THESIS

EFFECT OF IRRIGATION PRACTICES ON STREAM DEPLETION IN THE ARIKAREE RIVER, EASTERN COLORADO

Submitted by
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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY STEVEN D. GRIFFIN ENTITLED EFFECT OF IRRIGATION PRACTICES ON STREAM DEPLETION IN THE ARIKAREE RIVER, EASTERN COLORADO BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

EFFECT OF IRRIGATION PRACTICES ON STREAM DEPLETION IN THE ARIKAREE RIVER, EASTERN COLORADO

Irrigated agriculture is of paramount importance to the economy and livelihoods of those living in much of Eastern Colorado. Here, wells feeding center pivot systems draw groundwater from the High Plains Aquifer, and are commonly employed to supplement the meager amounts of natural precipitation. It is commonly accepted that a well actively pumping in the vicinity of a natural stream or river could, under certain circumstances, divert water from the stream itself and/or divert baseflow away from the river.

Recent studies conducted on the Arikaree River, located in Yuma County, Colorado, have shown a clear pattern of stream drying during the growing season. The river, fully connected and flowing during the winter months, eventually becomes a series of standing pools and dry runs until the return of flow late in the calendar year. The river is almost entirely fed by groundwater via springs and seeps along its reach. In order to preserve the riparian ecosystem in the Arikaree River valley (including a threatened species of fish, *Hybognathus hankinsoni* also known as the Brassy Minnow), the true nature of the stream depletion must first be found.

Irrigation practices of several farmers in the vicinity of the Arikaree were determined for 2003, while stage height in the river was monitored. It was found that initial declines in stage height were nearly temporally identical for 2002 and 2003. It was also found that most irrigation began 2-4 weeks later in 2003 than it had in 2002. Thus, the change in irrigation practices did not appear to impact stream depletion rates between these two years. Most stage height declines appeared in the record several weeks before the onset of the bulk of high-capacity pumping in the area, suggesting that there may be other factors besides irrigated agriculture contributing to the seasonal stream depletion.

Results of a simplified stream-depletion model currently used for water rights administration are presented, as well as data regarding the permeability of the Arikaree streambed at various locations along its reach. Recommendations are also made concerning future research and data collection to further determine the effect of irrigation on the Arikaree River.

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CHAPTER 1: INTRODUCTION

1.1 Background

The importance of water on the High Plains of the United States simply cannot be underestimated. This great expanse of land, with grasses reaching to the sky and yet devoid of the plentiful river water found eastward, so terrified and intimidated the early settlers in the days of American westward expansion that most turned back. In letters and accounts by these men and women, the scarcity of water was cited as a factor for avoiding the High Plains even more often than fears of attacks by Native Americans or starvation (Opie 2000). The brave souls that began farming in this vast region faced equally vast challenges in finding adequate water for healthy crops, with disastrous consequences if that water proved to be elusive.

Today, as in the early days of farming on the High Plains, the availability of water is of key importance. In Eastern Colorado, which forms part of the western boundary of the High Plains region, irrigated agriculture has been the dominant method of farming since the early 1960's (Gutentag 1984). In Yuma County, which borders Nebraska and Kansas, irrigated agriculture accounted for over 43 percent of the total cropland in the year 2000 (www.consideryumacounty.com). Most irrigation in this area is accomplished by employing high-capacity wells that feed movable center-pivot systems, though flood irrigation is also present. By penetrating the Ogallala Aquifer which underlies much of the High Plains, these wells area able to provide adequate supplies of water to sustain crops even during dry, desert-like conditions.

Since the advent of irrigated agriculture in Eastern Colorado, concern has grown as the water tables in the region have dropped. It is commonly thought that irrigated agriculture is the main cause of the lowering water levels below ground. Some have also speculated that high-capacity wells could be drawing significant amounts of water away from the region's rivers and streams. The Arikaree River, found in southeastern Yuma County, exhibits large reductions in streamflow and stage depth as the growing season progresses each summer, to the point that the river becomes a discontinuous series of standing pools by June or July (Scheurer 2002; Fardal 2003). In 1998, the brassy minnow (*Hybognathus hankinsoni*) was declared to be a threatened species by the State of Colorado, with many of the remaining populations appearing in the streams and rivers of eastern Colorado including the Arikaree (Scheurer 2003). Concern is widespread that this species, along with other wildlife and the natural state of the Arikaree River, is being adversely affected by irrigation withdrawals in the region throughout the growing season.

The Arikaree River lies in a valley, where the valley floor elevation lies just above the water table. Along the river valley, alluvium overlies the water-rich Ogallala formation. Where the water table intersects the valley floor and riverbed, springs and seeps appear which supplement the baseflow (Solek 1996). Riparian vegetation is abundant in the valley, with cottonwoods (*Populus deltoids*) and willows (*Salix exigua*) dominating the landscape. Cottonwoods have been identified as one of the principal plant users of groundwater in the valley (Solek 1996), and while much research has been conducted on this species and other groundwater-dependent plants classed as *phreatophytes* (="well plant"), their exact water usage remains somewhat uncertain. It is thought by some that the vegetation, rather than irrigation, is the principal cause of streamflow reduction in the Arikaree during summer months.

1.2 Problem Statement

In order to preserve the natural state of the Arikaree River and to protect the many plants and wildlife that inhabit the river valley, the source of the river's de-watering must be identified. If the source is artificial and controllable, then steps might be taken to reduce or even eliminate the de-watering during the summer months. If the source is primarily natural, then our understanding of the natural flow regime of the river could be greatly increased by studying the phenomenon.

Very little data have historically been collected on the Arikaree River. As a result, the behavior of the groundwater near the river, historical flow behavior and depths, and other physical properties of the river system are largely unknown. If the de-watering phenomenon is to be understood, a better grasp of the relationship between groundwater behavior and the Arikaree River during the growing season must be attained.

1.3 Objectives

The purpose of this study was to explore the possibility that high-capacity groundwater pumping was the principle cause of the de-watering of the Arikaree River during the growing season. Taking into consideration recent studies by Scheurer (2002, 2003) and

Fardal (2003), the site chosen for this study was The Nature Conservancy's Fox Ranch north of Kirk, Colorado. Specifically, the objectives were:

1. To record stage height at five locations along the Arikaree River, and to measure discharge at those locations when possible. It has been shown that stage height and discharge greatly decrease during the growing season (Scheurer 2002, 2003; Fardal 2003).

2. To measure the vertical hydraulic conductivity of the streambed at the same five locations. The hydraulic conductivity of the streambed may be different from the conductivity of the surrounding aquifer, thus limiting the speed at which water can leave or enter the streambed.

3. To measure the water table levels both below the streambed and adjacent to the river throughout early autumn and into winter. By quantitatively showing the behavior of the water table after high-capacity pumping in the surrounding area has ceased and local vegetation has ceased to transpire, the influence of various de-watering agents might be better ascertained.

4. To survey a small sample of farmers in the region, and to quantify the pumping habits throughout the irrigation season for each farmer.

5. To determine how much water was likely pumped away from the Arikaree River by surrounding high-capacity wells using an accepted technique from the USGS. This method might indicate whether or not there are likely to be other primary factors besides high-capacity pumping that are contributing to the de-watering.

CHAPTER 2: LITERATURE REVIEW

2.1 General Study Site Review

Much data concerning the High Plains region have been collected over the years, and certain investigations have even focused specifically on Yuma County in the vicinity of the study site.

Weist (1964) published an extensive survey of Yuma County's geology and groundwater supplies. Stratigraphy of the area, sources of groundwater recharge/discharge, uses of groundwater, and water quality were detailed. Transmissibility, hydraulic conductivity, and specific yield of the aquifer system throughout Yuma County were mapped. One very important conclusion made by Weist was that the development of groundwater supplies (in 1964) for irrigation and other uses could be accomplished without significant stream depletion in the North and South Forks of the Republican River as well as the Arikaree River; however, he notes that over-appropriation of the groundwater resources in the county could lead to stream depletion if left unchecked.

Boettcher (1966) published a survey of groundwater development in Eastern Colorado. In his report, Boettcher estimated future groundwater levels based upon the trends at the time of his writing. He also estimated that the Ogallala Aquifer in Eastern Colorado was being recharged at the rate of .85 in./yr.

Borman (1983a) detailed the changes in the water table for Eastern Colorado from predevelopment (i.e. early 1960's) until 1980. His data showed a definitive drop in water table levels during the period investigated. Also, Borman et al. (1983b) detailed changes in saturated thickness, specific yield, and changing well yields from predevelopment to 1980.

Gutentag, et al. (1984) published a comprehensive survey of the geohydrology of the entire High Plains Aquifer system, of which the Ogallala makes up 134,000 sq. mi. of the total 174,000 sq. mi. He found that sodium levels generally were less than 100 mg/L in Eastern Colorado (which agreed with Weist (1964)). An in-depth discussion of the geology in the High Plains region is presented, as well as some history concerning the development of the High Plains region.

Robson and Banta (1987) showed the properties of some of the deep bedrock aquifers below the High Plains aquifer in Colorado. In general, these aquifers were generally found to be unsuitable for development due to extreme depth below the surface and poor hydraulic conductivity.

VanSlyke and Joliat (1990) determined the annual loss of water table levels in the Northern High Plains of Colorado to be roughly one foot. They also found that natural recharge was being outmatched by natural discharge and groundwater pumping by 430,000 acre-feet/yr. An accounting of changes in saturated thickness of the Ogallala Aquifer from 1965 to 1989 was presented by groundwater management district, with the

Arikaree Groundwater Management District as a whole reporting an 18% decline in saturated thickness.

Helgesen, et al. (1993) published a detailed study of the hydrology of the Great Plains aquifer system as a whole. Included in their report were detailed descriptions of all strata of the geology of the Great Plains. Jorgensen, et al. (1993) published a study more specifically dealing with local aquifers (besides the Ogallala) in the High Plains region.

Finally, the Colorado Division of Natural Resources (2002), as it does every year, published an in-depth analysis of the changing water table levels in Eastern Colorado as measured in wells through 2002. This report gave water level drops in specific wells throughout the study area, breaking down the results by groundwater management district. Overall, the study found a regionwide ½% depletion in water table levels each year, translating to a 1.12 foot decline from 2001 to 2002.

2.2 Site-Specific Review

Compared with the volume of literature available for larger rivers nearby, such as the Republican River (which the Arikaree feeds into) or the South Platte, very few studies have specifically addressed the Arikaree River.

The Republican River Compact, signed by representatives of Colorado, Kansas, and Nebraska on May 26, 1943, has for 60 years provided the legal framework for water distribution in the Republican River Basin. According to the Compact, Kansas is to be allocated 1000 acre-feet of water from the Arikaree River drainage basin per year, while Nebraska is to receive 3300 acre-feet per year. By contrast, Colorado is to retain 15,400 acre-feet from the Arikaree drainage basin per year.

In the Bureau of Reclamation's 1956 Report on the Kansas River Basin: Colorado – Nebraska – Kansas, twelve potential reservoirs were mentioned as under consideration, seven of which were located in the Republican River basin. One of these reservoirs, the Pioneer Reservoir, was to be located on the Arikaree River immediately west of the border with Kansas. The original plan for this reservoir would have provided silt and flood control (but was not intended to supply irrigation waters), with a capacity of 34,000 acre-feet. As of 1956, the dam had been authorized via U.S. Senate Document 247, wherein the total capacity had been increased to 115,000 acre-feet; 10,000 acre-feet were now allocated for irrigation purposes. Searches for later publications by the Bureau of Reclamation regarding the Pioneer Dam proved futile, though the name is listed in a July 1991 report as being inactive (Bureau of Reclamation, Inactive Names of Reclamation Projects and Major Structures). The 1991 report also mentions that the project was authorized by the U.S. Corps of Engineers. It is uncertain why this project was abandoned, or what data concerning the Arikaree River may have been obtained during the planning stages of the Pioneer Dam.

Longenbaugh (1966) conducted a study on methods of artificial recharge on the Arikaree near Cope, Colorado in 1965. He concluded that, "…artificial recharge from ephemeral streams with flood flows is possible." (Longenbaugh 1966, pg. 11) His analysis showed that the benefits from artificial recharge exceeded the cost of construction of any structures used. Longenbaugh's report also mentions several flow rates from May through July 1965 at Cope, including a major flood event in which the flow approached 18,000 cfs.

Solek (1996) summarized the prior observations made by Weist, Boettcher, Borman, and others and applied their conclusions to the study site. Solek states,

> "*This aquifer* (the Ogallala) *continues to be depleted by agricultural activities, specifically by heavy pumping for irrigation. This groundwater depletion potentially could adversely affect Arikaree flows in the future.*" (Solek 1996, pg. 3)

Of the four sites for a nature preserve being considered by The Nature Conservancy along the Arikaree River, Solek recommended the Bowman Ranch as the best choice due to the vibrant ecosystem and large amounts of recharge from the northern sand dunes. This was the site ultimately chosen by TNC and used by this author as the study site for the current research.

McLaughlin Water Engineers (1999) issued a report to TNC concerning the study site. The conclusion of the MWE report was that the Arikaree River was not under immediate threat of losing its perennial (pool) nature, and that the drawdown in the aquifer supplying the flow into the Arikaree was insignificant from pre-development to 1999. MWE also concluded that, barring an increase in pumping from those wells hydraulically connected to the Arikaree River, the river could remain perennial without any further action taken.

Frenzl (2001) documented the different species of riparian plant life at the study site. Frenzl also qualitatively recorded the occurrences of these species.

Scheurer (2002) conducted research at the current study site as well as two downstream sites along the Arikaree concerning the brassy minnow (*Hybognathus hankinsoni*), a threatened species. She found that the minnows were more likely to survive the summer months when residing in the more perennial (upstream) segments of the river, and that deeper pools of water were tied to a greater chance of minnow survival. The major cause of non-survival was the drying of pools throughout the summer months.

Fardal (2003) studied the relationship between agricultural interests and the Arikaree River throughout 2002, which was to date the driest summer on record. Fardal found that most farmers were unable to sufficiently irrigate their crops in 2002 despite running their pumps continuously from activation through the end of the season. The volume of water being pumped for irrigation was found to increase as the stage levels in the Arikaree dropped, and as the volume of pumped water dropped in the autumn the river was found to begin recovery. Fardal concluded that,

> *"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." (Fardal 2003, pg. iv)*

2.3 Streambed Hydraulic Conductivity and Stream Depletion Analyses

Much research has been published concerning stream depletion determination by irrigation and other pumping wells. All of the earlier methods for determining stream depletion were analytical in nature, though most current research is being conducted in numerical methods and modeling.

Theis (1941) proposed the first analytical solution for transient stream depletion. This method used an integral to determine the ratio of water lost from the stream to the amount of water pumped from a well. Glover and Balmer (1954) derived a similar solution using the complementary error function.

Hantush (1959) developed a method for calculating stream depletion by which an "effective distance" is used to account for partial penetration of the streambed. Even after this adjustment had been made, the method tended to overestimate the stream depletion due to pumping for semi-pervious beds.

Moore and Jenkins (1966) conducted field experiments along the Arkansas River in Southeastern Colorado. It was found that,

> *"...pumping has lowered the water table below the level of the apparently pervious streambed, thereby breaking the hydraulic connection between the stream and the water table."* (Moore and Jenkins 1966, pg. 691)

The determination was made that the major control on infiltration loss in a case where the water table had retreated below the streambed was likely the least permeable layer of the streambed, such as layers of clay and silt in the top few inches of the bed.

Jenkins (1968, 1970) introduced a method of calculating stream depletion known as the stream depletion factor (*sdf*). This method, based largely upon the previous work of Glover and Balmer (1954), contains dimensionless plots of volume and stream depletion rates, thereby enabling calculation of stream depletion rates and volumes. Jenkins (1970) states that the *sdf* method would tend to overestimate the stream depletion if used in a case where streambed permeability were lower than aquifer permeability, or in a case where the water table were drawn lower than the streambed.

Sophocleous et al. (1995), as well as Conrad and Beljin (1996), found that analyses that do not account for partially clogging layers in a streambed tend to significantly overestimate stream depletion.

Mauclaire and Gibert (1998) found that water temperature, EC, and oxygen content rose (while pH levels fell) as a river was being influenced by pumping.

When attempting to determine overall flux into or out of a groundwater-dependent river, Cey et al. (1998) found that the velocity-area technique at several points along the river provided the most reliable estimate of groundwater discharge/recharge.

Hunt (1999) took the solutions of Theis (1941), Glover and Balmer (1954), and Hantush (1965) and modified these findings by assuming the river was of small width and penetration into the aquifer. It also took into account the possibility of a semi-pervious streambed. Zlotnik and Huang (1999) modified Hunt's model to take stream width into account.

Chen and Yin (1999) looked at the effects of aquifer and streambed hydraulic conductivity when looking at stream depletion due to irrigation. They recommended procedures for calculating aquifer hydraulic conductivity, and found that analytical solutions for stream depletion strongly overestimate the stream depletion for a anisotropic aquifer. Chen (2000) also recommended field procedures for measuring the streambed hydraulic conductivity and anisotropy.

Butler et al. (2001) quantified the analytical over-estimations of stream depletion as greater than 100%. Chen (2001a) also showed that, for the example of agricultural pumping, infiltrated stream water moved quite slowly inside the aquifer. Most of this stream water did not reach the pumping well at the end of a 90-day irrigation season. Thus, some of the water withdrawn from the stream by pumping may return to the stream during times of recovery.

Calver (2001) collected and presents stream permeability numbers from multiple sources. Conductivities varied considerably from 1.3×10^{-10} to 2.0×10^{-2} m/s for the entire sample.

Landon et al. (2001) conducted a study on the Platte River Basin in Nebraska. It was shown that any method used for determining the hydraulic conductivity of a streambed should take into account the location of sediments in the bed that would most affect the rate of ground water/surface water interaction.

Chen and Yin (2001b) found that,

> *"...the induced infiltration, the volume of water discharged from the stream to the aquifer, has a shorter term impact on streamflow, while the reduced baseflow curves show a longer term effect."* (Chen and Yin 2001b, pg. 185)

It was determined from the same simulation that annual overextraction of ground water can make a stream more vulnerable to depletion. The baseflow is reduced quickly by pumping, and also returns quite quickly after cessation of pumping. By contrast, stream depletion due to a reversal in gradient takes longer to form. Of particular interest is the finding that,

> *"If a stream is gaining water from the aquifer, it is not necessary for the well to reverse gradients below the stream and induce infiltration. It depletes streamflow simply by capturing some of the baseflow discharge before it reaches the stream."* (Chen and Yin 2001b, pg. 194)

Kishel and Gerla (2002) state that sediment heterogeneity is important to consider when trying to determine groundwater discharge to a body of water. It was found that temperature profiles and EC measurements were not extremely reliable methods to accomplish this.

Chen and Shu (2002) discovered that, for a shallow penetrating stream of low hydraulic conductivity a large part of total stream depletion came from baseflow reductions as opposed to a reversal in hydraulic gradient to the aquifer.

Fox (2003) quantified the vast difference in hydraulic conductivities between the streambeds in the South Platte River and its slough/backwater channels.

CHAPTER 3: STUDY SITE DESCRIPTION AND METHODOLOGY

3.1 Study Site

The field data for this project were all collected within the boundaries of The Nature Conservancy's Fox Ranch (hereafter referred to as the *study site*), located approximately eight miles north of Kirk, Colorado and seven miles northwest of Idalia, Colorado (Figures 3.1 and 3.2). The region studied was expanded to include the interviewed farmers as well as the irrigation wells considered in the pumping analysis, making the total study area roughly 288 square miles (746 sq. km.).

3.1.1 Regional Information

The study site, as described above, is found in the southeastern portion of Yuma County, which borders Kansas and Nebraska. Agriculture, government and retail make up the vast majority of employment for Yuma County's 9841 residents (2000 census). Ground elevation of Yuma County, while relatively flat, ranges quite widely from 5000 feet on the western end of the county to 3400 feet near the state line. Average June temperature is 75.2 degrees F with a yearly precipitation average of 17 inches (www.consideryumacounty.com).

Figure 3.1. Location of the Study Site.

The High Plains Aquifer, 174,000 square miles in area and covering sections of Colorado, Wyoming, Nebraska, South Dakota, Kansas, Oklahoma, Texas, and New Mexico, is present throughout Yuma County. The Ogallala Formation makes up 134,000 square miles of the High Plains Aquifer, and is the principal aquifer used for groundwater supplies in the area. Generally, the areas overlying the Ogallala and High Plains Aquifer are sunny and dry, with average annual precipitation increasing from west to east. Most precipitation generally occurs within the boundaries of the traditional

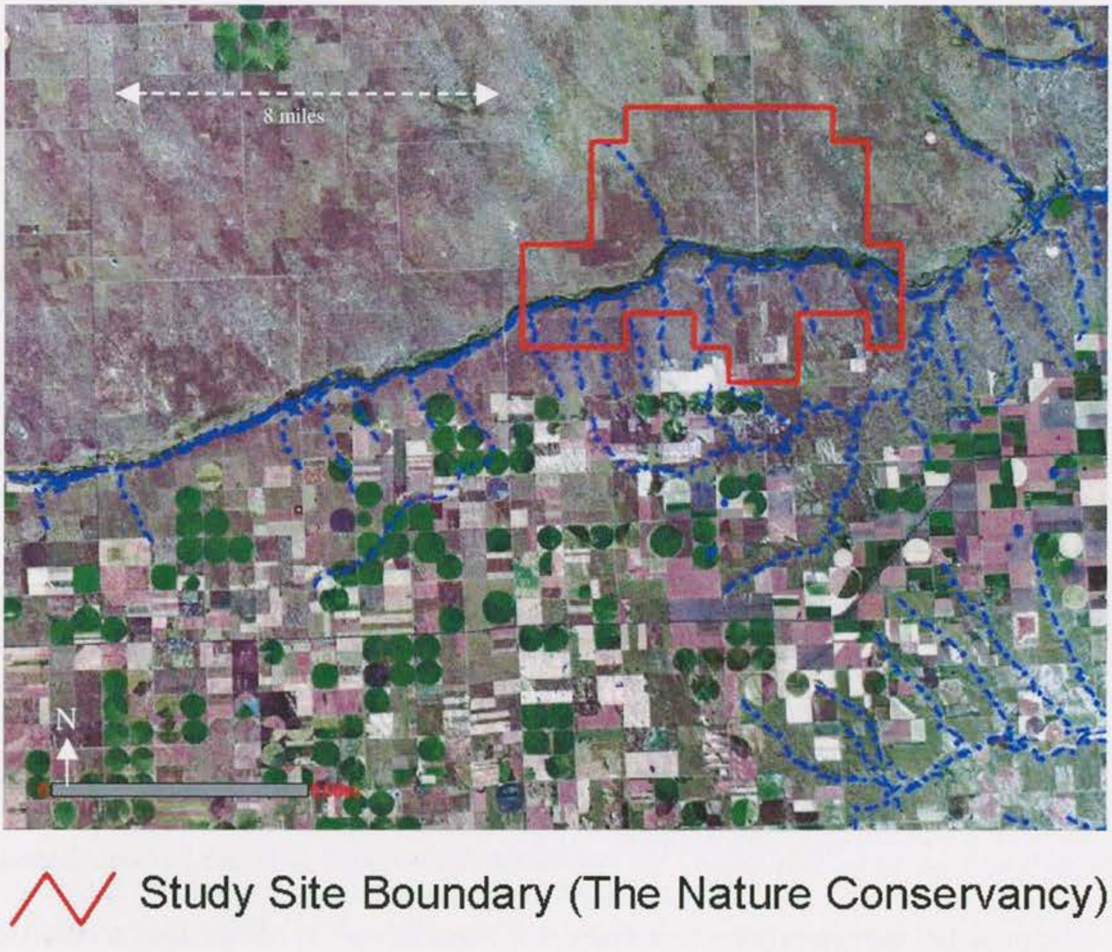


Figure 3.2. The Nature Conservancy Ranch on the Arikaree River.

growing season, while fast winds, high temperatures, and low humidity cause high rates of evapotranspiration throughout the High Plains (Gutentag 1984).

