03	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
9-Aug	0.39	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
10-Aug	0.33	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	3.03	0.12	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
11-Aug	0.32	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744

Appendix C-1
Corn

12-Aug	0.37	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
13-Aug	0.33	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
14-Aug	0.37	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
15-Aug	0.39	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
16-Aug	0.47	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
17-Aug	0.42	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	2.67	0	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
18-Aug	0.38	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
19-Aug	0.29	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
20-Aug	0.31	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
21-Aug	0.32	0	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
22-Aug	0.31	0.04	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
23-Aug	0.25	0.24	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
24-Aug	0.22	0.02	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
SUM	2.08	0.3	1.769348	2.060675	1.569958	1.873696	1.617559	1.256238	1.919469	1.008034	1.975381	1.666502	2.533512	1.223205
25-Aug	0.24	0.05	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
26-Aug	0.28	0.26	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
27-Aug	0.28	0.17	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
28-Aug	0.25	0.59	0.252764	0.294382	0.22428	0.267671	0.23108	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
29-Aug	0.19	0.29	0	0	0	0	0	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
30-Aug	0.18	0.01	0	0	0	0	0	0.179463	0.27421	0.144005	0.282197	0.238072	0.36193	0.174744
31-Aug	0.2	0.26	0	0	0	0	0	0	0	0	0.282197	0.238072	0.36193	0.174744
SUM	1.62	1.63	1.011056	1.177529	0.897119	1.070683	0.924319	1.076775	1.645259	0.864029	1.975381	1.666502	2.533512	1.223205
1-Sep			0	0	0	0	0	0	0	0	0	0	0	0
2-Sep			0	0	0	0	0	0	0	0	0	0	0	0
3-Sep			0	0	0	0	0	0	0	0	0	0	0	0
	35.70944	2.8	29.32062	34.14834	26.01644	31.04981	26.80526	13.99808	21.38837	11.23238	22.29359	18.80767	28.59249	13.80475

Appendix C-1
Corn

												650		
Green				Turquoise			***Brown***					100		
				400		450				Same well		0.241288		
800	800	800	600	800	800	900	450	900	325	800	1000	650		
130	129.3	142	135	58.8	158	80	119	104	125	91.9	151.9	100		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0.415472	0.314202	0.178288	ET - precip	Applied in.
													Crop need	Average irrig
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	1.263371	0	0	0	0	0	-0.05	0.052640444
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	0.180482	0	0	0	0	0		
0	0	0	0	0	0	0	1.263371	0	0	0	0	0	0.26	0.052640444
0	0	0	0	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	2.27273	1.691602	1.879264	1.263371	0	0.868638	0	2.199416	1.248015	0.12	0.423959183
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		

Appendix C-1
Corn

0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	1.263371	0	0.868638	2.908303	0	1.248015	0.32	0.580481127
0	0	0	0	0	0	0	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	1.263371	0	0.868638	0	2.199416	1.248015	0.36	0.550944169
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	0.180482	0	0.124091	0.415472	0	0.178288		
0	0	0	0	0	0	0	1.263371	0	0.868638	2.908303	0	1.248015	0.76	0.580481127
0	0	0	0	0	0	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	1.879264	1.263371	0	0.868638	0	2.199416	1.248015	1.17	0.629246829
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	0	0.868638	2.908303	0	1.248015	1.38	1.136050919
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		

Appendix C-1
Corn

0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	0	0.868638	0	2.199416	1.248015	2.4	1.244398979
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0.415472	0	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	0	0.868638	2.908303	0	1.248015	2.75	1.618648481
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0	0.124091	0	0.314202	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	0	0.868638	0	2.199416	1.248015	3.326798	1.589111524
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0.415472	0	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0.415472	0	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	2.891175	0.868638	2.908303	0	1.248015	3.27264	1.739114112
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		

Appendix C-1
Corn

0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	2.891175	0.868638	0	2.199416	1.248015	2.58	1.709577154
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	2.891175	0.868638	0	2.199416	1.248015	2.9	1.709577154
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	2.891175	0.868638	0	2.199416	1.248015	1.78	1.709577154
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	2.891175	0.868638	0	2.199416	1.248015	2.23	1.709577154
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	2.891175	0.868638	0	2.199416	1.248015	2.91	1.709577154
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		

Appendix C-1
Corn

0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	2.891175	0.868638	0	2.199416	1.248015	2.67	1.709577154
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0.180482	0.413025	0.124091	0	0.314202	0.178288		
2.055947	2.067077	1.882205	1.48485	2.27273	1.691602	1.879264	1.263371	2.891175	0.868638	0	2.199416	1.248015	1.78	1.709577154
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0	0.413025	0.124091	0	0.314202	0.178288		
0.293707	0.295297	0.268886	0.212121	0.324676	0.241657	0.268466	0	0.413025	0.124091	0	0.314202	0.178288		
0	0	0	0.212121	0.324676	0.241657	0.268466	0	0.413025	0.124091	0	0.314202	0.178288		
0	0	0	0	0.324676	0.241657	0.268466	0	0.413025	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	0	0.413025	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	0	0.413025	0.124091	0	0.314202	0.178288		
0	0	0	0	0	0	0	0	0	0	0	0	0		
0.587413	0.590593	0.537773	0.636364	1.298703	0.96663	1.073865	0	2.47815	0.744546	0	1.885214	1.069727	-0.01	1.119359273
0	0	0	0	0	0	0								
0	0	0	0	0	0	0								
0	0	0	0	0	0	0								
25.25877	25.39552	23.12423	18.45457	30.8442	22.95745	27.38356	24.00404	25.60755	15.51138	14.54152	28.27821	22.28598	32.909438	23.28411669