3.1.1.1 Historical Context of the Study Site

It has been theorized that ancient rivers and lakes once covered the majority of the High Plains area. As the Rocky Mountains were formed by means of massive geologic pressures to the west, weather patterns were blocked or changed and much of the High Plains region became arid and dry. However, massive quantities of this ancient water were stored in what came to be known as the Ogallala aquifer, very slowly draining to the east as the climate continued to cool and dry. In general, the Ogallala Aquifer is highly permeable and largely unconfined (TNC 2002), meaning that water could have been easily withdrawn and replenished naturally. However, natural recharge is quite small due to the arid and dry area in which the aquifer is located. Wet and dry periods (typically cycling every 22 years based on data collected from tree rings) seem to coincide with sunspot activity on the Sun, though the overall climate trends throughout the last thousand years do not in any way resemble the wet inland sea climate which once may have dominated the High Plains (Opie 2000).

In more recent history, Yuma County was inhabited by the American Indian tribes. Though it is not known how long this area was inhabited before the arrival of western-bound settlers, a substantial Indian population remained (coincidentally, near the Arikaree River) until the 1890's. The famous battle at Beecher Island took place in the Arikaree River valley (roughly 15 miles downstream of the Fox Ranch) on the morning of September 17, 1868 when 52 American soldiers were ambushed on Beecher Island by a large Indian force of Lakotas and Cheyennes (abuffalosoldier.com/beecherdix.htm). This confrontation, like many others, underscored the tension and danger involved with securing the High Plains for settlement.

By the 1890's the railroad had arrived, facilitating the arrival of range cattle (in place of the once prevalent bison herds). Due to the passage of the Homestead Act of 1882 opening up the plains region for individual purchase, both ranchers and farmers quickly populated the area (Gutentag 1984). A stiff spirit of competition existed between the two groups, until blizzards in 1886 and 1887 killed as much as 80 percent of the range cattle (Opie 2000). From that point on, farming became the occupation of choice.

Due to the scarcity of water, farmers quickly learned to access the vast supply of water underground for their crops and personal use. At first, irrigation wells were hand-dug and very simple in design, though irrigation canals and windmill-driven wells were becoming more common by the end of the 1800's. Wheat was the crop of choice during these times, and still makes for roughly 30 percent of total crop yield in Yuma County (www.nass.usda.gov/ipedb/report.htm). In order to plant, however, many of the native grasses had to be uprooted. In addition, land was rarely left to fallow, and the same crop was often planted for several seasons on the same field without alternation. The result was the tragic Dust Bowl phenomenon of the 1930's, where top soil, no longer anchored by the native vegetation, was scattered by the high winds and choked the air (Gutentag 1984).

It was not until the late 1950's and early 1960's that high-capacity wells arrived *en masse* to tap the Ogallala. These wells, which could provide pumping capacities of over 2000 gallons per minute, fueled the boom in center pivot irrigation on the High Plains, including Yuma County and much of Eastern Colorado (Gutentag 1984). In a 1964 report for the United States Geological Survey on the water resources of Yuma County, William Weist, Jr. stated,

> *"Moderate to large additional supplies of water can be developed throughout much of Yuma County, without affecting the flow of streams in the area. However, because the potential rate of replenishment is small in comparison to the potential rate of development, the aquifer could be overdeveloped locally and the supply depleted."* (Weist 1964, pg. J33)

Water development accelerated rapidly through the end of the 1960's, and significant drops in the water table have since been observed. Concern over lowering water levels has led to many states on the High Plains establishing groundwater management districts to monitor the situation and enforce local regulations on groundwater usage. Colorado passed the Ground Water Management Act in 1965 to establish these management districts (Figure 3.3). In a 2002 annual report issued by the Colorado State Engineer's Office, the average decline between nine Eastern Colorado groundwater management districts was ½ percent per year, translating to 1.12 feet of water table decline between water years 2001 and 2002 (CDNR 2002). This figure is supported by VanSlyke, who in 1990 reported that 17 million acre-feet had been mined from the aquifer since 1965, and that the 1990 withdrawal rate of 800,000-900,000 acre-feet per year led to an annual water level decline of roughly one foot. In addition, he reported that natural discharge and pumping exceeded precipitation recharge by 430,000 acre-feet per year (VanSlyke 1990).

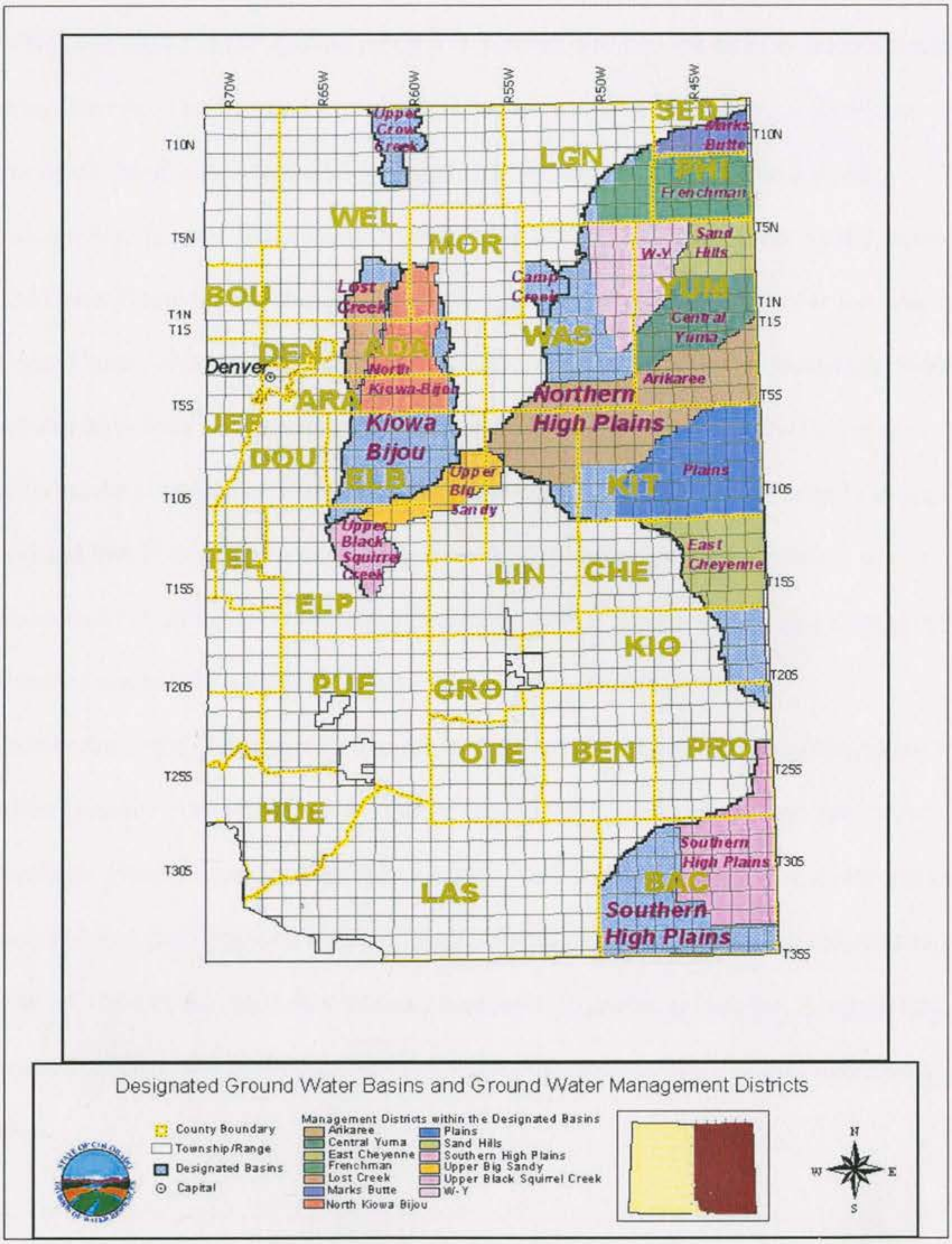


Figure 3.3. Ground Water Management Districts (taken from the Colorado Office of the State Engineer).

3.1.1.2 Regional Aquifer System

While the High Plains/Ogallala Aquifer is without question the most important water-bearing formation in Eastern Colorado, it is by no means the only. Below the Pierre Shale level which confines the High Plains Aquifer, the Apishapa confining unit, Apishapa Aquifer, and Maha Aquifer (Jorgensen 1993) collectively form what is known as the Great Plains aquifer system (Fig. 3.4). The Laramie-Fox Hills aquifer lies west of Morgan County and stretches to Denver and the foothills of the Rocky Mountains, while the Fort Hays-Codell aquifer lies in southeastern Colorado. The Dakota-Cheyenne aquifer encompasses all of Eastern Colorado, though its average depth (roughly at sea level) and low hydraulic conductivity below Yuma County make it impossible to withdraw any useful amounts of water from this aquifer. Likewise, the Lyons aquifer lies just below sea level throughout most of Yuma County (Robson, 1987).

Below the Great Plains aquifer system lie the Western Interior Plains confining and aquifer systems. Any stored water in these formations would lie much too deep to be accessible. Finally, one comes to the basement confining unit dating from Cambrian and Precambrian Age (Jorgensen 1993). Figure 3.4 lists the approximate Age and relative depths of some of the major formations beneath the High Plains Aquifer. A significant amount of information currently exists regarding the hydrogeology of the High Plains region.

REGIONAL AQUIFERS—GEOHYDROLOGIC FRAMEWORK

TABLE 2.—*Generalized correlation of stratigraphic units to geohydrologic units in most of the Plains subregion*

Geohydrologic unit		Principal stratigraphic unit(s)	Time-stratigraphic unit
High Plains aquifer		Ogallala Formation and unconsolidated deposits	Quaternary and Tertiary
Great Plains confining system		Pierre Shale, Niobrara Formation, Carlile Shale, Greenhorn Limestone, Graneros Shale (includes Lower Cretaceous)	Upper Cretaceous
Great Plains aquifer system	Maha aquifer	Dakota Sandstone, "D" sandstone, "J" sandstone, and equivalent of Newcastle Sandstone	Lower Cretaceous
	Apishapa confining unit	Kiowa Shale and equivalent of Skull Creek Shale	
	Apishapa aquifer	Cheyenne Sandstone and equivalent of Fall River and Lakota Sandstones	
Western Interior Plains confining system		Morrison Formation, Sundance Formation, Entrada Sandstone, Dockum Formation, Elk City Sandstone, Doxey Shale, Big Basin Sandstone, Cloud Chief Formation, Day Creek Dolomite, Whitehorse Sandstone, Nippewalla Group, Sumner Group, Chase Group, Council Grove Group, Admire Group, Wabaunsee Group, Shawnee Group, Douglas Group, Lansing Group, Kansas City Group, Pleasanton Group, Marmaton Group, Cherokee Group, Atokan rocks, Morrowan rocks, and Springer Group	Jurassic through Upper Mississippian (Chesterian)
Western Interior Plains aquifer system	Upper unit	Meramecian, Osagean, and Kinderhookian rocks	Upper Mississippian through Upper Cambrian
	Confining unit	Chattanooga and Woodford Shales	
	Lower units	Hunton Group, Sylvan Shale, equivalent of Galena Dolomite, Viola Limestone, Simpson Group, Arbuckle Group, and Reagan Group	
Basement confining unit		Mostly igneous and metamorphic rocks	Cambrian and Precambrian

Figure 3.4. Generalized Geology of the High Plains Region (from Jorgensen 1983).

3.1.1.3 Vital Regional Characteristics

The Ogallala Aquifer consists of poorly consolidated sediment and is generally unconfined and highly permeable (TNC 2002). In Eastern Colorado, specific yield of the Ogallala is generally 0.15 (Weist 1964; Boettcher 1966), ranging from 0.10 to 0.30 (Gutentag 1984). The aquifer is recharged by precipitation at a rate of .85 inches per year (Boettcher 1966; Opie 2000). Transmissibility (the ability of the aquifer to transmit water) ranges from 3700 to 300,000 gpd/ft for the Ogallala, while the transmissibility of the alluvium (where present) is roughly 15,000 gpd/ft. Where the Ogallala and alluvium are in contact with one another (thus forming a single geologic unit), the transmissibility has been tested at around 95,000 gpd/ft (Weist 1964). Sodium levels in the groundwater are low (<100 mg/L) , and average saturated thickness is around 110 feet (Gutentag 1984). The majority of subsurface recharge comes from Washington County immediately to the west of Yuma County, and was at one time estimated at 168,000 acre-feet per year (Weist 1964).

It was found in a 2001 study that only 1 to 2 percent of precipitation in the Republican River Basin translates to runoff, and that the watershed temperature has risen from 10.5 degrees C to 10.8 degrees C. This climate change, though significant, could not account for all of the historic decline in runoff in the Republican River Basin (Szilagyi 2001).

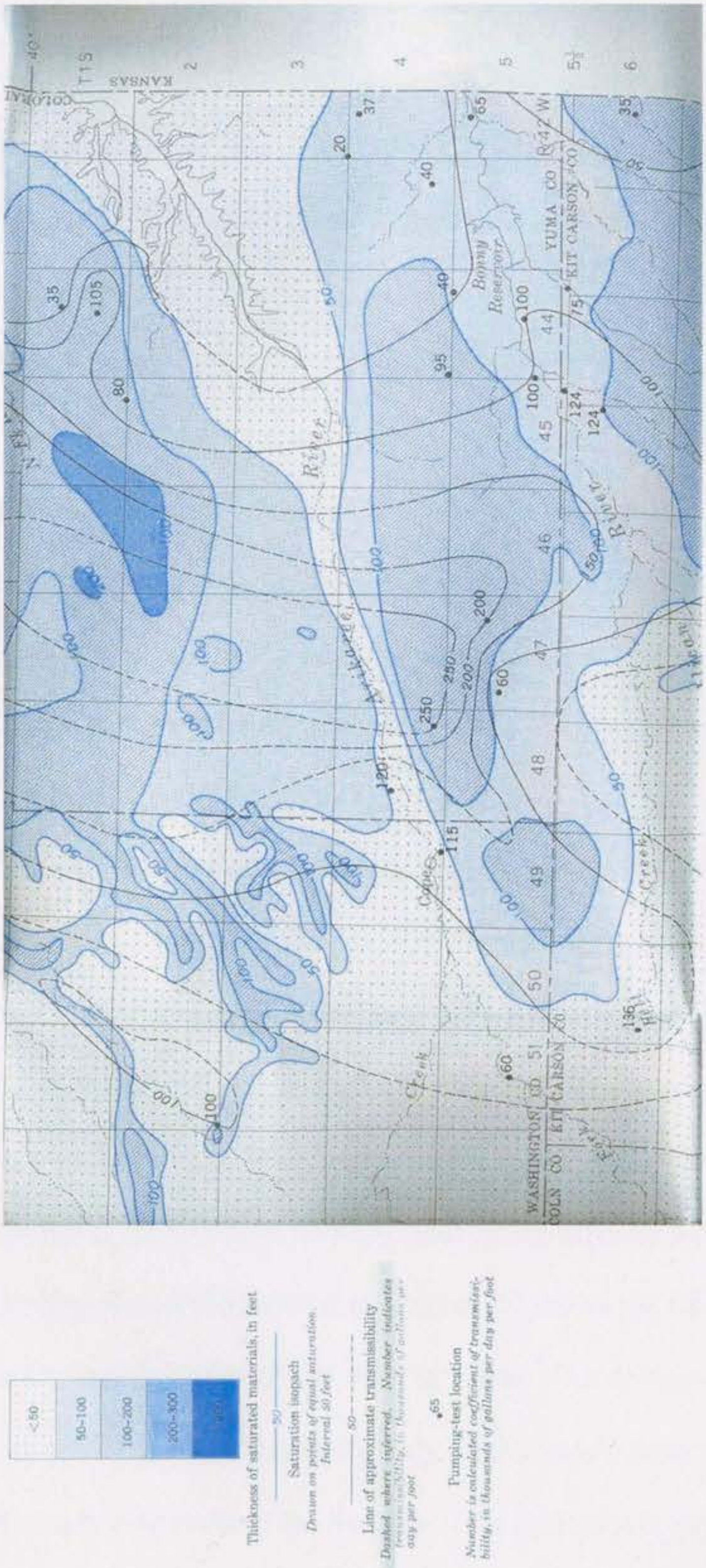


Figure 3.5. Saturated Thickness and Transmissibility for the Study Area. Taken from Borman, et al. 1983b.

3.1.2 Site-Specific Information

In their 1999 report to The Nature Conservancy, McLaughlin Water Engineers stated that the Arikaree River is a perennial river (MWE, 1999); it is, in the sense that water is present *somewhere* in the river year-round. However, both 1996 and 2001 reports to TNC seem to indicate that the Arikaree River does not possess perennial *flow* along any point of its full reach during drier years (Solek 1996; Frenzl 2001). On-site reports from TNC staff also indicate that the river has not flowed perennially since ownership was taken (personal communication). Scheurer observed that the sections of river downstream owned by Arikaree valley cooperative owners and the Division of Wildlife had less pooled water present in the summer than the upstream portion owned by TNC, and that the river became progressively drier as one traveled downstream (Scheurer 2002).

Figure 3.6 shows the geology of the study area as published in Weist's 1964 study of Yuma County. As can be seen, the Ogallala formation and alluvium form a single unit along the Arikaree River. South of the Arikaree, the Ogallala is present along with Peorian loess from the east until roughly township 4S-46. Dune sands are present immediately north of the river, so little irrigation takes place in that area.

The amount of water which can be pumped from a high-capacity well depends largely upon the local hydrogeologic characteristics. Figure 3.5 shows the saturated thickness and transmissibility variations throughout the study area. The average saturated thickness is 100 to 200 feet, while the transmissibility ranges quite widely from 150,000 to 250,000 gpd/ft within the study area south of the Arikaree. The hydraulic conductivity of the aquifer has been estimated at 50 to 100 ft/day (Borman et al., 1983b).

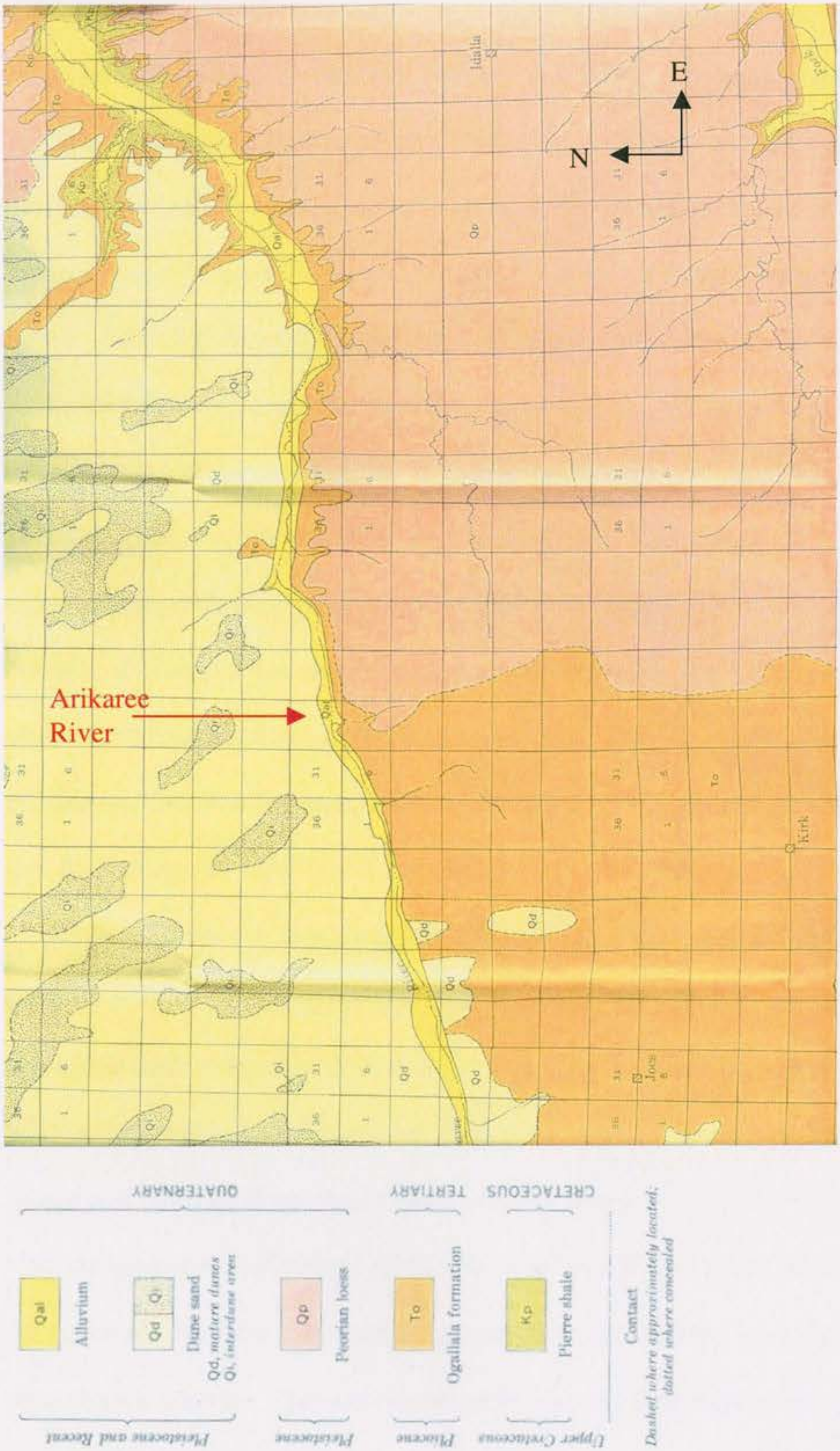


Figure 3.6. Geology of the Study Area. Taken from Weist 1964.

Large rates of baseflow recharge have been recorded coming from the dune sands to the north of the study site (Borman 1983a; Solek 1996). The amount of runoff due to precipitation, in general, is quite small due to the poor drainage in the area, and it is thought (particularly in the areas of loess) that water from precipitation is trapped in depressions, eventually evaporating or moving downward to the water table (Solek 1996). Table 3.1 shows the site-specific geology as published in a 2002 TNC report, and Table 3.2 (from the same report) qualitatively outlines a site-specific water balance.