Appendix C-2
Alfalfa

		GPM*(60min/hr)*(24hr/day)*(acre-ft/325851gal)*(12in/ft)*(1/acres)*(.9)								
			Green	***Turquoise***	***Brown***					
Date	ET alf	Precip.	500	450	1100	700	650	325		
			128	80	120	116	74	116		
			0.186435	0.268466	0.437501	0.28801	0.178297	0.133719	ET - precip	Applied in.
									Crop need	Average irrig
13-Apr		0	0	0	0.437501	0.28801	0.178297	0.133719		
SUM	0	0	0	0	0.437501	0.28801	0.178297	0.133719	0	0.172921
14-Apr		0	0	0	0.437501	0.28801	0.178297	0.133719		
15-Apr		0	0	0	0.437501	0.28801	0.178297	0.133719		
16-Apr		0.02	0	0	0.437501	0.28801	0.178297	0.133719		
17-Apr		0.01	0	0	0.437501	0.28801	0.178297	0.133719		
18-Apr		0	0	0	0.437501	0.28801	0.178297	0.133719		
19-Apr		0	0	0	0.437501	0.28801	0.178297	0.133719		
20-Apr		0.03	0	0	0.437501	0.28801	0.178297	0.133719		
SUM	0	0.06	0	0	3.062504	2.016068	1.248079	0.936032	-0.06	1.2104473
21-Apr		0	0	0	0.437501	0.28801	0.178297	0.133719		
22-Apr		0	0	0	0.437501	0.28801	0.178297	0.133719		
23-Apr		0	0	0	0.437501	0.28801	0.178297	0.133719		
24-Apr	0.03	0	0	0	0.437501	0.28801	0.178297	0.133719		
25-Apr	0.07	0	0	0	0.437501	0.28801	0.178297	0.133719		
26-Apr	0.08	0	0	0	0.437501	0.28801	0.178297	0.133719		
27-Apr	0.06	0.05	0	0	0.437501	0.28801	0.178297	0.133719		
SUM	0.24	0.05	0	0	3.062504	2.016068	1.248079	0.936032	0.19	1.2104473
28-Apr	0.05	0.08	0	0	0.437501	0.28801	0.178297	0.133719		
29-Apr	0.07	0	0	0	0.437501	0.28801	0.178297	0.133719		
30-Apr	0.08	0	0	0	0.437501	0.28801	0.178297	0.133719		
1-May	0.06	0.03	0	0	0.437501	0.28801	0.178297	0.133719		
2-May	0.06	0.02	0	0	0.437501	0.28801	0.178297	0.133719		
3-May	0.08	0	0	0	0.437501	0.28801	0.178297	0.133719		
4-May	0.11	0	0	0	0.437501	0.28801	0.178297	0.133719		
SUM	0.51	0.13	0	0	3.062504	2.016068	1.248079	0.936032	0.38	1.2104473
5-May	0.13	0	0	0	0.437501	0.28801	0.178297	0.133719		
6-May	0.15	0	0	0	0.437501	0.28801	0.178297	0.133719		
7-May	0.13	0.01	0	0	0.437501	0.28801	0.178297	0.133719		
8-May	0.14	0	0	0	0.437501	0.28801	0.178297	0.133719		
9-May	0.15	0	0	0	0.437501	0.28801	0.178297	0.133719		
10-May	0.22	0.03	0	0	0.437501	0.28801	0.178297	0.133719		
11-May	0.2	0.01	0	0	0.437501	0.28801	0.178297	0.133719		
SUM	1.12	0.05	0	0	3.062504	2.016068	1.248079	0.936032	1.07	1.2104473
12-May	0.2	0	0	0	0.437501	0.28801	0.178297	0.133719		
13-May	0.18	0	0	0	0.437501	0.28801	0.178297	0.133719		
14-May	0.26	0	0	0	0.437501	0.28801	0.178297	0.133719		
15-May	0.28	0	0	0	0.437501	0.28801	0.178297	0.133719		
16-May	0.27	0.06	0	0	0.437501	0.28801	0.178297	0.133719		
17-May	0.21	0.05	0	0	0.437501	0.28801	0.178297	0.133719		
18-May	0.24	0.01	0	0	0.437501	0.28801	0.178297	0.133719		
SUM	1.64	0.12	0	0	3.062504	2.016068	1.248079	0.936032	1.52	1.2104473
19-May	0.3	0	0	0	0.437501	0.28801	0.178297	0.133719		
20-May	0.36	0	0	0	0.437501	0.28801	0.178297	0.133719		
21-May	0.3	0	0	0	0.437501	0.28801	0.178297	0.133719		
22-May	0.32	0	0	0	0.437501	0.28801	0.178297	0.133719		
23-May	0.31	0	0	0	0.437501	0.28801	0.178297	0.133719		
24-May	0.29	0	0	0	0.437501	0.28801	0.178297	0.133719		
25-May	0.25	0	0	0	0.437501	0.28801	0.178297	0.133719		
SUM	2.13	0	0	0	3.062504	2.016068	1.248079	0.936032	2.13	1.2104473

Appendix C-2
Alfalfa

26-May	0.25	0	0	0.268466	0.437501	0.28801	0.178297	0.133719		
27-May	0.32	0	0	0.268466	0.437501	0.28801	0.178297	0.133719		
28-May	0.33	0	0	0.268466	0.437501	0.28801	0.178297	0.133719		
29-May	0.35	0	0	0.268466	0.437501	0.28801	0.178297	0.133719		
30-May	0.39	0	0	0.268466	0.437501	0.28801	0.178297	0.133719		
31-May	0.42	0	0	0.268466	0.437501	0.28801	0.178297	0.133719		
1-Jun	0.44	0	0	0.268466	0.437501	0.28801	0.178297	0.133719		
SUM	2.5	0	0	1.879264	3.062504	2.016068	1.248079	0.936032	2.5	1.5236579
2-Jun	0.45	0	0.186435	0.268466	0.437501	0.28801	0.178297	0.133719		
3-Jun	0.38	0.03	0.186435	0.268466	0.437501	0.28801	0.178297	0.133719		
4-Jun	0.27	0.1	0.186435	0.268466	0.437501	0.28801	0.178297	0.133719		
5-Jun	0.22	0.03	0.186435	0.268466	0.437501	0.28801	0.178297	0.133719		
6-Jun	0.27	0.01	0.186435	0.268466	0.437501	0.28801	0.178297	0.133719		
7-Jun	0.41	0	0.186435	0.268466	0.437501	0.28801	0.178297	0.133719		
8-Jun	0.53	0	0.186435	0.268466	0.437501	0.28801	0.178297	0.133719		
SUM	2.53	0.17	1.305044	1.879264	3.062504	2.016068	1.248079	0.936032	2.36	1.7411653
9-Jun	0.64	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
10-Jun	0.61	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
11-Jun	0.53	0.01	0.186435	0.268466	0.437501	0.28801	0	0.133719		
12-Jun	0.41	0.05	0.186435	0.268466	0.437501	0.28801	0	0.133719		
13-Jun	0.36	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
14-Jun	0.34	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
15-Jun	0.34	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
SUM	3.23	0.06	1.305044	1.879264	3.062504	2.016068	0	0.936032	3.17	1.5331521
16-Jun	0.35	0.01	0.186435	0.268466	0.437501	0.28801	0	0.133719		
17-Jun	0.39	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
18-Jun	0.46	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
19-Jun	0.49	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
20-Jun	0.45	0.07	0.186435	0.268466	0.437501	0.28801	0	0.133719		
21-Jun	0.48	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
22-Jun	0.53	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
SUM	3.15	0.08	1.305044	1.879264	3.062504	2.016068	0	0.936032	3.07	1.5331521
23-Jun	0.55	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
24-Jun	0.49	0.01	0.186435	0.268466	0.437501	0.28801	0	0.133719		
25-Jun	0.43	0.01	0.186435	0.268466	0.437501	0.28801	0	0.133719		
26-Jun	0.4267	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
27-Jun	0.4267	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
28-Jun	0.4583	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
29-Jun	0.562	0	0.186435	0.268466	0.437501	0.28801	0	0.133719		
SUM	3.3437	0.02	1.305044	1.879264	3.062504	2.016068	0	0.936032	3.3236667	1.5331521
30-Jun	0.594	0	0	0.268466	0.437501	0.28801	0	0.133719		
1-Jul	0.6	0	0	0.268466	0.437501	0.28801	0	0.133719		
2-Jul	0.52	0	0	0.268466	0.437501	0.28801	0	0.133719		
3-Jul	0.5	0	0	0.268466	0.437501	0.28801	0	0.133719		
4-Jul	0.45	0	0	0.268466	0.437501	0.28801	0	0.133719		
5-Jul	0.41	0	0	0.268466	0.437501	0.28801	0	0.133719		
6-Jul	0.38	0	0	0.268466	0.437501	0.28801	0	0.133719		
SUM	3.454	0	0	1.879264	3.062504	2.016068	0	0.936032	3.454	1.8913114
7-Jul	0.39	0	0	0.268466	0.437501	0.28801	0	0.133719		
8-Jul	0.41	0	0	0.268466	0.437501	0.28801	0	0.133719		
9-Jul	0.42	0	0	0.268466	0.437501	0.28801	0	0.133719		
10-Jul	0.4	0	0	0.268466	0.437501	0.28801	0	0.133719		
11-Jul	0.39	0	0	0.268466	0.437501	0.28801	0	0.133719		
12-Jul	0.37	0	0	0.268466	0.437501	0.28801	0	0.133719		
13-Jul	0.37	0	0	0.268466	0.437501	0.28801	0	0.133719		
SUM	2.75	0	0	1.879264	3.062504	2.016068	0	0.936032	2.75	1.773978