Most flow into the Arikaree River comes from springs and seeps which originate from the groundwater supply and enter the river as the bed elevation drops below the water table. The river channel bottom may be Pierre shale (MWE 1999). The riverbed largely consists of coarse to fine sand, although larger sediments of 10 to 20 mm were commonly observed throughout much of the 8-mile stretch of river. In addition, silt was much more prevalent at the extreme western end of the ranch. A comprehensive sizing of sediment (i.e. d_{50}) has not, to the author's knowledge, been attempted.

While the seeps are thought to feed the river largely from beneath the riverbed or laterally from the banks, many of the springs which feed the Arikaree are visible during the winter baseflow season (Figure 3.7). These springs dried throughout May and June of 2003, and places in the valley which commonly had long reaches of standing water in March and April no longer had visible water by May.

It has been commonly observed that there exists a large amount of beaver activity on the Arikaree. New dams frequently appear, and existing dams have shown evidence of repair by the beavers. This activity serves to alter the flow regime, as well as any discharge calibrations which may be in development. Figure 3.8 shows a typical beaver dam on the Arikaree.

TABLE 3.1 – REGIONAL HYDROGEOLOGY (taken from TNC 2002)

Stratigraphic Unit	**Hydrogeologic Unit**	**Physical Characteristics**	**Key Groundwater Flow and Aquifer Characteristics**
Alluvial Deposits	High Plains Aquifer	Unconsolidated gravel, sand, silt, and clay	
Peoria Loess			
Dune Sands			Highly permeable = important to recharge, where present
Valley Fill			Intermittent flows in the west. Perennial flows in the east where streams incise the water table in the Ogallala Formation.
Ogallala Formation		Unconsolidated, poorly sorted gravel, sand, silt, and clay	Regional west to east flow, but locally variable. Regional groundwater withdrawals and water level declines.
Pierre Shale	Confining Unit	Clay and silt	Low permeability Irregular surface

TABLE 3.2 – QUALITATIVE WATER BALANCE (taken from TNC 2002)

Inflows	**Outflows**
Precipitation	Evapotranspiration
Groundwater Inflow (Upgradient)	Groundwater Underflow (Downgradient)
Seepage from Intermittent Stream/Tributary Flows	Groundwater Discharge to Streams, Springs and Seeps
Seepage of Irrigation Return Water	Groundwater Extraction
Recharge from Sand Hills – Shallow (Lateral) and Deep	
Overland Flow/Direct Runoff to Stream	

Figure 3.7(a). A Spring Joining the Arikaree. Main river channel is on the left of this photo, spring is on the right (March 2003)

Figure 3.7(b). Origin of a Spring. This spring begins in the distance as the water table elevation intersects the ground elevation (March 2003)

Figure 3.8. Beaver Dam. Taken in March 2003.

3.1.2.1 Ground Water Table Drop

There has been very little significant drawdown of the water table 10 to 12 miles upstream of the western boundary of Fox Ranch (MWE 1999). Water table levels have remained relatively constant or have even risen in certain sections north of the Arikaree, while water levels to the south have dropped slightly since records have been kept (CDNR 2002; MWE 1999). Declines within a radius of a few miles south of the Arikaree averaged zero to 5 feet from the period 1992 to 2002, while losses further south (near Burlington) averaged 15 to 20 feet of loss during the same period (CDNR 2002).

The Arikaree Ground Water Management District, of which the study site is a part, reported an 18 percent loss in saturated thickness from pre-development levels to 1990 (VanSlyke 1990), with an average of 40 feet of saturated thickness remaining. Table 3.3, with information taken from the CDNR 2002 Ground Water report, lists groundwater level declines for several well owners in the vicinity of the study site. Most of these wells are located within the Arikaree Ground Water Management District. Disregarding the wells monitored long-term, the average water level decline for Table B is 6.83 feet from 1988 to 2002.

3.1.2.2 Vegetation at the Study Site

The Nature Conservancy staff, with assistance from the Colorado Natural Heritage Program, have identified the various communities of plant life in the Arikaree valley throughout the study area (Frenzl 2001). Table 3.4 lists each plant species of importance.

Descending into the Arikaree River valley, the landscape is dominated by stands of cottonwood. Plains cottonwoods (*Populus deltoides*) and willows (*Salix exigua*) have been identified as the two major plant users of water (Solek 1996), although research also indicates that tules (*Scirpus acutus*) consume similar amounts of water through the growing season (Johns 1989). The majority of the tule population is isolated to the western section of Fox Ranch along the river, while the cottonwoods and willows are much more prominent throughout the river reach on TNC property (Frenzl 2001).

TABLE 3.3 - REPRESENTATIVE WELL LEVELS

Location	Section	Well Owner	Distance from TNC Ranch, miles [1]	Change in Water Level [2]
Long-Term Monitoring				
T2S R48W	11	US Gov't Well NHP-17	14 NW from western boundary	-46 feet since 1972
T3S R46W	30	US Gov't Well NHP-19	2 NW from western boundary	+0 feet since 1977
T4S R43W	26	US Gov't Well NHP-20	15.7 SE from eastern boundary	-15 feet since 1970
Well Levels Reported 1998-2002				
T3S R45W	7	McDonald, Harvey	4.33 N from eastern boundary	-5 feet since 1988
T3S R47W	14	US Gov't	10.33 NW from eastern boundary	-3 feet since 1988
T4S R44W	4	Wilson, Elliott	6 E from eastern boundary	-4 feet since 1988
T4S R45W	8	Lidke, Otto	2.67 S from eastern boundary	-4 feet since 1988
T4S R45W	15	Sharp, Milton	3.33 S from eastern boundary	-7 feet since 1988
T4S R45W	31	Dutton, Leonard	6.67 SW from eastern boundary	-9 feet since 1988
T4S R45W	32	Dutton, Mildred	6.33 SW from eastern boundary	-3 feet since 1988
T4S R45W	35	Ingalls, Walter	6.33 S from eastern boundary	-8 feet since 1988
T4S R47W	18	Winger, Marion	7.33 SW from western boundary	-2 feet since 1988
T4S R47W	19	Gibson, Daniel	7.67 SW from western boundary	-13 feet since 1988
T4S R47W	26	Wise, Emmett	5.33 SW from western boundary	-15 feet since 1988
T4S R47W	31	Benton, Lee	8.67 SW from western boundary	-9 feet since 1988

[1] All distances approximate (± .7 miles)
[2] As reported in 2002 in CDNR 2002 Report

Populus deltoides, *Salix exigua*, and *Scirpus acutus* have each been identified as phreatophytes, meaning that these plants

> *"...habitually send their roots down to and draw water from the zone where the soil is saturated – the ground-water reservoir – where an adequate and perennial supply is assured."* (Robinson 1968, pg. 622)

Due to their typically high rates of water usage, it has long been thought that phreatophytes in the vicinity of a river or stream could significantly affect flows. Robinson (1968) states that phreatophytes reduce streamflow and discharge from springs during their growing seasons, to the point that some springs and streams may cease to flow entirely if the growth nearby is particularly dense. He also states that stream/spring flow typically returns to baseflow amounts after the early killing frosts.

The effect which a phreatophyte plant or stand has on a flowing body of water, known as the evapotranspiration draft, is evidenced by diurnal fluctuations in the groundwater levels as well as similar fluctuations and reductions in surface flow (Robinson, 1968). Robinson states,

> *"It is a well-known fact that during the growing season there is a daily fluctuation in the flow of western streams not affected by diversion or other regulation. These fluctuations are a measure of the rate at which water is withdrawn from the stream during a 24-hour period by riparian vegetation."* (Robinson 1952, pg. 59)

Most modern research on the behavior of phreatophytes can be traced back to work done for the USGS by White (1932). White also observed that the water table tended to fluctuate diurnally where phreatophytes were present, and that the daily drawdown was slightly greater than nightly recovery, indicating a net loss of water depth. He also observed that the fluctuations, as well as water table decline, began sometime in spring and ended with the killing frosts.

Phreatophyte control has become important as the potential water loss due to these plants has been realized, particularly in the Western U.S. Examples include Naff (1975) who investigated the effect of phreatophytes throughout rivers in New Mexico and Cunningham (1973) who quantified water loss of common New Mexico phreatophyte species. Government agencies, such as the Bureau of Reclamation, have been known to include a section on the effect of phreatophytes when reporting on water supplies of a stream or river (Bureau of Reclamation 1963). It has been observed that species of phreatophytes which have been part of the stable riparian stands of an area typically have less consumptive water use than more invasive species (i.e. *Tamarix* or salt cedar, which is of particular concern along the Colorado and Arkansas Rivers, as well as further downstream along the Republican River) (Cunningham, 1973).

While cottonwoods and willows have been identified as the principal plant users of water in the Arikaree valley (Solek 1996; Weist 1964), no publication to this author's knowledge has previously acknowledged the possible role of vegetation in the de-watering of the Arikaree River.

3.2 Stage Height and Discharge

Stage gages were installed at six points along the Arikaree River (Figure 3.9). Gages 1, 2, and 6 were placed in the vicinity of Fardal's stage gages from her 2002 study (designated West Ranch, U Road, and East Ranch respectively); it was determined that the original (2002) gages were no longer usable for the 2003 study. Gages 1 and 6 were installed at the western and eastern boundaries of the study site so as to compare the

TABLE 3.4 - PLANT TYPES OF THE ARIKAREE RIVER ALONG FOX RANCH

Common Name[1]	**Scientific Name**[1]	**Annual Water Use (inches)**	**Notes** [5]	**Degree of cover for waterfowl** [5]
Creeping Spikerush	*Eleocharis palustris*		No value to livestock	Good
Coyote Willow	*Salix exigua*	33.1 [2], 36.2[6]	Favorite food of beavers, provide food for cattle, provide stream bank stabilization	Excellent (particularly in Eastern Colorado)
Big Blue Stem (Indiangrass)	*Andropogon gerardii*		Food source for cattle in early season	Good
Tule (hardstem bulrush)	*Scirpus acutus*	59.4 [2]	No value for cattle	Good
Switch Grass	*Panicum virgatum*		Food source for cattle	Good
Plains Cottonwood	*Populus deltoides*	66.3 [2], 62.5 [3], 39 [4]	Provide critical habitat for several plains wildlife species	

[1] Taken from Frenzl (2001)
[2] Average values from all studies cited by Johns (1989)
[3] Taken from Blaney (1952)
[4] Taken from Dahm (2002) for mature cottonwood stands
[5] Information gathered from the US Forest Service website (fs.fed.us/database)
[6] Taken from Johns (1989)

behavior of river stage from input to output. One gage was installed at U-road (Gage 2) just upstream of the bridge. Gage 3 was placed approximately one mile downstream from Gage 2, and Gages 4 and 5 were placed within one-quarter mile of each other approximately one mile upstream from Gage 6.

Locations for the stage gages were based upon a few factors. First, the gages needed to be easily accessible; therefore, all the gages except Gage 1 are located immediately adjacent to an access road (reaching Gage 1 requires a roughly one-half mile trek due to

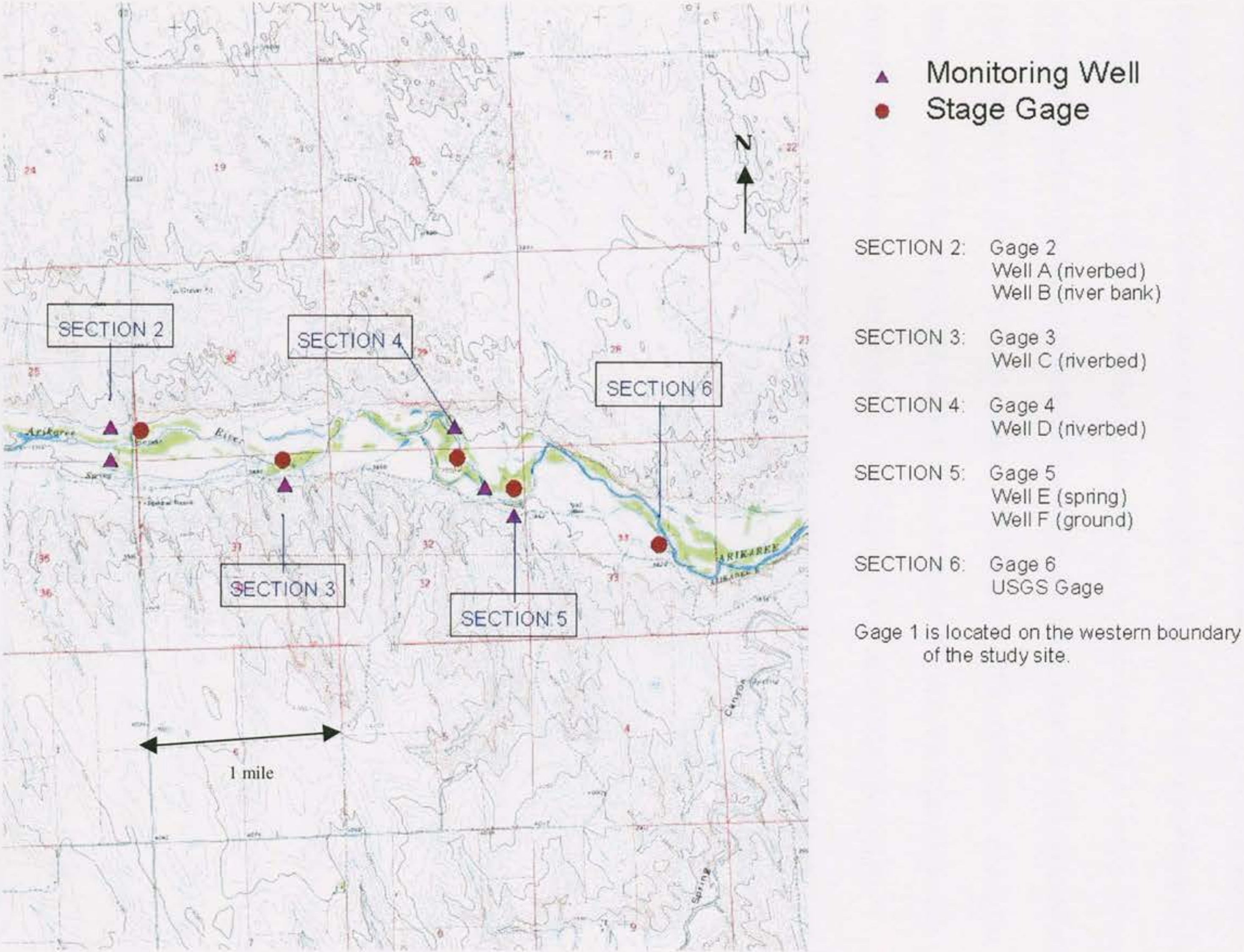


Figure 3.9. Locations of 2003 Stage Gages and Monitoring Wells.

the location of the property line of The Nature Conservancy's ranch). Also, as stated above, it was deemed extremely desirable that gages be placed at both boundaries of the study site to see if differences in stage behavior could be seen. Gage 2 is located near a major road, and can in fact be seen from the bridge of County Road U. This particular road intersects the river a little past the east-west midpoint of the study site. Along the eastern portion of the study site (which is far more accessible than the western portion and also has traditionally carried greater flow rates), it was decided to place gages roughly every mile between Gage 2 and the eastern boundary. Two gages (4 and 5) were placed in close proximity to one another (roughly one-quarter mile apart) one mile upstream of the eastern boundary due to dense plant growth and a high concentration of seeps and springs in the vicinity.

The stage gages consisted of 5-foot poplar wood segments, which were driven 2 feet into the streambed. The gages were scaled in millimeters, with 20 mm between each mark. Gages 3, 4, 5, and 6 were placed at or near the thalweg of the channel, while gages 1 and 2 were placed closer to the southern bank of the channel due to deeper pool depths at these locations. Stage height was measured monthly until the end of May, then weekly to bi-weekly through the end of August, when it was once again measured monthly.

Discharge was also measured at these six locations using the velocity-area method. The current meter used was an Ott-Kempten (propeller type) meter, which was re-calibrated on June 23, 2003 at the Engineering Research Center at Colorado State University's Foothills Campus. All discharges, when being analyzed, used the updated calibration for this meter. Due to the limitations of this type of current meter and records of past observed river behavior, it was not expected that discharge would be able to be collected year-round due to very low flow rates (with river flow eventually expected to become completely disconnected and stagnant).

Stage height and discharge were also recorded every fifteen minutes during 2003 by a recently installed USGS gauging station, located at the eastern boundary of the study site just upstream of Gage 6 (Fig. 3.9). While the USGS stage gage was deemed very reliable, the calibration for the discharge-stage relationship was still in the process of being established during 2003, and was complicated by occasional beaver activity changing the control boundaries for the pool. Also, since no hydraulic structures were placed in the river to measure the flow, the calibration curve continued to be quite susceptible to change.

3.3 Monitoring Wells

Six monitoring wells were installed along the study reach to record groundwater levels (Fig. 3.9), designated alphabetically from west to east. Wells were generally placed near one another at different elevations (i.e. in the riverbed and banks) to try and detect any reversals in groundwater gradient. Well A was placed in the bed just downstream of Gage 2 below the U-road bridge, while Well B was located on the bank adjacent to Well A. Well C was placed in the riverbed just downstream of Gage 3. Wells D, E, and F were placed in the vicinity of Gages 4 and 5; Well D in the streambed just downstream of Gage 4, Well E just above the bank near Gage 5 and Well F further up on the same bank. Wells were all placed near stage gages so that changes in river stage/discharge could be compared with changes in water table levels.

Figure 3.10 shows Well E being installed. The wells were constructed of 2 inch (inside diameter) PVC piping, which was cut lengthwise to varying dimensions depending on the well location. One-half inch diameter openings were drilled on both sides of the piping and were spaced six inches apart. The bottoms of the wells were capped, and each well was then covered with a filter sock commonly used for underground irrigation/drainage piping. Finally, each well was fitted with a removable cap for access. Figure 3.11 shows a couple wells in place.

Figure 3.10. Installation of Well E. Done on September 20, 2003. The hole was backfilled after this picture was taken (the well, thought here to be installed on a bank, was later submerged by a spring).

Figure 3.11 (a) and (b). Wells in Place. Fig. 3.11 (a) was taken in February of 2004, and shows Well E submerged in a spring adjoining the Arikaree (compare with Fig. 3.10 above). Fig. 3.11 (b) shows Well F further up on the bank.

The original intent was to drill each well using a truck-mounted Giddings rig with a four-inch auger. However, severe mechanical difficulties with the rig at the study site in July 2003 prevented any wells from being drilled in this manner. Wells A, B, D, and F were thus hand-dug and installed on August 21, 2003, and Wells C and E were installed on the next site visit (September 20, 2003). Water levels were to be measured by lowering a measuring tape or meter stick down into the well.

3.4 Farmer Contacts

Four representative farmers were interviewed throughout July and August 2003. Each farmer was asked a series of questions (Appendix A), including design and current well capacities. Irrigated crops for each farmer were recorded, as well as when their pumps were turned on. Exit interviews in November and December 2003 recorded the end of each farmer's pumping season and when the pumps had been shut off during the season, if at all. Yields for each crop were also determined.

For each type of crop, daily evapotranspiration rates were calculated throughout the growing season. ET rates for corn, pinto beans, and alfalfa were found on Colorado State University's CoAgMet website (ccc.atmos.colostate.edu/~coagmet/), which uses a modified Penman equation and is location-specific (for this project, all crop ET rates are as estimated at Idalia, CO). ET rates for millet were calculated using a crop coefficient equation as presented in Duke, et al. (1991). Sunflower ET rates were also calculated from a crop coefficient.

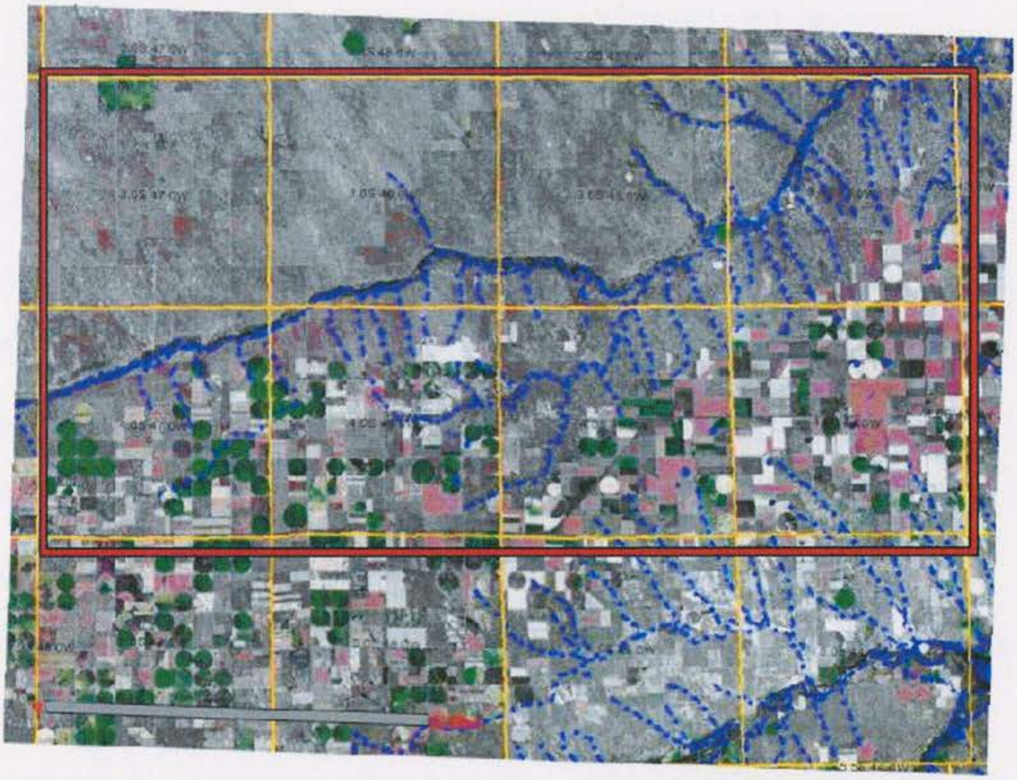
Daily precipitation for 2003 was also collected from the CoAgMet data, which is again region specific from nearby Kirk, CO. Weekly crop needs were established by subtracting the weekly precipitation from the sum of that week's evapotranspiration by a particular crop. Since pumping durations, approximate pumping capacities, and acreage of each crop were known, a daily and weekly depth of water applied could be calculated for each crop (Appendix B). For all farmers interviewed in 2003 using center pivots for irrigation, an application efficiency of .9 was used in calculating the depth of water applied (so as to have consistent results with Fardal's 2002 study).

3.5 Surrounding Well Analysis

Data including 8 townships (Figure 3.12) were collected from the Colorado State Engineer's Office for the well analysis. The most recent records (updated February 2004) were examined for each of the 8 townships, and any active well permit for 100 gpm capacity wells or greater was recorded for inclusion into the analysis. Very good estimates for the distance of each well from the study site were obtained from the State Engineer's interactive website (165.127.86.125/website/lttools/). Distances from well to study site were recorded for three different analyses (centered on the eastern and western boundaries of the study site, as well as the Arikaree at U-road). This data was then cross-checked with information on file with Y-W Well Test in Wray, as well as aerial photographs on file with the State Engineer's Office (Figure 3.12).

As stated above, only high-capacity wells (defined in this study as any well with a design pumping capacity of 100 gpm or greater) designated for irrigation were considered for the analysis. This qualification excluded stock, domestic, and commercial wells. Wells whose permits had expired or had been classified as "abandoned" were not considered. Wells whose permit applications were classified as "denied" were also not considered. Any wells with point-to-point distance to the study site of 60,000 feet or greater (~11.4 miles) were not considered for that particular analysis. Wells *were* still considered, however, even if the aerial photograph did not seem to indicate a crop circle or other evidence of irrigated agriculture in vicinity of the well.

The method of analysis chosen was the Jenkins (1968; 1970) method, more commonly referred to as the *stream-depletion factor* method. This method was chosen both for ease of use and because it remains the most commonly used method in water rights determination. "Stream depletion" can refer to either direct depletion from the stream or reduction in return/recharging flows (Jenkins 1968). Solek (1996) also recommended



Selected Area Includes Townships:

3S-44 through 3S-47
4S-44 through 4S-47

Figure 3.12. Wells Considered in *sdf* Analysis.

that this approach be used by The Nature Conservancy at this study site. Huang (2000) notes that the *sdf* approach is the most commonly used tool for determining the amount of water depleted from a stream or river by a pumping well for legal purposes (i.e. water rights) in the U.S. and in many other countries.

This method of analysis is based upon a number of assumptions, which are detailed in Jenkins (1968; 1970). Briefly summarizing, there assumptions are that:

-Transmissivity of the aquifer does not change with time
-The temperature of the stream is the same as of water in the aquifer
-The aquifer is isotropic, homogeneous, and semi-infinite
-The stream fully penetrates the aquifer
-Water is released instantaneously from storage
-Wells are open to the full saturated thickness of the aquifer
-The pumping rates are steady

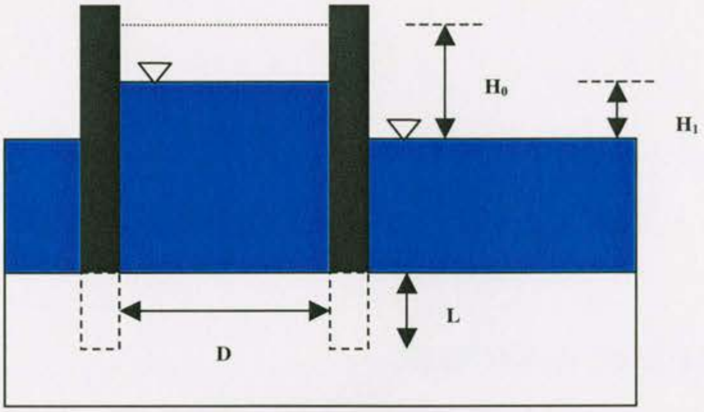
In addition to these original assumptions, Jenkins states that, if the water table is drawn below the bottom of the streambed and the riverbed permeability is low compared to that of the aquifer, then the *sdf* approach as presented is not accurate (Jenkins 1970); this is due to the weakening or breaking of the hydraulic connection between the streambed and aquifer. Specifically, the *sdf* approach, as presented by Jenkins, has been shown to significantly **overestimate** the amount of water which is drawn away from a stream by pumping wells for streams with low streambed hydraulic conductivity (Moore and Jenkins 1966; Sophocleous et al. 1995; Conrad and Beljin 1996; Huang 2000; Butler 2001). If the hydraulic conductivity of the streambed of the Arikaree were found to be significantly less than the surrounding aquifer (see below), then one could deduce that the predicted stream depletion of the *sdf* analysis would be greater than the actual stream depletion.

3.6 Connectivity

Throughout 2003, connectivity of the river was recorded along the eastern portion of the study site (from U-Road to the eastern boundary of the site). This is the same portion of the Arikaree for which connectivity was recorded in Scheurer (2002) and Fardal (2003) for 2000-2002. Notes were made concerning the nature of flow along the river channel at roughly ½ mile increments, and overall flow was classified as connected, pooled, or dry for the entire eastern portion of the river.

3.7 Hydraulic Conductivity

The hydraulic conductivity of the streambed can easily be measured in the field by means of a standpipe placed into the riverbed, as outlined by Chen (2000) and Landon et al. (2001). For this study, five standpipes of varying lengths and 2 inch inside diameter were placed 25 cm into the submerged streambed, being careful to keep disturbances of the sediment at a minimum. A hydraulic head was then imposed by filling the standpipe with water. After a pre-determined time period had elapsed (usually around 20 minutes), the water level in the standpipe relative to the free water surface of the stream was measured. The Darcy equation was then used to determine the vertical hydraulic conductivity of the streambed in meters per day. These tests were only done during times of flow in the river. The 25 cm intrusion was chosen so that results would be comparable with previous publications (Landon et al. 2001), however it is possible that even at this small distance the limiting layer of the organic seal may have already been bypassed. While it might be ideal to test the conductivity at a range of standpipe depths, time limitations simply did not allow for this.



Where: L = depth standpipe is pushed into streambed
D = inside diameter of standpipe
H_0 = distance from stream free surface to initial water level in standpipe (at time t=0)
H_1 = distance from stream free surface to final water level in standpipe at time t_1

One arrives at the hydraulic conductivity by use of the Darcy equation: $K_v = \frac{L}{t_1 - t_0} \ln \frac{H_0}{H_1}$

Figure 3.13. Depiction of Test for Hydraulic Conductivity of the Streambed (Landon et al. 2001)

CHAPTER 4: RESULTS

4.1 General Climate for 2003

The CoAgMet station at Kirk, Colorado reported a total precipitation of 13.16 inches for 2003, which is about 78% of the long-term mean of 17 inches and 68% of the 1971-2000 average of 19.26 inches (as reported by the High Plains Climate Center). However, 4.29 inches of the total was recorded in June, which is a key time for most of the crops. In the area of the study site, precipitation was about 150% of normal for the month of June (High Plains Climate Center, www.hprcc.unl.edu). In combination with an average April and slightly below average May, the heavy precipitation in June meant that most farmers in the region did not need to start irrigating as early as in 2002, when the entire year's precipitation for the study site was just over nine inches. Figure 4.1 and Table 4.1 show cumulative precipitation for 2003.

The maximum temperature (as recorded at the Kirk station) for 2003 was 106.3 °F, recorded in the early afternoon of July 25th. The minimum temperature was –6.2 °F, occurring just before sunrise on February 24th. Average maximum temperature for 2003 was 63.7 °F and average minimum was 36.1 °F, which are respectively 5% lower and 6% lower than 1988-2003 averages (High Plains Climate Center). Table 4.2 summarizes a few basic climatic conditions.

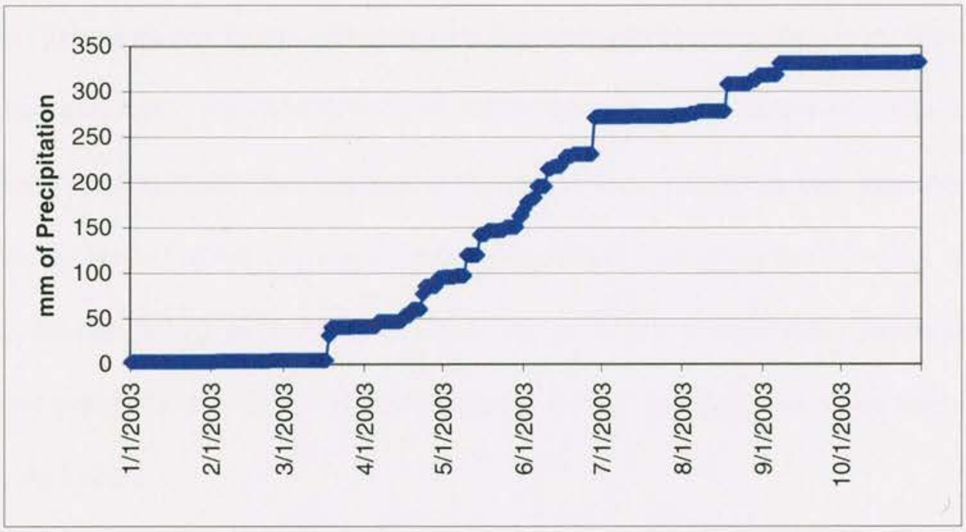


Figure 4.1. Cumulative Precipitation at Kirk, Colorado for 2003 (mm.)

TABLE 4.1 – PRECIPITATION AT KIRK, COLORADO FOR 2003 (in.)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
.11	.05	1.46	2.11	2.7	4.29	.05	1.74	.54	.03	.08	.03	**13.16**

TABLE 4.2 - CLIMATE FOR FOUR YEARS NEAR THE STUDY SITE

	2003	2002	2001	2000
Average Max. Temperature (°F)	63.7	66.52	65.62	65.97
Average Min. Temperature (°F)	36.1	29.13	37.68	33.62
Precipitation (inches)	13.16	9.53	14.71	17.52
% of long-term precipitation (17 inches)	77.4%	56.1%	86.5%	~100%

4.2 River Discharge

Beginning on the March 30th site visit, cross-sections were chosen near to installed stage gages and flow rates were measured in the river (Figure 4.2). The eastern boundary of the study site flowed at around 5 cfs through April, while the flow at the western boundary was minimal (though visibly present). As can be seen from Figure 4.4, discharge was shown to, in general, increase as one progressed downstream from the western boundary due to the influence of seeps and springs along the river. Two visits were made in April, which both showed similar discharges at the same locations as were measured in March. By the next visit at the end of May, discharge had decreased by roughly 50 percent at the two easternmost gages (the measurements at U-road, although gaged, did not yield a discharge due to low velocities and thick channel vegetation). It was also noted that the flow was visibly slower during the May visit along many sections of the Arikaree.

Figure 4.2. Gage 2 and Line for Sectioning Off Cross-Section for Discharge (April 2003).

On the site visit of June 6th (one week after the May visit), discharge measurements were attempted at Gages 6 and 2. However, the velocities along the cross-sections had by this time slowed to the point that the propeller on the meter no longer turned.

It was observed on the May 29th visit that the vegetation both on the banks and in the channel itself was much thicker than it had been on April 24th. This increase in vegetation is likely to have increased the relative roughness in the channel and thus may account for some of the reduced discharge (Figure 4.3). The discharge at Gage 2 could not be measured on this date due to both substantially reduced velocities and thick channel vegetation that continually interfered with the Ott meter's propeller.

Figure 4.3. Vegetation in the Channel. This was taken in February 2004 near Well E. In the midst of the growing season, the heavy vegetation in the channel provides significant resistance to the flow.

The bed slope of the Arikaree was judged from topographic maps to be between .004 and .005 m/m along the study site reach, although flatter segments of river are likely present. The Manning's **n** roughness coefficient was estimated from on-site velocity measurements and observation to be around 0.040 during the winter months; this is a typical value for a highly vegetated channel. It is assumed that this roughness would

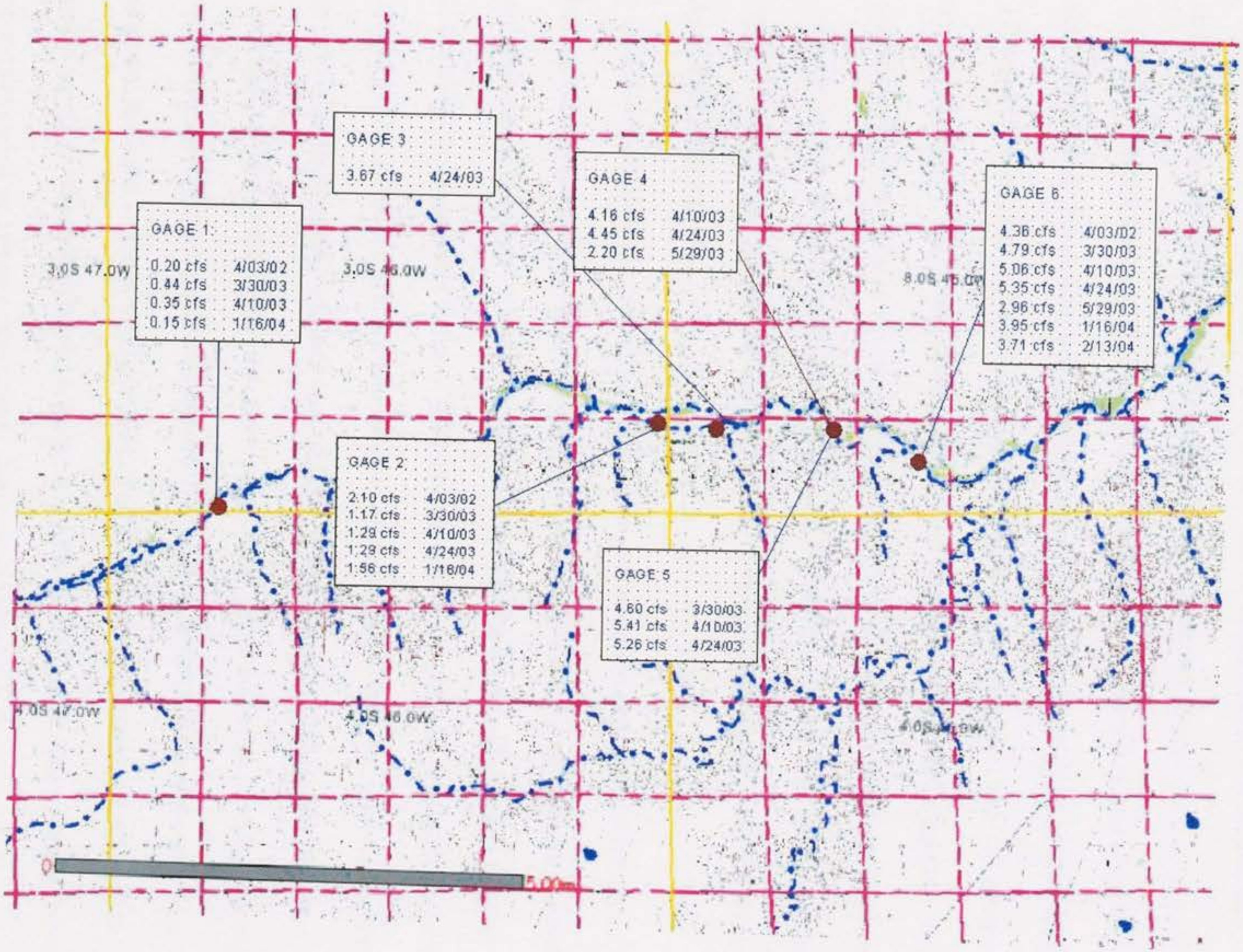


Figure 4.4. Measured Discharges Along the Arikaree.

increase as the growing season began. Thus, some reductions in flow velocities and discharge are easily attributable to the vegetation in the channel itself.

The USGS gage upstream of Gage 6 was recording throughout 2003, and according to the calibration of this station, measured discharges on four site visits compared within 13% of the calibration. It must be noted, however, that the calibration was still being developed in early 2003 when discharges were being determined, and that greater confidence should likely be given to the discharges taken on-site during that time period.

Discharges in the vicinity of Gages 1, 2, and 6 were also taken by TNC personnel on April 3rd, 2002; these numbers appear in Figure 4.4, and compare fairly closely with the April 10th, 2003 site visit.

The Colorado Water Conservancy Board claims in-stream water rights of 3.5 cfs between the western boundary of the study site and U-road, and 7.0 cfs between U-road and the eastern boundary. Clearly, these recommendations have not been met in either 2002 or 2003. These water rights (CWCB case numbers 1-74W7734, A and B) are both dated June 21, 1974, and it is not known how these recommended flow rates were arrived at. It may be that the river has had historically higher flows than the last few years.

Though water levels had begun to recover by October (see below), a flowing river was not present until December. On the January 16th, 2004 site visit, discharges were measured at Gages 1, 2, and 6 (Figure 4.4). The discharge on this date had returned to similar levels as was recorded in March and April the previous year. It seems that, around December or January, flow slowly increases to initial baseflow levels and remains relatively constant until the next spring.

4.3 Measured Stage Height

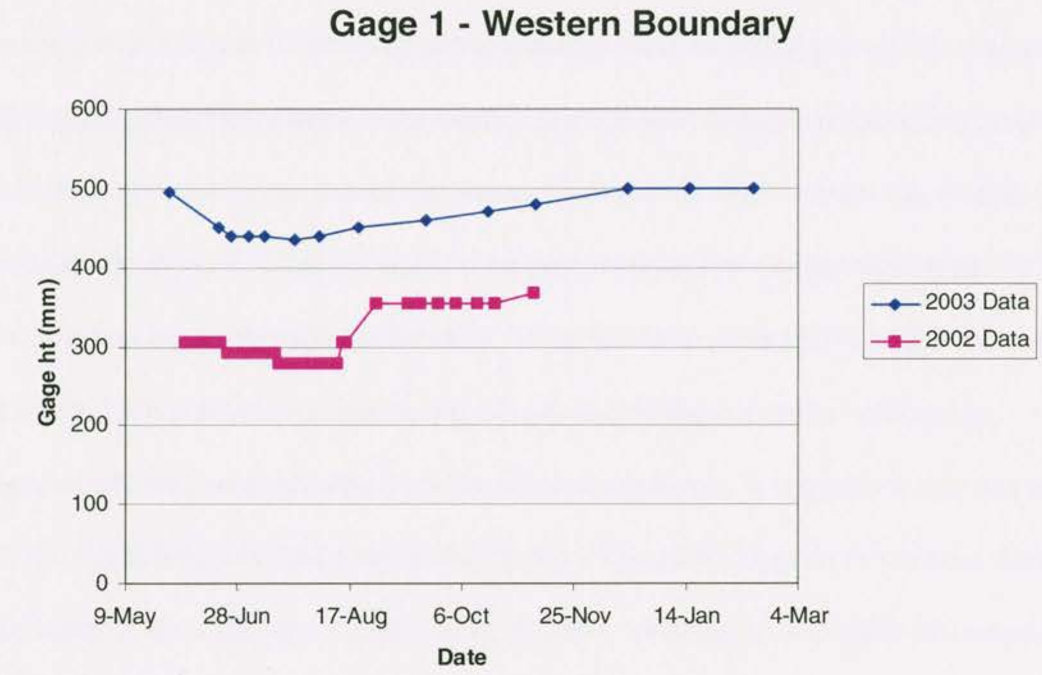
When each of the six stage gages were originally placed into the streambed, markers were placed into the bed adjacent to the gage, so that if a gage were to be washed out or damaged it could be replaced in the same location. On the October 18th 2003 visit to the site it was found that most of Gage 6 had been gnawed away, likely by beavers. On the same visit, Gage 2 was found floating on the surface of the pool, intact. Gage 5, likewise, was found to be floating on the water surface, intact, on the December 19th visit (all gages were replaced in the same locations and on the same site visit as they were discovered defective). It is most likely that, as the water table beneath the streambed began to rise (see **4.5 Monitoring Wells**, below), the pressure from the rising water "pushed" the gages up out of the bed. The wells in the streambed, which are of course heavier than the stage gages, were not affected in the same way.

Thick ice was present along most of the river on the December 19th visit. Consequently, no discharge measurements were possible that day, and the stage height and well level measurements taken may well have been skewed slightly higher due to the ice. The discharge measurement taken at Gage 6 on the February 13th 2004 visit was also lower than previous off-season values due to heavy ice just upstream.

Graphs showing the entire record of stage height for the six gages are shown in Figure 4.5 (original data sets appear in Appendix C). Although the gages are not in the exact locations as Fardal's (2002) gages, Gages 1, 2, and 6 were placed in the general vicinity of Fardal's, and thus a comparison of river behavior at these locations is possible between 2002 and 2003. Figure 4.5, where applicable, shows Fardal's 2002 data as well. It should be noted that one disadvantage for such a comparison would be that Fardal's data begin in June, while the 2003 data begin in March. Thus, trends at the beginning of the growing season are not able to be compared.

4.3.1 Gage 1 and "West Ranch"

Gage 1 is in close proximity to Fardal's "West Ranch Stage Height". The river at this section can be seen to have behaved similarly for both years. Both years show an initial stage decrease, followed in early to mid-August by a gradual increase in depth until the end of the year. As can be seen from Figure 4.5 (a), the behavior at this section of river is quite different from sections further downstream, an observation which is further confirmed by TNC staff (Frenzl 2001). A thick layer of organic material was present throughout 2003 along the channel, and this section generally resembled a wetland throughout the summer months. Bullfrogs and insects (in particular the bothersome deerflies) were much more prevalent here than further downstream, as were populations of tules (*Scirpus acutus*) in the vicinity of the river. Mclaughlin Water Engineers (1999) state that, in this area, the shale is not exposed and that the water table has retreated far enough below the channel evelation that there is not much groundwater discharge into the river. When the channel bed is disturbed here, silt quickly clouds the water and one tends to "sink" into the muddy streambed, which is not the case further downstream where the channel bed surface is primarily sand.



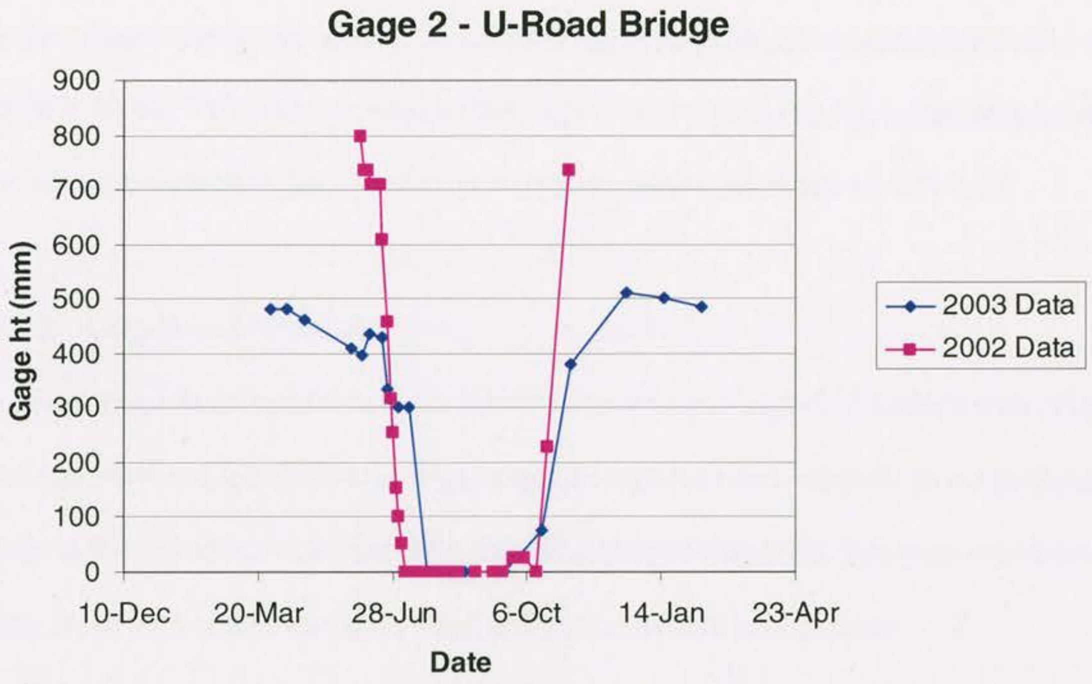


Figure 4.5 (a) and (b). Stage Heights for Gages 1 and 2 (2002 and 2003).