Appendix C-2
Alfalfa

14-Jul	0.42	0	0	0.268466	0.437501	0.28801	0	0.133719		
15-Jul	0.5	0	0	0.268466	0.437501	0.28801	0	0.133719		
16-Jul	0.56	0	0	0.268466	0.437501	0.28801	0	0.133719		
17-Jul	0.57	0	0	0.268466	0.437501	0.28801	0	0.133719		
18-Jul	0.55	0	0	0.268466	0.437501	0.28801	0	0.133719		
19-Jul	0.54	0	0	0.268466	0.437501	0.28801	0	0.133719		
20-Jul	0.56	0	0	0.268466	0.437501	0.28801	0	0.133719		
SUM	3.7	0	0	1.879264	3.062504	2.016068	0	0.936032	3.7	1.9323114
21-Jul	0.54	0	0	0.268466	0.437501	0.28801	0	0.133719		
22-Jul	0.49	0	0	0.268466	0.437501	0.28801	0	0.133719		
23-Jul	0.45	0	0	0.268466	0.437501	0.28801	0	0.133719		
24-Jul	0.43	0	0	0.268466	0.437501	0.28801	0	0.133719		
25-Jul	0.46	0	0	0.268466	0.437501	0.28801	0	0.133719		
26-Jul	0.42	0	0	0.268466	0.437501	0.28801	0	0.133719		
27-Jul	0.42	0	0	0.268466	0.437501	0.28801	0	0.133719		
SUM	3.21	0	0	1.879264	3.062504	2.016068	0	0.936032	3.21	1.8506447
28-Jul	0.37	0	0	0.268466	0.437501	0.28801	0	0.133719		
29-Jul	0.42	0	0	0.268466	0.437501	0.28801	0	0.133719		
30-Jul	0.3	0	0	0.268466	0.437501	0.28801	0	0.133719		
31-Jul	0.57	0	0	0.268466	0.437501	0.28801	0	0.133719		
1-Aug	0.57	0	0	0.268466	0.437501	0.28801	0	0.133719		
2-Aug	0.52	0	0	0.268466	0.437501	0.28801	0	0.133719		
3-Aug	0.5	0.01	0	0.268466	0.437501	0.28801	0	0.133719		
SUM	3.25	0.01	0	1.879264	3.062504	2.016068	0	0.936032	3.24	1.8556447
4-Aug	0.45	0.08	0	0.268466	0.437501	0.28801	0	0.133719		
5-Aug	0.42	0.01	0	0.268466	0.437501	0.28801	0	0.133719		
6-Aug	0.45	0	0	0.268466	0.437501	0.28801	0	0.133719		
7-Aug	0.55	0	0	0.268466	0.437501	0.28801	0	0.133719		
8-Aug	0.55	0.03	0	0.268466	0.437501	0.28801	0	0.133719		
9-Aug	0.41	0	0	0.268466	0.437501	0.28801	0	0.133719		
10-Aug	0.34	0	0	0.268466	0.437501	0.28801	0	0.133719		
SUM	3.17	0.12	0	1.879264	3.062504	2.016068	0	0.936032	3.05	1.823978
11-Aug	0.34	0	0	0.268466	0.437501	0.28801	0	0.133719		
12-Aug	0.39	0	0	0.268466	0.437501	0.28801	0	0.133719		
13-Aug	0.35	0	0	0.268466	0.437501	0.28801	0	0.133719		
14-Aug	0.38	0	0	0.268466	0.437501	0.28801	0	0.133719		
15-Aug	0.41	0	0	0.268466	0.437501	0.28801	0	0.133719		
16-Aug	0.49	0	0	0.268466	0.437501	0.28801	0	0.133719		
17-Aug	0.45	0	0	0.268466	0.437501	0.28801	0	0.133719		
SUM	2.81	0	0	1.879264	3.062504	2.016068	0	0.936032	2.81	1.783978
18-Aug	0.42	0	0	0.268466	0.437501	0.28801	0	0.133719		
19-Aug	0.32	0	0	0.268466	0.437501	0.28801	0	0.133719		
20-Aug	0.35	0	0	0.268466	0.437501	0.28801	0	0.133719		
21-Aug	0.36	0	0	0.268466	0.437501	0.28801	0	0.133719		
22-Aug	0.36	0.04	0	0.268466	0.437501	0.28801	0	0.133719		
23-Aug	0.3	0.24	0	0.268466	0.437501	0.28801	0	0.133719		
24-Aug	0.27	0.02	0	0.268466	0.437501	0.28801	0	0.133719		
SUM	2.38	0.3	0	1.879264	3.062504	2.016068	0	0.936032	2.08	1.6623114
25-Aug	0.3	0.05	0	0.268466	0.437501	0.28801	0.178297	0.133719		
26-Aug	0.36	0.26	0	0.268466	0.437501	0.28801	0.178297	0.133719		
27-Aug	0.37	0.17	0	0.268466	0.437501	0.28801	0.178297	0.133719		
28-Aug	0.33	0.59	0	0.268466	0.437501	0.28801	0.178297	0.133719		
29-Aug	0.26	0.29	0	0	0.437501	0.28801	0.178297	0.133719		
30-Aug	0.25	0.01	0	0	0.437501	0.28801	0.178297	0.133719		
31-Aug	0.28	0.26	0	0	0.437501	0.28801	0.178297	0.133719		
SUM	2.15	1.63	0	1.073865	3.062504	2.016068	1.248079	0.936032	0.52	1.4760915

Appendix C-2
Alfalfa

1-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
2-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
3-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
4-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
5-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
6-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
7-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
SUM	0	0	0	0	3.062504	2.016068	1.248079	0.936032	0	1.2104473
8-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
9-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
10-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
11-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
12-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
13-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
14-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
SUM	0	0	0	0	3.062504	2.016068	1.248079	0.936032	0	1.2104473
15-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
16-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
17-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
18-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
19-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
20-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
21-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
SUM	0	0	0	0	3.062504	2.016068	1.248079	0.936032	0	1.2104473
22-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
23-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
24-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
25-Sep			0	0	0.437501	0.28801	0.178297	0.133719		
26-Sep			0	0	0	0	0	0		
27-Sep			0	0	0	0	0	0		
28-Sep			0	0	0	0	0	0		
SUM	0	0	0	0	1.750002	1.152039	0.713188	0.534875	0	0.6916842
	47.268								44.467667	35.673159