Though it seems quite evident that this section of river is disconnected from the water table by elevation and low streambed permeability (see **4.6 Hydraulic Conductivity** below), it also seems evident that some recharge must be taking place at this section through the summer months. One would expect evaporation from a standing pool such as this one to be quite large during the summer months. In other words, this section of river, without any type of recharge, would have been expected to display significant evaporation losses through the summer. What has been observed in both 2002 and 2003, however, is a gradual *increase* in stage depth during those months without any appreciable discharge coming from the channel upstream. It is possible that this section of river is being recharged year-round by water known to come from the sand dunes to the north of the study site (Solek 1996). Further, monitoring well NHP-19 two miles to the northwest of Gage 1 (Table 3.3) shows no net decline in water levels since 1977, and in fact some wells to the north of this section have shown slight increases in water levels (MWE 1999). This seems to suggest that high-capacity pumping for irrigation may not be adversely affecting the area immediately surrounding the Arikaree at Gage 1.

4.3.2 Gage 2 and "U Road"

Gage 2 can be compared with Fardal's "U Road Stage Height". The 2002 data (Figure 4.5 (b)) show a slight decline in stage height throughout June, followed by a significant drop at the end of June and into July. By the middle of July 2002, this gage was already dry. Recovery, which was quite rapid, did not begin until mid-October.

The 2003 data show a decline in depth beginning as early as mid-April (which, as mentioned above, cannot be compared to 2002 data). After a precipitation event in mid-

June raised the depth slightly, Gage 2 shows a steep decline in stage beginning at the end of June until the end of July, when the gage was no longer wetted (although it should be noted that a disconnected pool remained near Gage 2 for the entire summer, Figure 4.6). The gage was again wetted in mid-October, and recovery was rapid until early April stage levels were attained. As can be seen, the behavior of the river stage at this section was practically identical in 2002 and 2003. The rapid drop in stage height, as well as the recovery, occurred at roughly the same times of the year in both Fardal's study and the present study.

4.3.3 Gage 6 and "East Ranch"

The pool which Gage 6 was placed in was much deeper than the pool just downstream where Fardal's "East Ranch" gage was placed in 2002; this was desirable for the present study so that, during the summer months, usable data could still be gathered for this section of river. Fardal's data (Figure 4.5 (c)) show a decline in stage height from June until the beginning of July, when the gage became dry. Recovery began in early September, with a noticeable "dip" in mid-October.

The 2003 data show slight increases in stage throughout April, which were precipitation induced. The end of May shows a rapid decline which continued through mid-September. By mid-October the stage had almost completely recovered. The slight increase in stage depth for December 19th reflects the presence of thick ice around the gage.

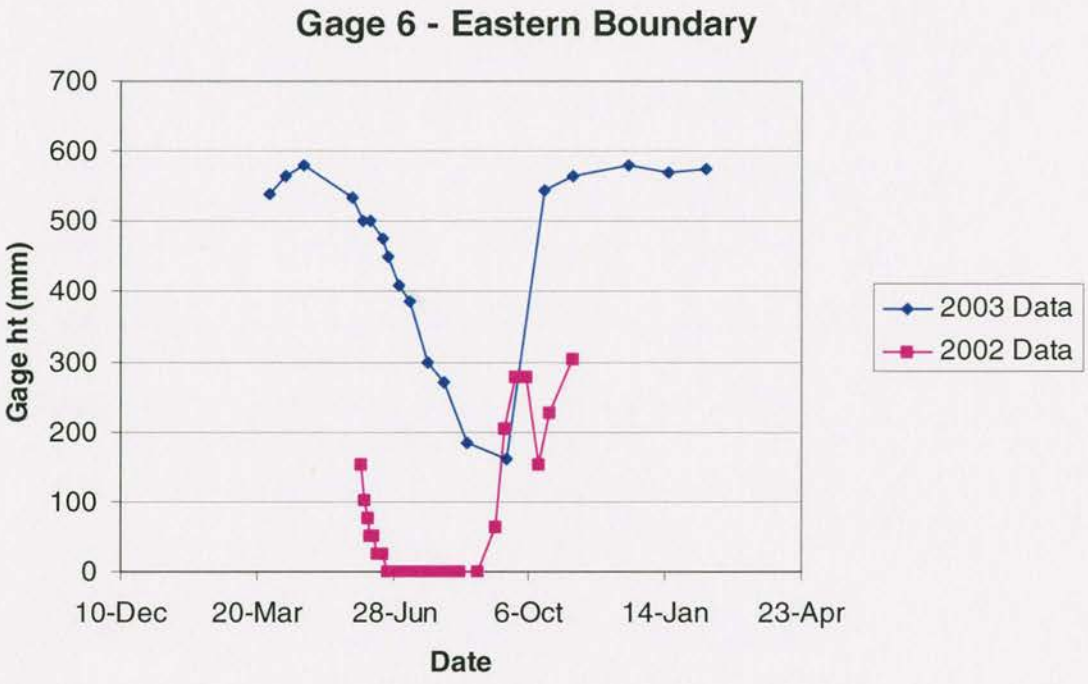
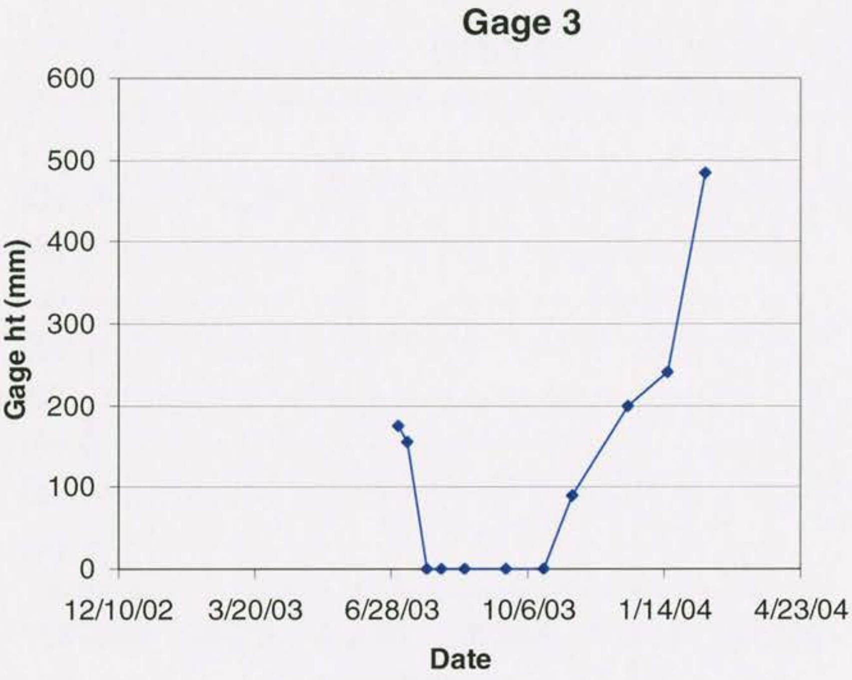


Figure 4.5 (c). Stage Height at Gage 6 (2002 and 2003).

Comparing the 2002 and 2003 data for this section is difficult due to the small amount of data available from early in the 2002 season before gage drying. However, it can be said that the recovery occurred slightly later in 2003 at this section than the previous year, a statement which is echoed in the Connectivity section below. Also, there is no indication in the 2003 data of a "dip" in stage height similar to that observed in 2002.

4.3.4 Gages 3, 4, and 5

These locations were not gaged in 2002, and thus no comparison of stage height can be made between the two years. Each of the three gages exhibits nearly identical data, and are thus treated here under the same heading (Figure 4.5 (d) through (f)).



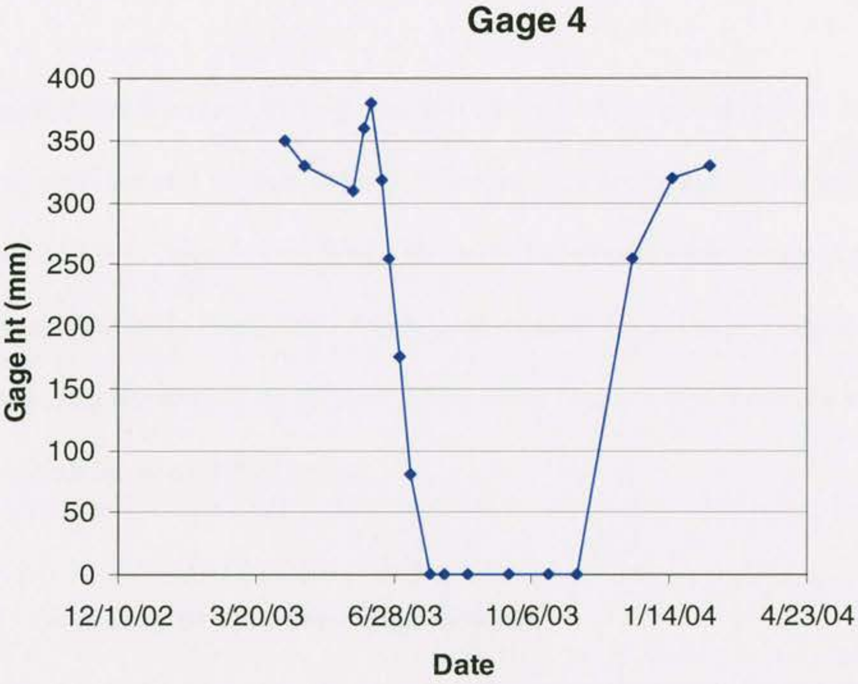


Figure 4.5 (d) and (e). Stage Height at Gages 3 and 4 for 2003.

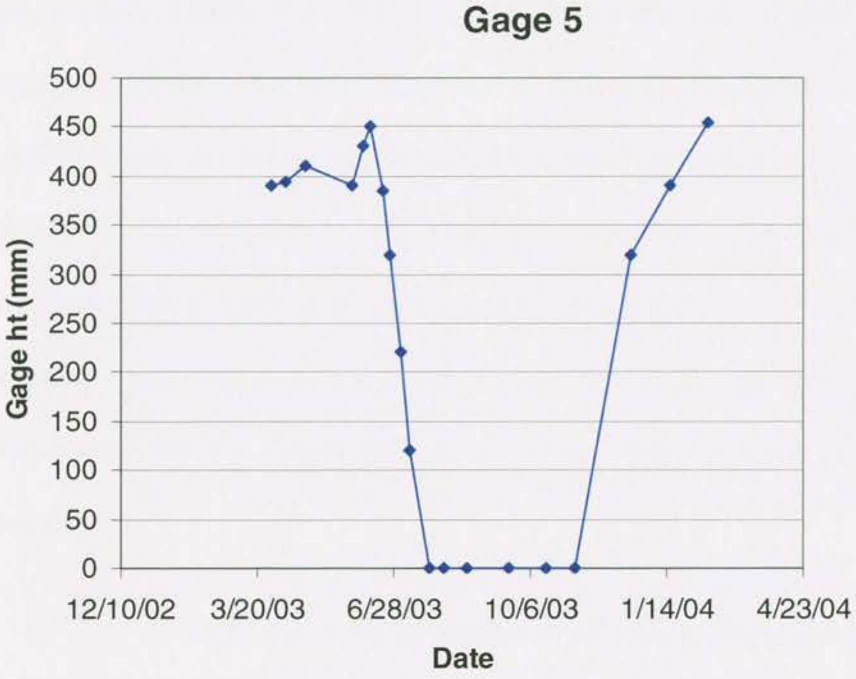


Figure 4.5 (f). Stage Height at Gage 5 for 2003.

Gages 4 and 5 were relatively constant (disregarding the early June precipitation events) until the end of June, when the decline in stage began. Both gages had dried at the end of July. Gage 3, which was not installed until the beginning of July, also shows a continual decline in depth until drying at the end of July. Gage 3 began did not begin to recover until the beginning of November, while Gages 4 and 5 did not show recovery until sometime in mid-November.

4.3.5 Summary of Measured Gage Heights

Table 4.3 summarizes the above discussions, and shows that initial stage height declines and post-growing season recoveries were comparable in 2002 and 2003. While recovery at U-road occurred at roughly the same time for both years, the recovery at the eastern end of the study site was a few weeks later in 2003 than in 2002. Based upon this data, it seems that the stage height of the eastern section and U-road decline first, at the beginning of June. The rest of the river (with the notable exception of the western portion) begins declining roughly two weeks later. Recovery times are much more varied, with the eastern boundary showing recovery long before the rest of the river. The section at U-road began showing increases in depth about three weeks after the eastern boundary, with Gage 3 (one mile downstream of U-road) showing recovery after another three weeks. Finally, Gages 4 and 5 show recovery a month and a half after the eastern boundary.

TABLE 4.3 - SUMMARY OF STAGE HEIGHT DATA

	Gage 2	**Gage 3**	**Gage 4**	**Gage 5**	**Gage 6**
Begin of Decline 2002	June 7				June 5 (?)
Begin of Decline 2003	May 29		June 20	June 20	May 29
Begin of Recovery 2002	October 23				September 12
Begin of Recovery 2003	October 18	November 8	mid-November	mid-November	end of September

4.4 Gage Height from USGS Gaging Station

The gaging station just upstream of Gage 6 recorded continuously for all of 2003 (Figure 4.7). Despite significant rainfall events in June 2003, it records a very gradual decrease in baseflow beginning the first week of May and continuing through mid-June. At this point the decline becomes much more drastic, finally reaching the lowest level in the first week of September. An abrupt increase in stage depth is recorded at the very end of September, reaching a steady depth by mid-December. These data compare well with Gage 6 (above), and certainly provides more detail about the river behavior.

Figure 4.6 (a) and (b). Section Containing Gage 2. View (a) was taken April 10, 2003, and view (b) was taken at the end of July 2003. Although Gage 2 (visible in (b) on the left hand side of the picture) became dry in the summer, a pool remained in the location year-round.

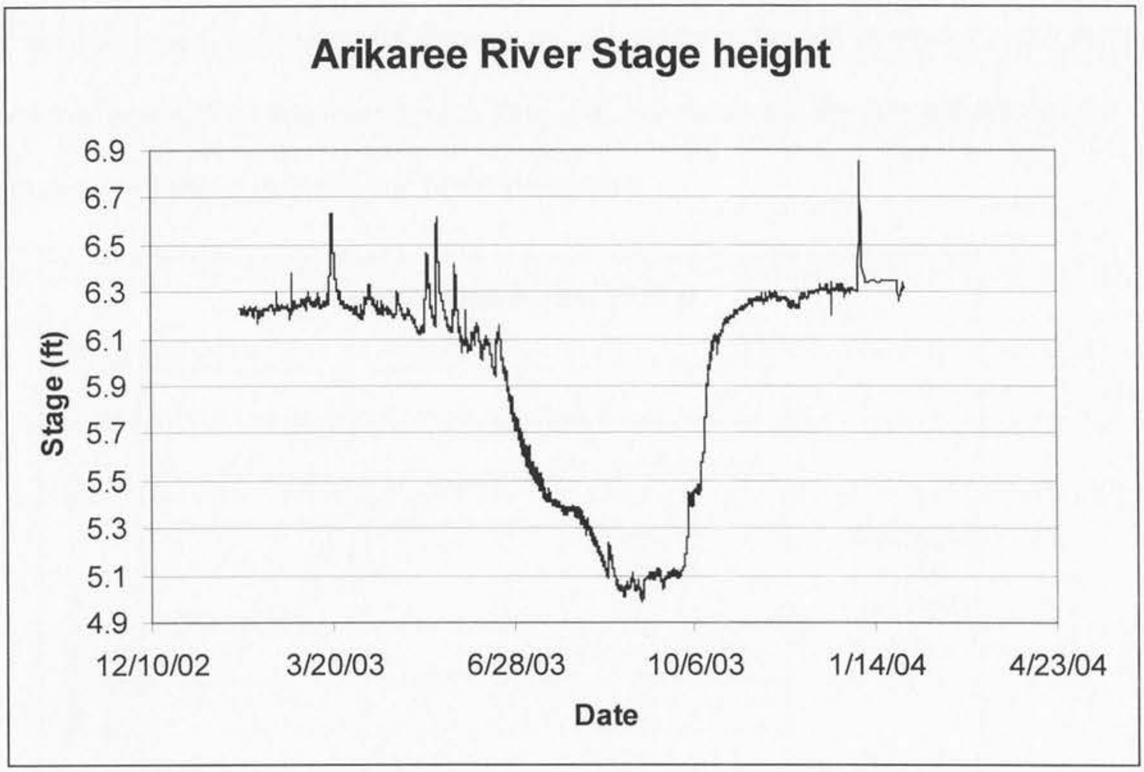


Figure 4.7. Stage Height As Recorded by USGS Gaging Station.

4.5 Monitoring Wells

Collection of data from each well took place from the time it was installed through February 2004. Wells B and F were dry upon installation, with Well B showing water on the next field visit. Well F, on the other hand, did not show water until January of 2004.

4.5.1 Wells A and B

Wells A and B were in the vicinity of Gage 2 adjacent to U-road. Figure 4.8 shows the depths to water for Wells A and B along with the record for Gage 2. The depths in Fig. 4.56 are relative to the ground elevation for each well and gage, which is useful in comparing the behavior of the water table. Elevations at the base of each well and Gage

2 were surveyed, and Figure 4.9 shows the same results as Fig. 4.8 presented as the depth to water below Well B (on the bank). Thus, Fig. 4.9 shows the absolute behavior of the water table both on the bank and in the streambed.

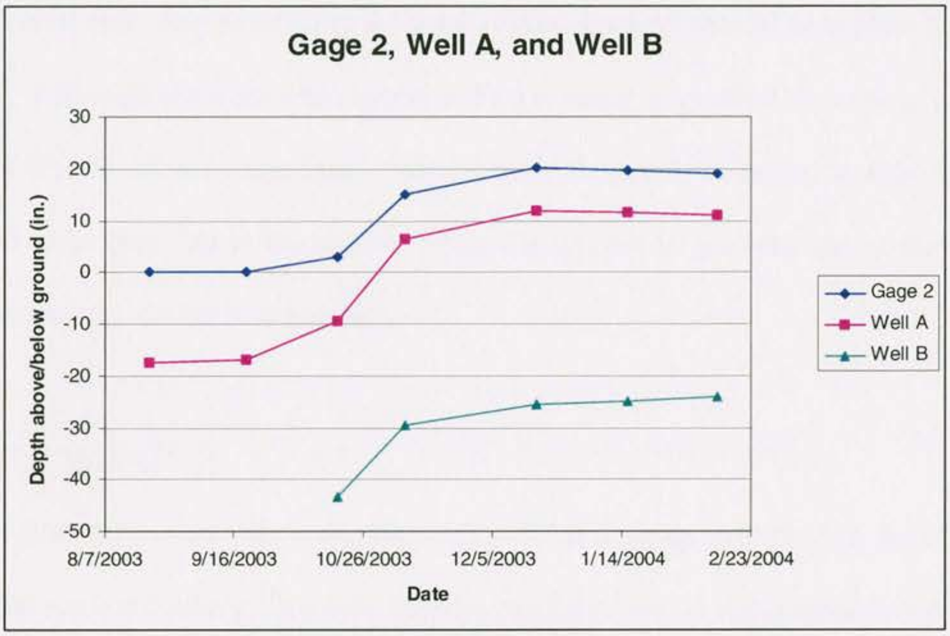


Figure 4.8. Depth to Water for Wells A and B Relative to Ground Level.

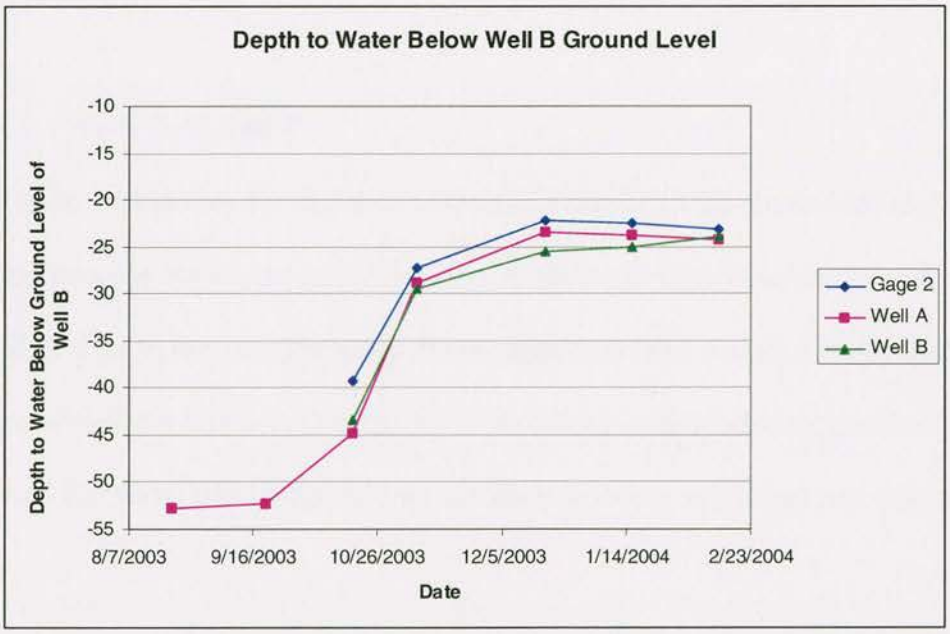


Figure 4.9. Depth to Water for Wells A and B Relative to Well B Ground Level.

As is very evident from Figure 4.8, the water table seems to rise in an identical fashion both on the bank and in the streambed in the vicinity of Gage 2. As the water table rises underneath the river bank, the water table underneath the streambed is also rising at an identical rate. Any reversal in the groundwater gradient should be evident from Figure 4.9. Although there does not appear to be a reversal in gradient, it must be understood that Well B did not immediately have water in it upon installation, thus the data for this well came quite late in the season. Thus, the reversal in gradient may or may not have been present earlier in the season.

4.5.2 Well C

Figure 4.10 shows the water table below Well C along with Gage 3, both of which are at the same elevation. This data shows a rapid increase in water table elevation beneath the streambed until the water table finally broke above ground towards the end of October.

4.5.3 Wells D, E, and F

Figure 4.11 shows the depths to water for Wells D (in the streambed) and E (in a spring near the bank), as well as Well F (on the bank) relative to the ground elevation of Well F. Due to the fact that water did not appear in Well F until January 2004, it is impossible from this data to determine if a reversal in groundwater gradient had taken place. The water table behaved very similarly between streambed and adjacent spring.

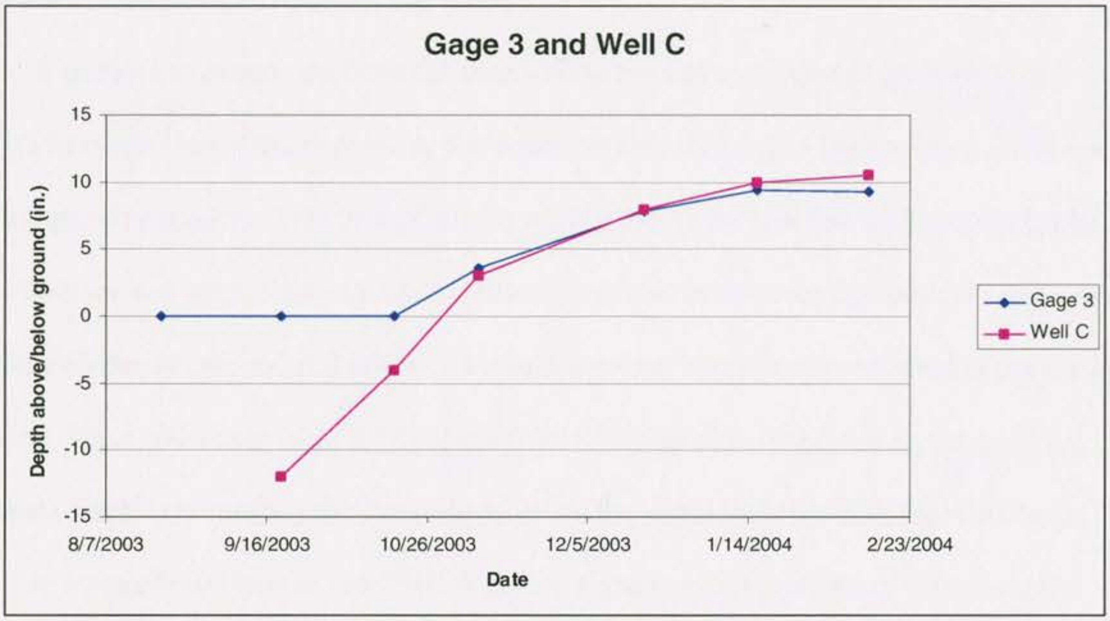


Figure 4.10. Depth to Water for Well C Relative to Streambed.

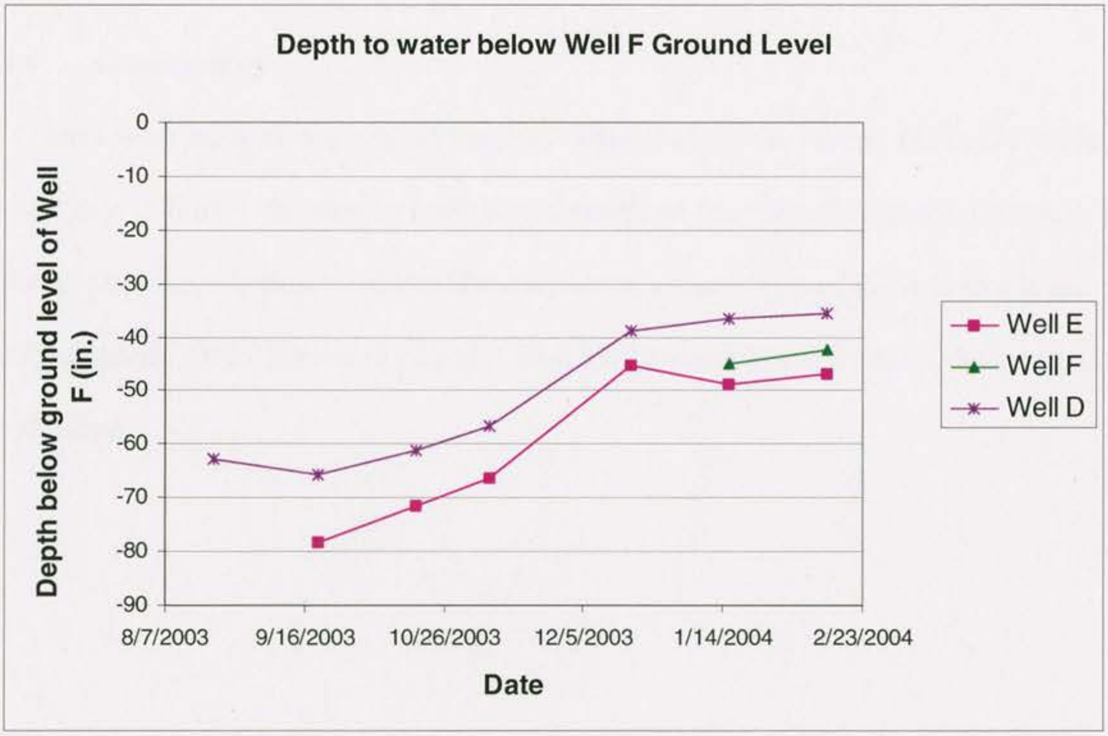


Figure 4.11. Depth to Water for Wells D, E, and F Relative to Well F Ground Level.

4.5.4 Summary of Monitoring Wells

It cannot be determined from the data whether or not a reversal in groundwater gradient has indeed taken place as the water begins returning to the Arikaree at the end of the growing season. This lack of data is mainly due to the shallow wells on the banks which are not wetted until late fall. However, it has been shown that both the water table beneath the streambed and laterally beneath the river bank recover at roughly the same rate. Thus, the water table is being drawn beneath the streambed during the growing season and is at roughly the same elevation as the water table beneath the river bank.

It is significant to note that Well A shows a rise in water table level between mid-August and mid-September, before the effect of irrigation well de-activation would have been felt at the river (see Table 4.7 below).

4.6 Connectivity

Notes were made on the state of the river channel along the eastern section of the study site (from U-road to the eastern boundary) throughout the year. Scheurer (2002) and Fardal (2003) made similar observations along the same stretch of the Arikaree from 2000 through 2002. Figures 4.12 and 4.13 show Scheurer's and Fardal's observations as published.

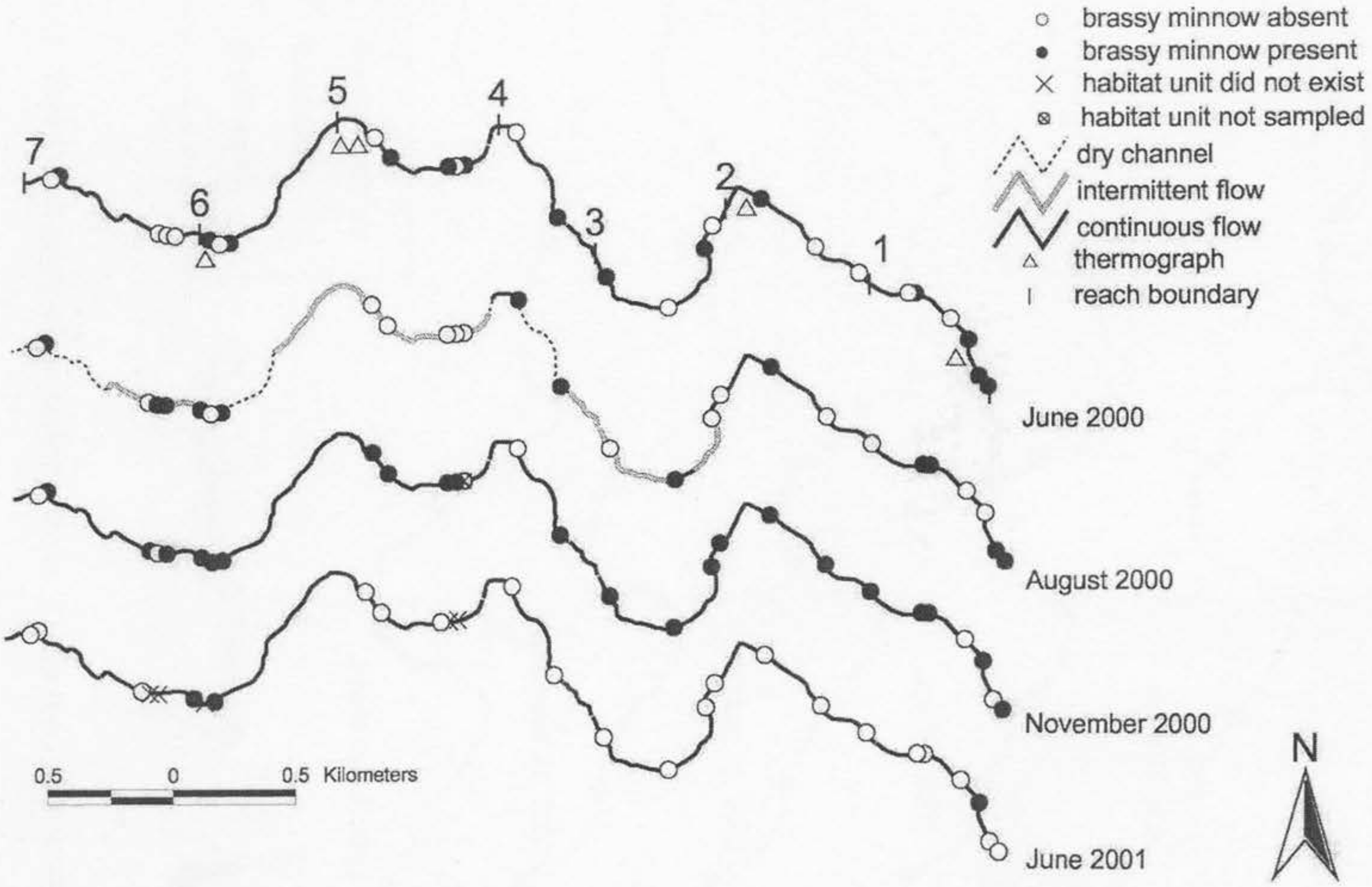


Figure 4.12. 2000 and 2001 Connectivity of the Arikaree. Taken from Scheurer 2002.

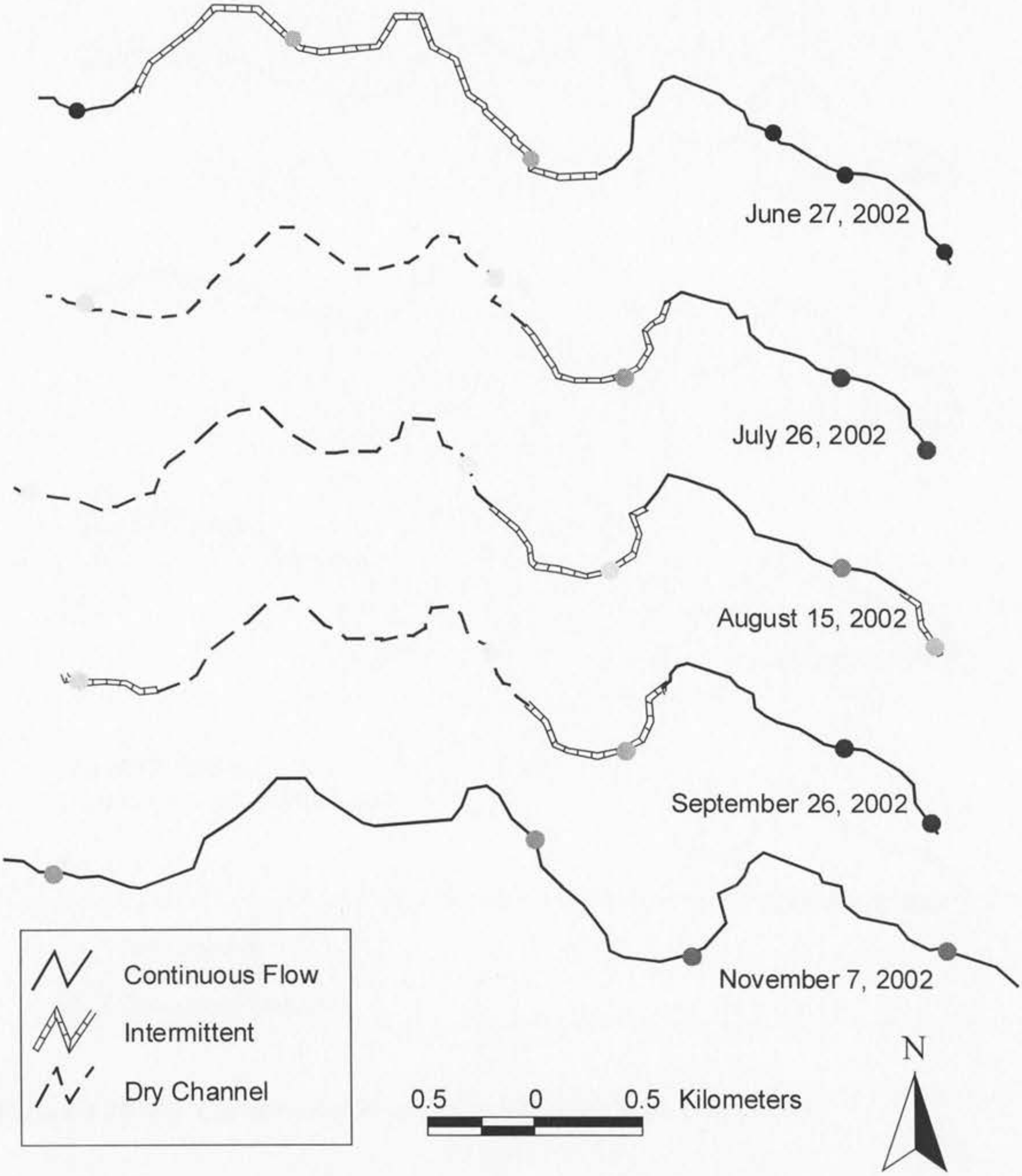


Figure 4.13. 2002 Connectivity of the Arikaree River. Taken from Fardal 2003.

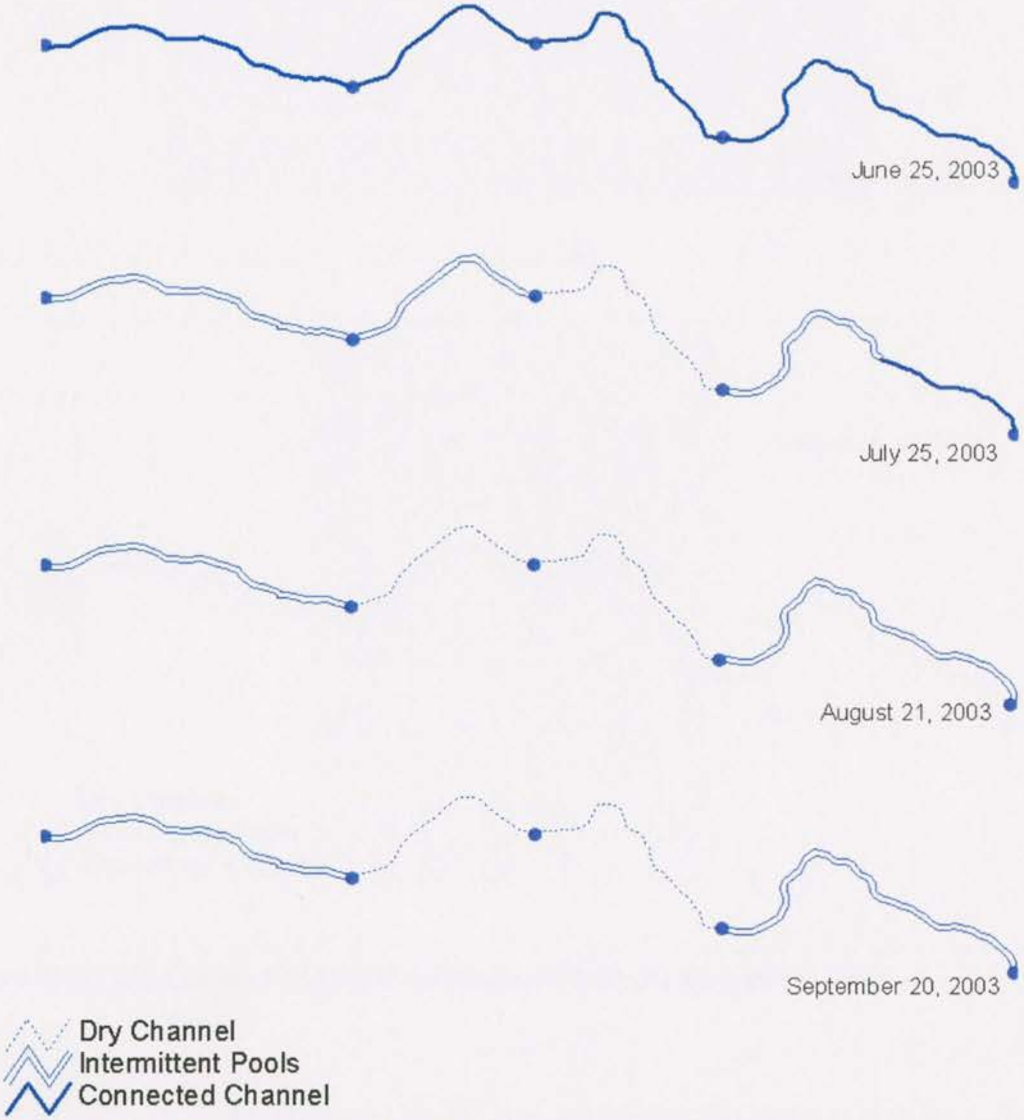


Figure 4.14 (a). Connectivity From June Through September 2003.

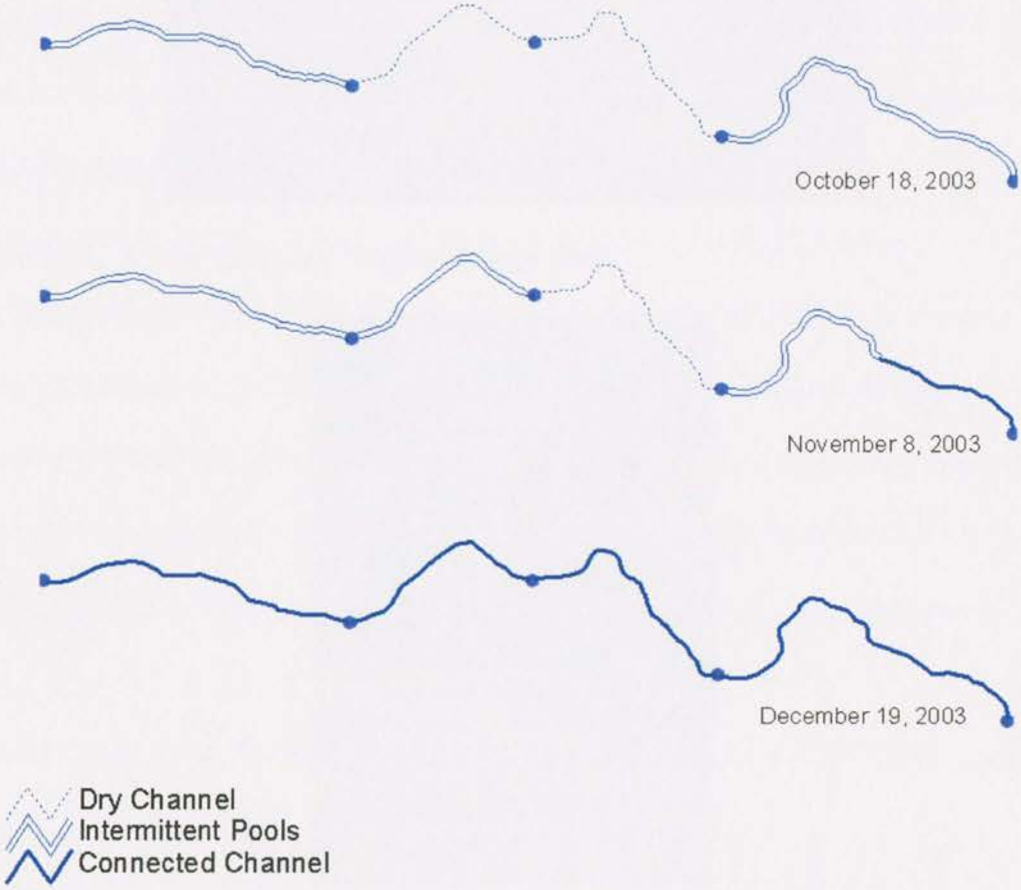


Figure 4.14 (b). Connectivity From October Through December 2003.

For the purposes of the 2003 study, a "dry channel" was defined as a section of river either entirely dry or with only small areas of dampness (Figure 4.15). A dry section did not possess any pools or standing water. A stretch designated as having "intermittent pools" still contained pools of some depth, while the runs between the pools were completely dry (Figure 4.16). Finally, a "connected channel" had water at all points (although, in some cases, the water was not visibly flowing downstream) (Figure 4.17).

Figure 4.15. A Dry Channel. Taken August 2003.

Figure 4.16. An Intermittent Channel. Taken end of July 2003 at Gage 2. This pool has become isolated from pools upstream and downstream by dry runs in-between.

Figure 4.17. A Connected Channel. Taken March 30, 2003.

4.7 Hydraulic Conductivity

Table 4.4 shows the results of the hydraulic conductivity tests of the streambed in the vicinity of five gaging stations (full data set is in Appendix E). At most testing locations, a few trials gave a result of "zero" hydraulic conductivity (i.e. the water level in the standpipe did not decrease during the testing time). Since the standpipes were intentionally placed at random along the cross-section of the bed, it is possible that certain locations along the cross-section would have a lower, almost negligible hydraulic conductivity than other locations. Another possibility might be that the standpipe was placed above a large piece of sediment or organic debris within the streambed. Table 4.4 shows the results of these tests including the results of "zero" as well as neglecting them.

TABLE 4.4 - SUMMARY OF STREAMBED HYDRAULIC CONDUCTIVITY DATA

	Gage 1	Gage 2	Gage 3	Gage 4	Gage 6
Average hydraulic conductivity including tests which registered as zero (m/day)	.89	3.9	1.5	2.85	8.2
n (# of runs)	15	14	15	17	14
Average hydraulic conductivity discounting tests with results of zero (m/day)	1.3	5.0	2.9	5.13	8.2

Jenkins (1966) states that the major control on loss through infiltration is the least permeable layer of the streambed. Also, Huang (2000) states that the amount of water moving between stream and aquifer is determined, in part, by the degree of permeability of the streambed sediment. At all locations measured in 2003, the hydraulic conductivity was on the order of 10^{-6} meters per second. Extensive riverbed permeability data as collected by Calver (2001) suggest that this amount of permeability is typical of a sandy streambed, possibly with a clogged bed layer. Landon's (2001) data suggest that these numbers are quite low, especially when compared with main-stem rivers. Even Landon's data on hydraulic conductivity of tributary sites (which are typically lower than main-stem) bottoms out around 20 meters per day. Fox (2003) measured hydraulic conductivity of the South Platte River and a slough channel, and found that the average permeability of the slough was around .3 m/day, which is quite comparable to the data presented in Table 4.4 (the average permeability for the South Platte was 143.7 m/day). Thus, it can be said that the hydraulic conductivity of the tested portions of the Arikaree is quite low, and is comparable to a tributary or slough channel with large amounts of organic material lining the streambed.