Appendix C-3
Beans

GPM*(60min/hr)*(24hr/day)*(acre-ft/325851gal)*(12in/ft)*(1/acres)*(.7)						
			Orange			
			1334	1170		
			95	113		
			0.2380758	0.36193242	ET - precip	Applied in.
Date	ET bean	Precip (in)			Crop need	Average irrig
2-Jun	0.09	0	0	0		
3-Jun	0.08	0.03	0	0		
4-Jun	0.06	0.1	0	0		
5-Jun	0.05	0.03	0	0		
6-Jun	0.06	0.01	0	0		
7-Jun	0.1	0	0	0		
8-Jun	0.14	0	0	0		
Sum	0.58	0.17	0	0	0.41	0
9-Jun	0.19	0	0	0		
10-Jun	0.2	0	0	0		
11-Jun	0.19	0.01	0	0		
12-Jun	0.16	0.05	0	0		
13-Jun	0.15	0	0	0		
14-Jun	0.15	0	0.2380758	0.36193242		
15-Jun	0.16	0	0.2380758	0.36193242		
Sum	1.2	0.06	0.47615159	0.72386484	1.14	0.600008218
16-Jun	0.18	0.01	0.2380758	0.36193242		
17-Jun	0.21	0	0.2380758	0.36193242		
18-Jun	0.26	0	0.2380758	0.36193242		
19-Jun	0.3	0	0.2380758	0.36193242		
20-Jun	0.29	0.07	0.2380758	0.36193242		
21-Jun	0.34	0	0.2380758	0.36193242		
22-Jun	0.4	0	0.2380758	0.36193242		
Sum	1.98	0.08	1.66653057	2.53352696	1.9	2.100028762
23-Jun	0.43	0	0.2380758	0.36193242		
24-Jun	0.4	0.01	0.2380758	0.36193242		
25-Jun	0.38	0.01	0.2380758	0.36193242		
26-Jun	0.42666667	0	0.2380758	0.36193242		
27-Jun	0.42666667	0	0.2380758	0.36193242		
28-Jun	0.45833333	0	0.2380758	0.36193242		
29-Jun	0.562	0	0.2380758	0.36193242		
Sum	3.08366667	0.02	1.66653057	2.53352696	3.063666667	2.100028762
30-Jun	0.594	0	0.2380758	0.36193242		
1-Jul	0.6	0	0.2380758	0.36193242		
2-Jul	0.52	0	0.2380758	0.36193242		
3-Jul	0.5	0	0.2380758	0.36193242		
4-Jul	0.45	0	0.2380758	0.36193242		
5-Jul	0.41	0	0.2380758	0.36193242		
6-Jul	0.38	0	0.2380758	0.36193242		
Sum	3.454	0	1.66653057	2.53352696	3.454	2.100028762
7-Jul	0.39	0	0.2380758	0.36193242		
8-Jul	0.41	0	0.2380758	0.36193242		
9-Jul	0.42	0	0.2380758	0.36193242		
10-Jul	0.4	0	0.2380758	0.36193242		
11-Jul	0.39	0	0.2380758	0.36193242		
12-Jul	0.37	0	0.2380758	0.36193242		
13-Jul	0.37	0	0.2380758	0.36193242		
Sum	2.75	0	1.66653057	2.53352696	2.75	2.100028762
14-Jul	0.42	0	0.2380758	0.36193242		
15-Jul	0.5	0	0.2380758	0.36193242		

Appendix C-3
Beans

16-Jul	0.56	0	0.2380758	0.36193242		
17-Jul	0.57	0	0.2380758	0.36193242		
18-Jul	0.55	0	0.2380758	0.36193242		
19-Jul	0.54	0	0.2380758	0.36193242		
20-Jul	0.56	0	0.2380758	0.36193242		
Sum	3.7	0	1.66653057	2.53352696	3.7	2.100028762
21-Jul	0.54	0	0.2380758	0.36193242		
22-Jul	0.49	0	0.2380758	0.36193242		
23-Jul	0.45	0	0.2380758	0.36193242		
24-Jul	0.43	0	0.2380758	0.36193242		
25-Jul	0.46	0	0.2380758	0.36193242		
26-Jul	0.42	0	0.2380758	0.36193242		
27-Jul	0.42	0	0.2380758	0.36193242		
Sum	3.21	0	1.66653057	2.53352696	3.21	2.100028762
28-Jul	0.37	0	0.2380758	0.36193242		
29-Jul	0.42	0	0.2380758	0.36193242		
30-Jul	0.3	0	0.2380758	0.36193242		
31-Jul	0.57	0	0.2380758	0.36193242		
1-Aug	0.57	0	0.2380758	0.36193242		
2-Aug	0.52	0	0.2380758	0.36193242		
3-Aug	0.5	0.01	0.2380758	0.36193242		
Sum	3.25	0.01	1.66653057	2.53352696	3.24	2.100028762
4-Aug	0.45	0.08	0.2380758	0.36193242		
5-Aug	0.42	0.01	0.2380758	0.36193242		
6-Aug	0.45	0	0.2380758	0.36193242		
7-Aug	0.55	0	0.2380758	0.36193242		
8-Aug	0.55	0.03	0.2380758	0.36193242		
9-Aug	0.41	0	0.2380758	0.36193242		
10-Aug	0.34	0	0.2380758	0.36193242		
Sum	3.17	0.12	1.66653057	2.53352696	3.05	2.100028762
11-Aug	0.34	0	0.2380758	0.36193242		
12-Aug	0.39	0	0.2380758	0.36193242		
13-Aug	0.35	0	0.2380758	0.36193242		
14-Aug	0.38	0	0.2380758	0.36193242		
15-Aug	0.41	0	0.2380758	0.36193242		
16-Aug	0.49	0	0.2380758	0.36193242		
17-Aug	0.45	0	0.2380758	0.36193242		
Sum	2.81	0	1.66653057	2.53352696	2.81	2.100028762
18-Aug	0.42	0	0.2380758	0.36193242		
19-Aug	0.32	0	0.2380758	0.36193242		
20-Aug	0.35	0	0.2380758	0.36193242		
21-Aug	0.36	0	0.2380758	0.36193242		
22-Aug	0.36	0.04	0.2380758	0.36193242		
23-Aug	0.3	0.24	0.2380758	0.36193242		
24-Aug	0.27	0.02	0.2380758	0.36193242		
Sum	2.38	0.3	1.66653057	2.53352696	2.08	2.100028762
25-Aug	0.3	0.05	0.2380758	0.36193242		
26-Aug	0.36	0.26	0.2380758	0.36193242		
27-Aug	0.37	0.17	0.2380758	0.36193242		
28-Aug	0.33	0.59	0.2380758	0.36193242		
29-Aug	0.26	0.29	0.2380758	0.36193242		
30-Aug	0.25	0.01	0.2380758	0.36193242		
31-Aug	0.28	0.26	0.2380758	0.36193242		
Sum	2.15	1.63	1.66653057	2.53352696	0.52	2.100028762
	33.7176667				31.32766667	23.7003246
					2.409820513	0.756530158

Appendix C-4
Millet/Milo

GPM*(60min/hr)*(24hr/day)*(acre-ft/325851gal)*(12in/ft)*(1/acres)*(.9)										
			Red			400		Turquoise		
			400	400	200	200	300	400		
			125	60	30	120	111.2	58.8		
			0.1527275	0.3181822	0.0795456	0.1590911	0.1287608	0.3246758	ET - precip	Applied in.
Date	ET sorg	Precip.	Sorg	millet	Sorg	Sorg/Millet	Millet	Sorg	Crop need	Average irrig
									Sorg	
14-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
15-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
16-Apr		0.02	0	0	0.0795456	0.1590911	0.1287608	0		
17-Apr		0.01	0	0	0.0795456	0.1590911	0.1287608	0		
18-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
19-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
20-Apr		0.03	0	0	0.0795456	0.1590911	0.1287608	0		
Sum	0	0.06	0	0	0.5568189	1.1136378	0.9013256	0	-0.06	0.428630387
21-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
22-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
23-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
24-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
25-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
26-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
27-Apr		0.05	0	0	0.0795456	0.1590911	0.1287608	0		
Sum	0	0.05	0	0	0.5568189	1.1136378	0.9013256	0	-0.05	0.428630387
28-Apr		0.08	0	0	0.0795456	0.1590911	0.1287608	0		
29-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
30-Apr		0	0	0	0.0795456	0.1590911	0.1287608	0		
1-May		0.03	0	0	0.0795456	0.1590911	0.1287608	0		
2-May		0.02	0	0	0.0795456	0.1590911	0.1287608	0		
3-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
4-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
Sum	0	0.13	0	0	0.5568189	1.1136378	0.9013256	0	-0.13	0.428630387
5-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
6-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
7-May		0.01	0	0	0.0795456	0.1590911	0.1287608	0		
8-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
9-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
10-May		0.03	0	0	0.0795456	0.1590911	0.1287608	0		
11-May		0.01	0	0	0.0795456	0.1590911	0.1287608	0		
Sum	0	0.05	0	0	0.5568189	1.1136378	0.9013256	0	-0.05	0.428630387
12-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
13-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
14-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
15-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
16-May		0.06	0	0	0.0795456	0.1590911	0.1287608	0		
17-May		0.05	0	0	0.0795456	0.1590911	0.1287608	0		
18-May		0.01	0	0	0.0795456	0.1590911	0.1287608	0		
Sum	0	0.12	0	0	0.5568189	1.1136378	0.9013256	0	-0.12	0.428630387
19-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
20-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
21-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
22-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
23-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
24-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
25-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
Sum	0	0	0	0	0.5568189	1.1136378	0.9013256	0	0	0.428630387
26-May		0	0	0	0.0795456	0.1590911	0.1287608	0		

Appendix C-4
Millet/Milo

27-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
28-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
29-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
30-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
31-May		0	0	0	0.0795456	0.1590911	0.1287608	0		
1-Jun	0.098406	0	0	0	0.0795456	0.1590911	0.1287608	0		
Sum	0.098406	0	0	0	0.5568189	1.1136378	0.9013256	0	0.098406	0.428630387
2-Jun	0.089892	0	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
3-Jun	0.051614	0.03	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
4-Jun	0.026098	0.1	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
5-Jun	0.056122	0.03	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
6-Jun	0.081218	0.01	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
7-Jun	0.107083	0	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
8-Jun	0.12207	0	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
Sum	0.534098	0.17	0	0	0.5568189	1.1136378	0.9013256	2.2727303	0.36409791	0.807418764
9-Jun	0.145004	0	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
10-Jun	0.093625	0	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
11-Jun	0.076815	0.01	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
12-Jun	0.072588	0.05	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
13-Jun	0.064947	0	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
14-Jun	0.073534	0	0	0	0.0795456	0.1590911	0.1287608	0.3246758		
15-Jun	0.072148	0	0.1527275	0	0.0795456	0.1590911	0.1287608	0.3246758		
Sum	0.598662	0.06	0.1527275	0	0.5568189	1.1136378	0.9013256	2.2727303	0.53866158	0.832873343
16-Jun	0.082011	0.01	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
17-Jun	0.106226	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
18-Jun	0.121714	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
19-Jun	0.114852	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
20-Jun	0.086976	0.07	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
21-Jun	0.157749	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
22-Jun	0.164553	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
Sum	0.834081	0.08	1.0690923	0	0	1.1136378	0.9013256	2.2727303	0.75408092	0.892797664
23-Jun	0.105926	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
24-Jun	0.122749	0.01	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
25-Jun	0.135729	0.01	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
26-Jun	0.112277	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
27-Jun	0.136126	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
28-Jun	0.181148	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
29-Jun	0.228159	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
Sum	1.022114	0.02	1.0690923	0	0	1.1136378	0.9013256	2.2727303	1.00211424	0.892797664
30-Jun	0.184094	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
1-Jul	0.210116	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
2-Jul	0.161634	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
3-Jul	0.177829	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
4-Jul	0.177111	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
5-Jul	0.127564	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
6-Jul	0.164985	0	0.1527275	0	0	0.1590911	0.1287608	0.3246758		
Sum	1.203333	0	1.0690923	0	0	1.1136378	0.9013256	2.2727303	1.20333304	0.892797664
7-Jul	0.198964	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
8-Jul	0.172987	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
9-Jul	0.189444	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
10-Jul	0.197115	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
11-Jul	0.176517	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
12-Jul	0.178645	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
13-Jul	0.205551	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
Sum	1.319222	0	1.0690923	2.2272757	0	1.1136378	0.9013256	2.2727303	1.31922235	1.264010274
14-Jul	0.269987	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		