It is of interest to note that the streambed in the vicinity of Gage 6 (at the eastern boundary of the study site) consistently recorded higher hydraulic conductivity than sections further upstream, testing as high as 18 m/day. Also, this was the only section tested for which there were no "zeros" (i.e. every test resulted in some decline in standpipe water level during the testing time). It was found that this section recorded the earliest declines and recoveries in stage height for 2003 (see **4.3 Measured Stage Height**, above), and thus it is possible that the higher hydraulic conductivity at this section results in de-watering and re-wetting at earlier times than sections with lower permeabilities upstream. Also, the earlier recovery at the Gage 2 location (relative to Gages 3, 4, and 5) may have something to do with the slightly higher hydraulic conductivity in the vicinity of this section. Finally, it was found that the hydraulic conductivity at Gage 1 (the western boundary) was the lowest tested, less than a meter per day with one-third of the trials recorded as "zero". This result is expected, as visibly this section of river has the most organic matter lining the channel bed. It is interesting to note, however, that permeabilities further downstream (i.e. at Gages 3 and 4) were only slightly higher, despite the fact that the surface layer at those sections is mostly sand. The amount of organic material just beneath the surface layer of sand at these sections was found to be significant while wells were being dug in the streambed.

As mentioned in **3.1 Study Site**, the hydraulic conductivity of the aquifer in the vicinity of the study site is between 50 and 100 feet per day (Borman et al., 1983b), or 15 to 30 meters per day. This is on the order of 10^{-5} meters per sec., while the permeability of the streambed has now been shown to be 10^{-6} meters per sec., or an order of magnitude less than the aquifer. Thus it can be concluded that, for the sections tested, *the hydraulic conductivity of the streambed is less than that of the surrounding aquifer*, thus limiting the rate and amount of water exchanged between the Arikaree and the aquifer.

4.8 Stream-Depletion Factor Test

The results of the well analysis for the areas surrounding the study site are listed in Table 4.5 (full data set, including location and design capacities of every well considered, appears in Appendix F). The estimated depletion from the eastern boundary of the study site was found to be quite low (~2% of off-season baseflow), while depletion from the vicinity of U-road was found to be roughly 9% of typical off-season flows for 2003. Stream depletion from surrounding wells was found to be over 100% for the western boundary of the study site.

TABLE 4.5 - RESULTS OF STREAM-DEPLETION FACTOR MODEL

	Irrigation Season (days)	**Total estimated stream depletion at end of season (cfs)**	**Measured baseflow (cfs)**	**% depletion**
Gage 1 (Western Boundary)	64	.323	.29	112 %
Gage 2 (U-road)	64	.120	1.34	8.93 %
Gage 6 (Eastern Boundary)	64	.119	5.5	2.16 %

These results are quite revealing and significant. It bears repeating, however, that these results are most certainly overestimates of the actual stream depletion due to irrigation pumping. First, the *sdf* test (as used here) has been shown by several authors to significantly overestimate the stream depletion for rivers of low permeability where the water table drops below the streambed bottom; it has now been shown that the Arikaree falls into this category. Second, the test as run used original design capacities of all wells considered. In reality, most of these wells are likely operating at around 80% of their original design capacities (Y-W Well Test, personal communication). Furthermore, as stated above, all irrigation wells with current permits with the State Engineer's Office were considered, even if evidence of irrigation from the aerial view was not apparent. Thus, some wells may have been considered which, in reality, were not operating in 2003. As a result of the above caveats, the *sdf* test should provide a very conservative estimate of the stream depletion due to irrigation pumping.

At Gage 1, the stream depletion was predicted to be .323 cfs, which is 112 % of the average measured flow at this section. In other words, one would expect from this result that the river here would be completely depleted before the end of the growing season. Given the small amount of data on discharges at this section as well as the very low flow rates, however, it must be kept in mind that the average measured flow rate at this section of river is subject to rather high error. The best that can be said is that the flow, while present, is quite small. While measurable flow does cease early in the season, the stage (and consequently, the volume of water) in the river at this section shows only a slight decrease throughout the season, and in fact shows a gradual *recovery* beginning in the midst of the irrigation season. This observation leads further evidence to the disconnection of this portion of the Arikaree from the water table.

At Gages 2 and 6 the model predicts, respectively, around 9 % and 2 % depletions in stream water over the growing season. As stated above, the entire river eventually becomes disconnected and ceases to flow during the season, so it can also be said that the *sdf* method predicts that 9 % and 2 % of the total baseflow reduction should be expected to come from high-capacity irrigation pumping at these two sections.

Again, it bears repeating that the stream-depletion model, as used here, would be expected to overestimate the total stream depletion for the Arikaree. Thus, the actual stream depletion at Gage 2 is, in all likelihood, much less than the 9 % of off-season baseflows as predicted by the *sdf* model. The stream depletion (as caused by high-capacity irrigation wells) at Gage 6 is quite negligible even as predicted by the model; considering that this analysis is also an over-estimation, and it can be said that the depletion at this section is basically zero.

4.9 Farmer Interviews and Data

Table 4.6 shows the results of the data collected from the four representative farmers (full data set appears in Appendix B). Due to the wet June, crop-water requirements for most crops were lower than in 2002 and irrigation began and ended later in the year for 2003. Table 4.7 summarizes the contents of Table 4.6 and compares this data with that collected by Fardal (2002). Generalizations have been made concerning the approximate start/stop times for pumping during both the 2002 and 2003 seasons.

TABLE 4.6 - CROP WATER REQUIREMENTS VS. WATER APPLIED

	Farmer A	Farmer B	Farmer C	Farmer D
Crop-Water Requirements (inches)				
Corn	19.31	19.31	18.69	17.62
Sunflower		14.95	14.95	
Alfalfa			27.37	
Millet		12.65	15.41	12.65
Pinto Bean	18.89			
Average Applied Irrigation (inches)				
Corn	20.85	20.85	10.43	15.80
Sunflower		11.22	14.39	
Alfalfa			24.63	
Millet		9.54	17.47	12.27
Pinto Bean	9.58			
Amount of Crop-Water Requirements Met[1]				
Corn	100%	100%	55.8%	89.7%
Sunflower		75.1%	96.3%	
Alfalfa			90.0%	
Millet		75.4%	113%	97.0%
Pinto Bean	50.8%			

[1] Percentages are color-coded according to the following:

Green: Amount of water applied was within 10% of calculated crop-water requirement
Blue: Amount of water applied was significantly less than calculated crop-water requirement
Yellow: Amount of water applied was significantly greater than calculated crop-water requirement

In general, irrigation for corn, alfalfa, and beans came 2-4 weeks later in 2003 than the year before (millet start times were significantly later). Corn, millet, and bean irrigation ceased 1-2 weeks after the previous year, and alfalfa irrigation actually ceased a few weeks earlier. Thus, the irrigation season was of shorter duration (~64 days for corn) than the 2002 irrigation season, again mostly due to the wet June. Table 4.8 shows the 2003 yields for each crop.

TABLE 4.7 - COMPARISON OF 2002-2003 IRRIGATION SEASONS

	Typical 2002 Start Date[1]	Typical 2003 Start Date	Typical 2002 Ending Date[1]	Typical 2003 Ending Date
Corn	1st 2 weeks of June (76% of sample)	1st week of July	Last week of August (100% of sample)	Mid-September
Sunflower	---	Early- to Mid-July	---	1st week of September
Alfalfa	Mid-April (67% of sample)	End of April	Last week of September (67% of sample)	1st week of September
Millet	Mid-April (67% of sample)	Last week of July/beginning of August	Last week of August (100% of sample)	Mid-September
Pinto Beans	Mid-June (100% of sample)	Mid-July	Last week of August (100% of sample)	1st week of September

[1] Taken from Fardal (2002)

TABLE 4.8 – YIELDS FOR EACH FARMER FOR 2003

	Farmer A		Farmer B		Farmer C		Farmer D	
	Well (gpm)	**Yield**	**Well (gpm)**	**Yield**	**Well (gpm)**	**Yield**	**Well (gpm)**	**Yield**
Corn (bu/ac)	750 900 950 1350 1150	173 148 173.5 228 188	Same as Farmer A		800	180	850 1200	172 185
Sunflower (lb/ac)			900 1350	2062 3094	800	1500		
Alfalfa (ton/ac)					500	4		
Millet (tons/ac)			500	2.2	600	50 (bu/ac)	750	1.8
Pinto Beans (cwt/ac)	900	19						

Figure 4.18 compares the amount of crops grown in Yuma County throughout 2002 (the last full data year available, from www.nass.usda.gov/ipedb/report.htm). Corn is by far the most grown crop in the county, and accounted for 77% of all irrigated crops grown in 2002. This number is likely a little lower for 2003 since many of the farmers reported switching from corn to less water-intensive crops; however, the 2002 data are taken to be a fair approximation of what was grown in 2003 near the study site.

Figure 4.18. Crops Grown in the Study Area, 2002.

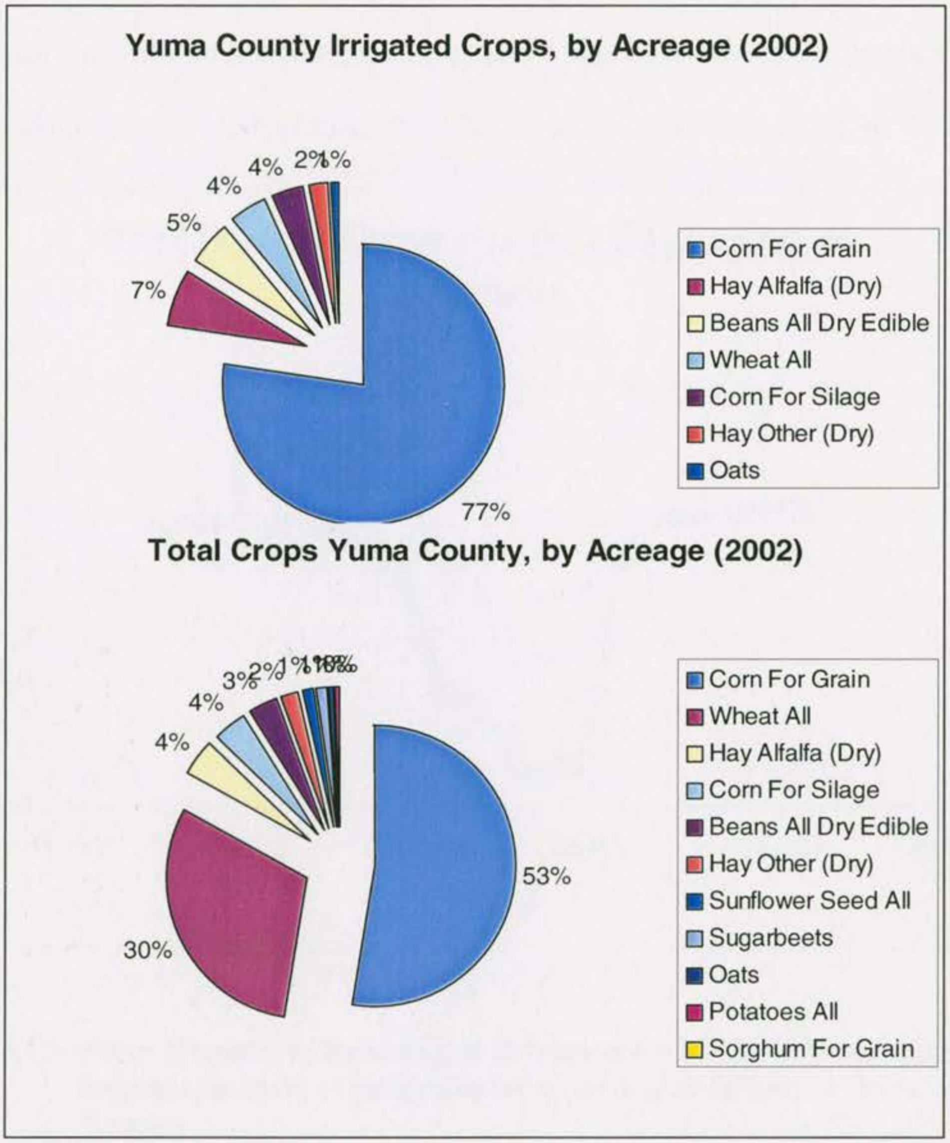


Figure 4.19 shows the gage height as recorded at the USGS gaging station (same as Fig. 4.7) with the 2003 irrigation start times overlaid. As was demonstrated from Table 4.7, the bulk of irrigation began in early- to mid-July, well after the decline in stage height was underway. It must also be considered that, even after irrigation pumping began, a certain "lag time" would be expected before the effects of a pump activation would be felt at the stream. Considering that all pumps considered around the study site were at least a couple miles away from the Arikaree, that lag time could reasonably be expected to be at least one to two weeks.

Thus, by the time one would expect the effect of irrigation to be felt at the river, the stage height at this section was already nearing its lowest point of the season.

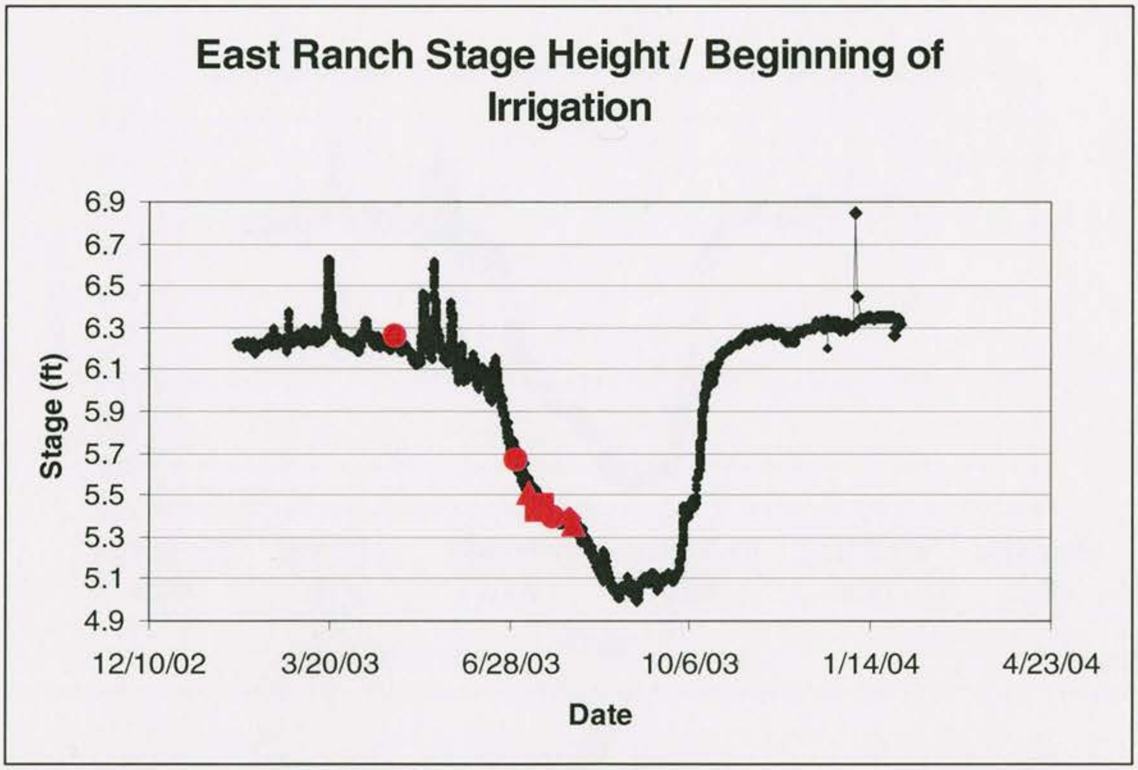


Figure 4.19. Stage Height vs. Beginning of Irrigation for 2003. Colored symbols indicate the start of irrigation for a particular farmer or for several farmers.

Figure 4.20 shows the USGS stage height data along with the ending of irrigation. As almost all irrigation was stopped in early- to mid-September in 2003, the stage height had basically bottomed out by the time pumps were switched off. Fig. 4.20 does demonstrate a one- to three-week lag between the ending of irrigation and the rapid increase in stage height, which by itself supports a connection between irrigation pumping and stage height. However, this connection does not seem to be demonstrated by the beginning of high-capacity pumping in relation to stage height (Fig. 4.19).

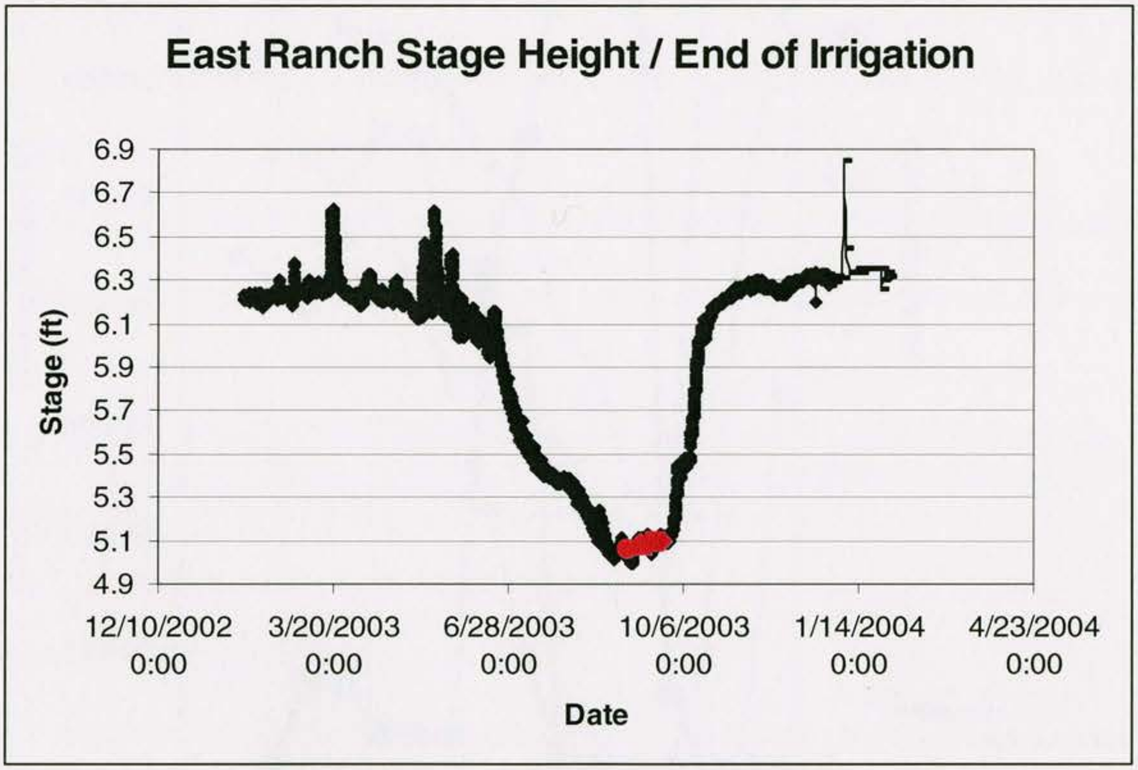


Figure 4.20. Stage Height vs. End of Irrigation for 2003.

Finally, Figure 4.21 shows a graph of the volume of irrigation water pumped from the representative farmers alongside the declines and rise in stage height of the river. This graph also demonstrates that the declines in stage height seem to begin before most of the irrigation water has been pumped.

It must be kept in mind that the sample of four farmers interviewed in 2003 is taken to be representative of the farming population near the Arikaree. This assumption, though thought to be reasonable, must be acknowledged.

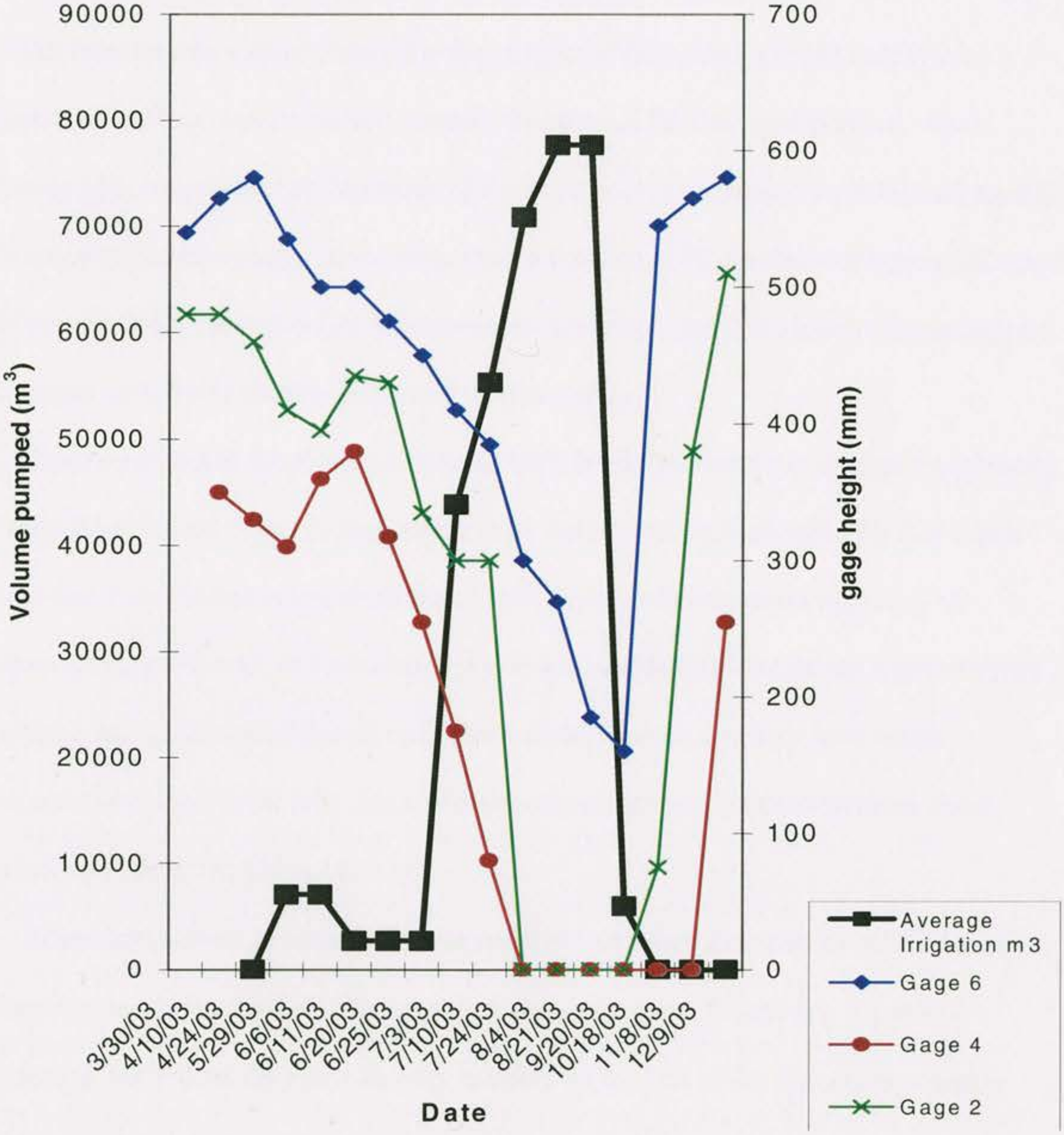


Figure 4.21. Volume of Water Pumped and Stage Height.