Appendix C-4
Millet/Milo

15-Jul	0.319017	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
16-Jul	0.330335	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
17-Jul	0.310635	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
18-Jul	0.300754	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
19-Jul	0.34823	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
20-Jul	0.375874	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
Sum	2.254831	0	1.0690923	2.2272757	0	1.1136378	0.9013256	2.2727303	2.25483132	1.264010274
21-Jul	0.28867	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
22-Jul	0.272489	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
23-Jul	0.312427	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
24-Jul	0.272975	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
25-Jul	0.351465	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
26-Jul	0.253909	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
27-Jul	0.278364	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
Sum	2.0303	0	1.0690923	2.2272757	0	1.1136378	0.9013256	2.2727303	2.03030042	1.264010274
28-Jul	0.264548	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
29-Jul	0.371938	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
30-Jul	0.481369	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
31-Jul	0.449339	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
1-Aug	0.390616	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
2-Aug	0.388034	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
3-Aug	0.410222	0.01	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
Sum	2.756066	0.01	1.0690923	2.2272757	0	1.1136378	0.9013256	2.2727303	2.74606633	1.264010274
4-Aug	0.281898	0.08	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
5-Aug	0.344383	0.01	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
6-Aug	0.504056	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
7-Aug	0.543154	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
8-Aug	0.374362	0.03	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
9-Aug	0.149382	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
10-Aug	0.382023	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
Sum	2.579259	0.12	1.0690923	2.2272757	0	1.1136378	0.9013256	2.2727303	2.45925857	1.264010274
11-Aug	0.368056	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
12-Aug	0.303682	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
13-Aug	0.276286	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
14-Aug	0.481651	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
15-Aug	0.369225	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
16-Aug	0.521823	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
17-Aug	0.373469	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
Sum	2.694192	0	1.0690923	2.2272757	0	1.1136378	0.9013256	2.2727303	2.69419152	1.264010274
18-Aug	0.272304	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
19-Aug	0.257553	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
20-Aug	0.470574	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
21-Aug	0.308519	0	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
22-Aug	0.251129	0.04	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
23-Aug	0.275491	0.24	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
24-Aug	0.24078	0.02	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
Sum	2.07635	0.3	1.0690923	2.2272757	0	1.1136378	0.9013256	2.2727303	1.77634971	1.264010274
25-Aug	0.347778	0.05	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
26-Aug	0.453185	0.26	0.1527275	0.3181822	0	0.1590911	0.1287608	0.3246758		
27-Aug	0.263688	0.17	0	0	0	0	0	0.3246758		
28-Aug	0.239609	0.59	0	0	0	0	0	0.3246758		
29-Aug	0.272297	0.29	0	0	0	0	0	0		
30-Aug	0.228775	0.01	0	0	0	0	0	0		
31-Aug	0.338744	0.26	0	0	0	0	0	0		
Sum	2.144076	1.63	0.3054549	0.6363645	0	0.3181822	0.2575216	1.298703	0.51407641	0.469371043
	22.14499	2.85								

Appendix C-5
Wheat

GPM*(60min/hr)*(24hr/day)*(acre-ft/325851gal)*(12in/ft)*(1/acres)*(.9)										
			Turquoise			***Red***				
			800	800	900	400	400	200		
			157.5	118	200	126.3	120	90		
			0.24242	0.32358	0.19091	0.15116	0.15909	0.07955	ET - precip	Applied in.
Date	ET	Precip							Crop need	Average irrig
14-Apr	0.1	0	0	0	0	0.15116	0.15909	0.07955		
15-Apr	0.13	0	0	0	0	0.15116	0.15909	0.07955		
16-Apr	0.13	0.02	0	0	0	0.15116	0.15909	0.07955		
17-Apr	0.16	0.01	0	0	0	0.15116	0.15909	0.07955		
18-Apr	0.17	0	0	0	0	0.15116	0.15909	0.07955		
19-Apr	0.15	0	0	0	0	0.15116	0.15909	0.07955		
20-Apr	0.11	0.03	0	0	0	0.15116	0.15909	0.07955		
Sum	0.95	0.06	0	0	0	1.05809	1.11364	0.55682	0.89	0.45475749
21-Apr	0.09	0	0	0	0	0.15116	0.15909	0.07955		
22-Apr	0.12	0	0	0	0	0.15116	0.15909	0.07955		
23-Apr	0.16	0	0	0	0	0.15116	0.15909	0.07955		
24-Apr	0.2	0	0	0	0	0.15116	0.15909	0.07955		
25-Apr	0.2	0	0	0	0	0.15116	0.15909	0.07955		
26-Apr	0.17	0	0	0	0	0.15116	0.15909	0.07955		
27-Apr	0.14	0.05	0	0	0	0.15116	0.15909	0.07955		
Sum	1.08	0.05	0	0	0	1.05809	1.11364	0.55682	1.03	0.45475749
28-Apr	0.12	0.08	0	0	0	0.15116	0.15909	0.07955		
29-Apr	0.16	0	0	0	0	0.15116	0.15909	0.07955		
30-Apr	0.18	0	0	0	0	0.15116	0.15909	0.07955		
1-May	0.14	0.03	0	0	0	0.15116	0.15909	0.07955		
2-May	0.13	0.02	0	0	0	0.15116	0.15909	0.07955		
3-May	0.15	0	0	0	0	0.15116	0.15909	0.07955		
4-May	0.21	0	0	0	0	0.15116	0.15909	0.07955		
Sum	1.09	0.13	0	0	0	1.05809	1.11364	0.55682	0.96	0.45475749
5-May	0.23	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
6-May	0.25	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
7-May	0.21	0.01	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
8-May	0.22	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
9-May	0.22	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
10-May	0.3	0.03	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
11-May	0.26	0.01	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
Sum	1.69	0.05	1.69697	2.26503	1.33637	1.05809	1.11364	0.55682	1.64	1.337818059
12-May	0.24	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
13-May	0.21	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
14-May	0.29	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
15-May	0.3	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
16-May	0.28	0.06	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
17-May	0.21	0.05	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
18-May	0.24	0.01	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
Sum	1.77	0.12	1.69697	2.26503	1.33637	1.05809	1.11364	0.55682	1.65	1.337818059
19-May	0.3	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
20-May	0.36	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
21-May	0.3	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
22-May	0.32	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
23-May	0.31	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
24-May	0.29	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
25-May	0.25	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
Sum	2.13	0	1.69697	2.26503	1.33637	1.05809	1.11364	0.55682	2.13	1.337818059
26-May	0.25	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
27-May	0.32	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		

Appendix C-5
Wheat

28-May	0.33	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
29-May	0.35	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
30-May	0.39	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
31-May	0.41	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
1-Jun	0.43	0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
Sum	2.48	0	1.69697	2.26503	1.33637	1.05809	1.11364	0.55682	2.48	1.337818059
2-Jun	0.43	0	0	0	0.19091	0.15116	0.15909	0.07955		
3-Jun	0.35	0.03	0	0	0.19091	0.15116	0.15909	0.07955		
4-Jun	0.25	0.1	0	0	0.19091	0.15116	0.15909	0.07955		
5-Jun	0.2	0.03	0	0	0.19091	0.15116	0.15909	0.07955		
6-Jun	0.24	0.01	0	0	0.19091	0.15116	0.15909	0.07955		
7-Jun	0.35	0	0	0	0.19091	0.15116	0.15909	0.07955		
8-Jun	0.43	0	0	0	0.19091	0.15116	0.15909	0.07955		
Sum	2.25	0.17	0	0	1.33637	1.05809	1.11364	0.55682	2.08	0.677485056
9-Jun	0.49	0	0	0	0.19091	0.15116	0.15909	0.07955		
10-Jun	0.44	0	0	0	0.19091	0.15116	0.15909	0.07955		
11-Jun	0.37	0.01	0	0	0.19091	0.15116	0.15909	0.07955		
12-Jun	0.26	0.05	0	0	0.19091	0.15116	0.15909	0.07955		
13-Jun	0.22	0	0	0	0.19091	0.15116	0.15909	0.07955		
14-Jun	0.2	0	0	0	0.19091	0.15116	0.15909	0.07955		
15-Jun	0.18	0	0	0	0.19091	0.15116	0.15909	0.07955		
Sum	2.16	0.06	0	0	1.33637	1.05809	1.11364	0.55682	2.1	0.677485056
1-Sep		0				0.15116	0.15909	0.07955		
2-Sep		0				0.15116	0.15909	0.07955		
3-Sep		0				0.15116	0.15909	0.07955		
4-Sep		0				0.15116	0.15909	0.07955		
5-Sep		0				0.15116	0.15909	0.07955		
6-Sep		0				0.15116	0.15909	0.07955		
7-Sep		0				0.15116	0.15909	0.07955		
						1.05809	1.11364	0.55682		
8-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
9-Sep		***	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
10-Sep		0.02	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
11-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
12-Sep		0.58	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
13-Sep		0.09	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
14-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
			1.69697	2.26503	1.33637	1.05809	1.11364	0.55682		
15-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
16-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
17-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
18-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
19-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
20-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
21-Sep		0	0.24242	0.32358	0.19091	0.15116	0.15909	0.07955		
			1.69697	2.26503	1.33637	1.05809	1.11364	0.55682		

						Appendix E								
10-Apr	13-Apr	14-Apr	24-Apr	28-Apr	5-May	15-May	26-May	2-Jun	14-Jun	30-Jun	7-Jul	17-Jul	25-Jul	3-Aug
	1100	400	450	800	662		900	800	900	900	1000			
	700	400		800	771			800	925	500	900			
		400		900	578			500	454		400			
		300		650	673			600	745					
				900	581			800	1170					
				650	900				1334					
					900				400					
									900					
16-Aug	24-Aug	26-Aug	27-Aug	28-Aug	30-Aug	31-Aug	1-Sep	14-Sep	25-Sep	15-Oct				
	450	800	600	662	900	454	1000		650					
		800		771	925	745			650					
		800		578	900	1170			1100					
		400		673		1334			700					
		400		581										
		400		800										
		300		900										
				800										
	6-Apr	13-Apr	20-Apr	27-Apr	4-May	11-May	18-May	25-May	1-Jun	8-Jun	15-Jun	22-Jun	29-Jun	6-Jul
Gallons	0	2592000	3.3E+07	3.6E+07	8.5E+07	1.2E+08	1.2E+08	1.2E+08	1.3E+08	1.6E+08	1.7E+08	2.1E+08	2.1E+08	2.1E+08
acre-ft	0	27.4794	352.652	380.131	903.003	1251.91	1251.91	1251.91	1348.09	1690.06	1851.21	2173.94	2173.94	2216.68
m3	0.0E+00	3.4E+04	4.3E+05	4.7E+05	1.1E+06	1.5E+06	1.5E+06	1.5E+06	1.7E+06	2.1E+06	2.3E+06	2.7E+06	2.7E+06	2.7E+06
	13-Jul	20-Jul	27-Jul	3-Aug	10-Aug	17-Aug	24-Aug	31-Aug	7-Sep	14-Sep	21-Sep	28-Sep	5-Oct	
Gallons	2.1E+08	2.1E+08	2.1E+08	2.1E+08	2.1E+08	2.1E+08	2.1E+08	1.3E+08	4.3E+07	6.9E+07	6.9E+07	1.3E+07	0	
acre-ft	2270.12	2270.12	2270.12	2270.12	2270.12	2270.12	2263.25	1327.22	459.516	726.677	726.677	141.977	0	
m3	2.8E+06	2.8E+06	2.8E+06	2.8E+06	2.8E+06	2.8E+06	2.8E+06	1.6E+06	5.7E+05	9.0E+05	9.0E+05	1.8E+05	0.0E+00	