4.9.1 Farmer Interviews

In order to better understand how the water pumped from the Ogallala is being used for irrigation, each farmer was asked a series of questions (Appendix A). Initial interviews were conducted at the end of July and throughout August, as this generally seemed to be a slightly less busy time for farmers in the area.

All farmers interviewed stated that they expected their yields (for all crops) to be higher in 2003 as opposed to 2002, mostly because of the June precipitation. Each farmer also stated that they had reduced the amount of corn planted for 2003, substituting less water-intensive crops. One farmer stated that one of his fields, which grew 242 acres of corn in 2002, was now split between corn, sunflower, and pinto beans. Other farmers changed their fields entirely from corn to other crops.

One farmer out of the sample employed both flood and center pivot irrigation systems, while the rest used center pivots exclusively. An interesting realization for this author was that every farmer interviewed based their decision to irrigate on sight, i.e. by observing the behavior of corn early in the season and taking note of any signs of stress in the crop. Considering how closely many of the farmers met their crop-water requirements (see Table 4.6), it is a tribute to these farmers that their instincts about watering their crops are so accurate.

When interviewed, a couple of the farmers had switched their pumps off for a couple days due to August rainfall. These pumps were only kept off until dry conditions returned, but it does demonstrate responsibility on the part of the farmers to conserve their resources. Each farmer also had at least one dryland crop (predominately wheat).

The farmers also stated that they were aware of the lowering water table levels in their area. One farmer stated that some of his wells begin to draw air near the end of the irrigation season; his reasoning was that this was due to the combined drawdown effects of irrigation wells surrounding his farm belonging to other farmers. Another farmer estimated a 6-inch drop in his well levels each year, and he also estimated that this figure was below average for his farming community (actual declines in his vicinity over the past ten years have been 6 to 12 inches per year, as estimated by the State Engineer's Office).

These farmers faced distinct challenges during the 2003 growing season. One farmer had had a tornado hit one of his center pivots, while lightning had struck another of his wells. Most farmers cited the lack of rainfall from July to August as a major (though not entirely unexpected) challenge.

Farmers were also specific about the types of information and supplies that would be helpful for them to have. Among the items listed:

-Gypsum blocks (at affordable cost)
-Public meetings with other farmers and state officials
-Pamphlets which show water levels in surrounding wells
-Instruction and help on how to convert flood irrigation to sprinkler irrigation
-Information on pharmaceutical research involving corn (i.e. insulin trial plots)

In general, these farmers seemed quite aware of the issues surrounding irrigated agriculture in Eastern Colorado. One farmer (who was educated at Colorado State University) went so far as to postulate the effects of the local geology on the water table in his area. A couple farmers also observed that the aquifer was likely not being recharged to the extent that it was being pumped, though one did believe that the aquifer could be adequately recharged if precipitation were higher, such as it was in the 1930's and 1940's. Most noted that the last really bad winter was in the late 1970's, and that since that time summers have been generally extreme while winters have been mostly mild.

4.10 Vegetation

Throughout the year, the USGS gaging station at the eastern boundary of the study site took stage depth readings every 15 minutes. First noticeable in mid-June 2003, a distinct pattern of diurnal fluctuations appears in the stage depth record (Figure 4.22). The pattern becomes more pronounced as the June precipitation ceases, and the pattern is clearly visible throughout the growing season until the middle of September.

Referring to Figure 4.5 (above), the beginning of substantial declines in stage height for this section of river begin in mid-June, around the same time as the diurnal fluctuations begin to be evident. Likewise, the end of these fluctuations coincides with the leveling off of stage depth decline at the beginning of September. In other words, as the vegetative influences (specifically the cottonwoods and willows, as both were classified as the dominant phreatophytes at the study site) on the river become significant the stage height begins its rapid descent, a descent which bottoms out when the vegetative influences subside in the stage record. This lends support to the possibility that the reductions in stage height and discharge along the Arikaree are due, certainly in part, to the vegetation in the Arikaree valley.

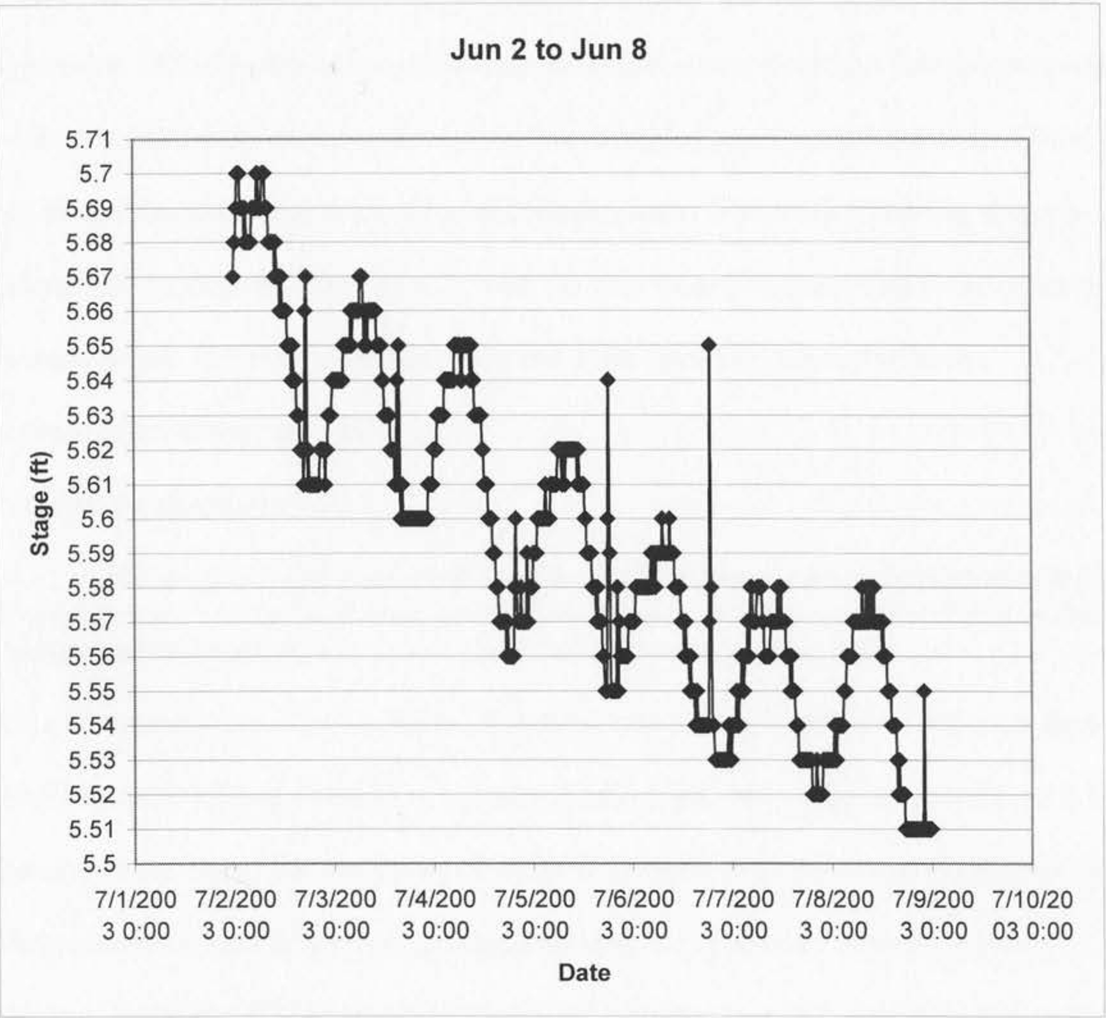


Figure 4.22. Diurnal Fluctuations in Stage Height.

Robinson (1968) states that,

> *"Phreatophytes reduce the discharge of springs and the flow of streams during the growing season. Stockmen who graze livestock on the open range in the Western United States often rely on springs for stock water. They are aware that during the summer months the discharge will diminish or that small springs may cease to flow entirely where vegetation is dense around the spring or in its drainage area, and that following killing frosts in the fall it will increase, or resume flowing."* (Robinson 1968, pg. 626)

According to the CoAgMet data, the first mild frost of the season took place on September 14th when the temperature dropped to just above freezing. The diurnal pattern (with very little daily declines in stage by this point) is present until September 13 and 14, around the same time as the first cold temperatures. The week following shows a gradual rise in stage height (Fig. 4.7), with the next week demonstrating a drastic increase in water levels. This could be due to the end of the growing season for these phreatophytes along the valley.

Robinson also states that,

> *"The evapotranspiration draft by phreatophytes, shown by the variation in the flow of springs, and in the diurnal fluctuation of water in wells, is reflected also in the fluctuations and reduction in stream flow."* (Robinson 1968, pg. 626)

It is quite common to observe diurnal fluctuations in both groundwater levels and stage height records, so long as the river is hydraulically connected to the water table (as it is at the eastern section of the study site). Naff (1975) observed clear diurnal fluctuations in the groundwater near several irrigation canals due to a species of *Populus* in New Mexico. Robinson (1968) observed these fluctuations, along with a reduction in stage height and flow, on the Gila River near Geronimo, Arizona (populated with moderate amounts of saltcedar). White (1932) also observed these fluctuations in groundwater levels and stage due to phreatophytes.

It is significant to note that, as mentioned above, the Arikaree is fed primarily by seeps and springs along the valley surface. Most visible springs were found to begin drying quite early in the season; by the beginning of June, many of the springs had retreated below ground.

A qualitative observation made by this author is that, near the western and eastern boundaries of the study site as well as near U-road, typically only one or two sparse rows of cottonwoods are present in the vicinity of the river. By contrast, fairly dense cottonwood stands are present in the areas of Gages 3, 4, and 5 (Figures 4.25 and 4.26). Populations of willow, while present along the Arikaree throughout the study site reach, are particularly dense in the same area. As shown above, most of the discharge in the river is picked up in the region between U-road (Gage 2) and the eastern boundary (Gage 6) where the visible springs are most prevalent. It makes sense that higher numbers of these phreatophytes would be present in this area, where the water table frequently was observed to intersect the valley floor elevation during the off-season. It also makes sense that the consumptive use of these cottonwood and willow stands would be greater, both because of the shallow depth to water and higher numbers of individual plants.

Using the Blaney-Criddle method and information from the Western Regional Climate Center for 2003 (www.wrcc.dri.edu/CLIMATEDATA.html), evapotranspiration for a cottonwood stand at the study site was estimated at 62.3 inches for the year, 49.8 inches of which would have been from April to September. This compares very well with the values presented in Table 3.4 (above). Though specific *k* values could not be located for *Salix exigua*, it is likely that ET values for this phreatophyte would also be comparable to those found in Table 3.4 (~39 inches for the year). Thus, consumptive use for these two plants is quite high, and given their vicinity to the Arikaree along the study site reach it is not difficult to imagine a substantial amount of water being depleted from the stream by vegetation.

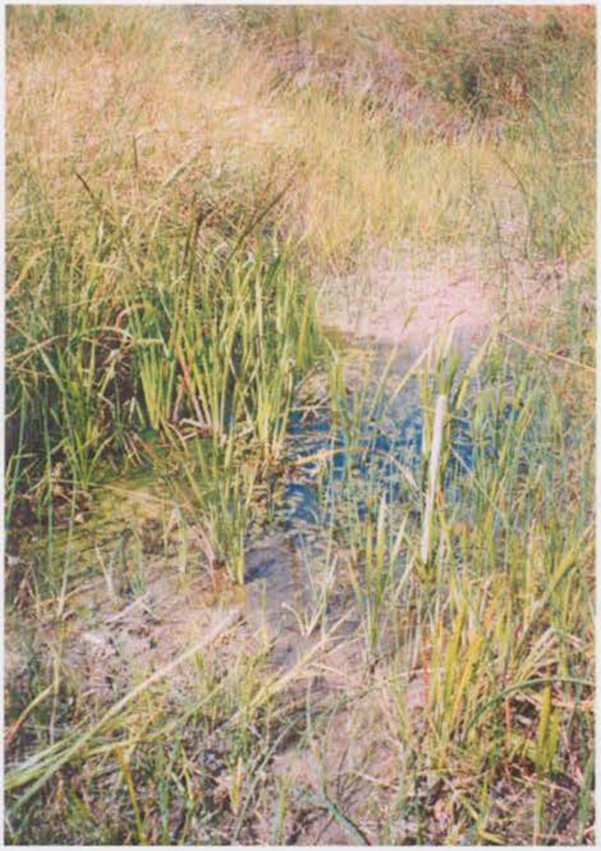


Figure 4.23. *Panicum virgatum* Near Gage 3. Taken September 2003. This was the first field visit where water was observed to be returning to this section of river. Switch grass was quite commonly found growing in the streambed throughout the river reach.

Figure 4.24 (a) and (b). Overlooking the Arikaree, March vs. June 2003. Both views overlook roughly the same portion of the Arikaree.

Figure 4.25 (a) and (b). Vegetation in the Arikaree Valley. Both taken February 2004 near Gages 3, 4, and 5. Of note is the dense vegetation in the vicinity of the river and the high density of the cottonwood stand. This was the last area to see flow return.

Figure 4.26. Vegetation Near Gage 1. By contrast to the area around Gages 3, 4, and 5, the region upstream near Gage 1 had very thin stands of cottonwoods. These cottonwoods also appeared much older than those further downstream. The cottonwood stand in the vicinity of Gage 6 was similar in appearance.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The need to determine the principal cause or causes of the de-watering of the Arikaree River during the growing season was defined. Data were collected throughout 2003 regarding stage height and discharge, hydraulic conductivity, water table levels, and connectivity along an eight mile stretch of the Arikaree River. A simple pumping analysis considering all irrigation wells of consequence was conducted using the stream-depletion factor analysis as presented by Jenkins (1968; 1970). Representative farmers were interviewed so as to ascertain irrigation practices for the 2003 growing season, including the beginning and ending of irrigation for the year for each farmer. Where possible, data were compared with data collected by Fardal (2003) along the same stretch of the Arikaree River.

Irrigation of crops, in general, was found to begin two to four weeks later in 2003 than it had in 2002 due to a wet June. However, the declines in stage height at three points along the studied river reach began at almost the exact same time of year in both 2003 and 2002, suggesting that the initial decline in stage height is not solely attributable to localized irrigation practices. Furthermore, stage height at the eastern portion of the study site had already displayed significant declines by the time the majority of the representative farmers' pumps had even been switched on for the first time. Finally, recovery in the water table as measured in at least one monitoring well occurred before the effects of irrigation pump de-activation would have been seen at the river.

Hydraulic conductivity of the streambed was shown to be, in general, an order of magnitude less than the hydraulic conductivity of the aquifer. Therefore, the exchange of water entering or leaving the streambed along this stretch of the Arikaree is principally limited by the low streambed permeability. It was shown that higher values of streambed hydraulic conductivity corresponded to earlier stage height recovery times, possibly identifying a link between streambed hydraulic conductivity and recovery of the river at the end of the growing season.

The pumping analysis showed that the highest percentage of discharge expected to be depleted from the Arikaree would come from the western portion of the study site. However, this area was the most perennial stretch of the entire study site, and in fact was even being recharged throughout the growing season. The analysis showed fairly insignificant depletions from the two points analyzed further downstream.

The effect of the high density of water-intensive phreatophytes along the study site reach (*Populus deltoides* and *Salix exigua*) may not be negligible. Considering that the water table is very near the surface throughout the baseflow season and that the Arikaree is fed primarily by springs and seeps, these types of vegetation are possibly drawing large amounts of water from the water table during the growing season which would otherwise reach the Arikaree. The fact that stage height declines were nearly identical in 2002 and 2003 despite changes in irrigation practices lends support to the supposition that the de-watering of the Arikaree River may be partially attributable to vegetation along the Arikaree valley floor.

It has been conclusively proven that, from year to year, water table levels throughout Eastern Colorado experience declines due to high-capacity irrigation pumping, and though the declines in the vicinity of the Arikaree River have been fairly small the declines within the study region have been, and continue to be, quite significant. While the possibility now exists that the seasonal de-watering of the Arikaree may not be principally attributable to irrigation, the steady declines in groundwater levels may still be affecting the river over time.

5.2 Recommendations

The water usage of the riparian vegetation within the Arikaree valley must be more rigorously quantified if the true effect of such vegetation upon the local water table and river flows is to be understood. This vegetation, in particular the cottonwoods and willows, should be surveyed and consumptive use identified for each section of the river.

Future research should involve a detailed groundwater model which takes streambed permeabilities into account. Localized aquifer tests could also be conducted so as to ascertain the true hydraulic connection between the Arikaree River and the irrigation wells in the region.

As many representative farmers as possible should be involved in future research to maximize the understanding of irrigation patterns and practices near the Arikaree. Fostering a cooperative atmosphere between agricultural and ecological interests in the region must be a continued goal of future research so that possible solutions to the de-watering issue can be implemented to everyone's benefit.

Additional monitoring wells should be installed so additional data can be collected on the behavior of the water table at different points along the Arikaree. This data should be taken year-round so as to be able to compare off-season water table levels with those during the growing season, and it would be preferable if both monitoring wells and stage gages could take automated readings.

Localized water balances at several cross-sections along the Arikaree should be attempted, which would include water used by the riparian vegetation. Along with this, the location of inflows to the Arikaree should be more precisely identified so that the seasonal effects of de-watering can be observed at the source. It is currently thought that the inflows are largely originating from the sand dunes on the north side of the Arikaree.

Due to the possibility of beaver activity altering the flow regime in the vicinity of stage gages, this data should only be relied upon as a primary indicator of river activity after flow has completely stopped. For the remainder of the year, it might be prudent to acquire a current meter which is more sensitive to lower flow velocities than the Ott-Kempten meter and does not have moving parts which can be choked or influenced by vegetation in the streambed. Thus, reliable flow estimates should be possible through a greater portion of the year.

As these recommendations are followed, the main cause or causes of the de-watering of the Arikaree River should become apparent. Whether or not high-capacity irrigation pumping is the chief cause of seasonal flow variations in the river, however, the annual declines in water table levels throughout the region may well eventually affect the river more directly and is already a concern for both agricultural and ecological interests. Sustainable and responsible agriculture must continue to be a priority so that the natural state of the Arikaree, along with other river habitats in the High Plains, may flourish.

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APPENDIX A1 – INITIAL FARMER INTERVIEW

Farm Survey

Name

Date

Total Farm Area

Well Capacity	Crop	Acres	Irrigation Began

In general, do you think this year will be more successful (higher yield)?

What changes did you make after last year's drought?

Do you use center pivots exclusively?

How do you decide when to irrigate?

Have your pumps been shut off at any time thus far?

Any dryland crops this year?

Is the lower water table noticeable in your wells throughout the year?

What has been the biggest challenge thus far this year?

What type of information would be most helpful to you?

APPENDIX A2 – FARMER EXIT INTERVIEW

XXXX XXXX
Xxxxx xxxxxx
Xxxxx, CO xxxxx

November 19, 2003

Dear Mr. XXXX,

Thanks so much for your help with our pumping survey for this year. At this time, we'd like to ask you to help us finish out the year's survey by filling in the yields for your crops, as well as when you completed irrigation pumping for the year. As always, your answers will remain completely confidential.

Well Capacity	**Crop**	**Acres**	**Irrigation Began**	**Irrigation Ended**	**Yield for crop**
(900) 750 gpm	**Corn**	100	7/2/03		
(1100) 900 gpm	**Corn**	106	7/3/03		
	Pinto Beans	106	7/9/03		
	Sunflower	30	7/14/03		
(1100) 950 gpm	**Corn**	200	7/2/03		
(1600) 1350 gpm	**Corn**	161	7/2/03		
	Sunflower	45	7/23/03		
(900) 500	**Millet**	120	8/3/03		
(1300) 1150	**Corn**	122	7/2/03		

Were your pumps shut off at any time between the beginning and end of your irrigation season? If so, how many days was that for?

Were you pleased with your yields for this year? Were they about what you expected?

Thanks again for your input!

Steven Griffin
Department of Civil Engineering
Colorado State University
Fort Collins, CO 80523

APPENDIX B1 – CORN, FARMERS A AND B

			Well 1	Well 2	Well 3	Well 4	Well 5		
		GPM	750	900	950	1350	1150		
		Acres	100	242	200	206	122		
		Feet per day	0.357955	0.177498	0.22670484	0.312776	0.44988882	Weekly	Avg. Irrigation
								Crop Need	For Week
Date	ET corn (in.)	Precipitation (in.)						(ET-p)	
14-Apr		0							
15-Apr		0.04							
16-Apr		0.23							
17-Apr		0							
18-Apr		0							
19-Apr		0.26							
20-Apr	0.01	0							
SUM	0.01	0.53						-0.52	
21-Apr	0.03	0							
22-Apr	0.04	0							
23-Apr	0.04	0.67							
24-Apr	0.03	0.33							
25-Apr	0.02	0							
26-Apr	0.03	0							
27-Apr	0.04	0							
SUM	0.23	1						-0.77	
28-Apr	0.03	0							
29-Apr	0.03	0.36							
30-Apr	0.03	0							
1-May	0.03	0.04							
2-May	0.03	0.01							
3-May	0.04	0							
4-May	0.04	0							
SUM	0.23	0.41						-0.18	
5-May	0.05	0							
6-May	0.04	0.05							
7-May	0.04	0							
8-May	0.04	0							
9-May	0.04	0							
10-May	0.03	0.89							
11-May	0.04	0							

SUM	0.28	0.94						-0.66	
12-May	0.04	0							
13-May	0.05	0							
14-May	0.04	0							
15-May	0.03	0.89							
16-May	0.04	0.01							
17-May	0.04	0							
18-May	0.04	0.17							
SUM	0.28	1.07						-0.79	
19-May	0.05	0							
20-May	0.04	0							
21-May	0.06	0							
22-May	0.06	0							
23-May	0.06	0.01							
24-May	0.05	0							
25-May	0.05	0.14							
SUM	0.37	0.15						0.22	
26-May	0.05	0							
27-May	0.07	0							
28-May	0.09	0							
29-May	0.05	0							
30-May	0.09	0.48							
31-May	0.12	0.01							
1-Jun	0.09	0.3							
SUM	0.56	0.79						-0.23	
2-Jun	0.09	0.28							
3-Jun	0.09	0.04							
4-Jun	0.09	0.09							
5-Jun	0.06	0.07							
6-Jun	0.06	0.49							
7-Jun	0.08	0							
8-Jun	0.11	0							
SUM	0.58	0.97						-0.39	
9-Jun	0.13	0							
10-Jun	0.14	0.75							
11-Jun	0.14	0.01							
12-Jun	0.14	0.09							

13-Jun	0.13	0.02							
14-Jun	0.12	0							
15-Jun	0.13	0							
SUM	0.93	0.87						0.06	
16-Jun	0.15	0.21							
17-Jun	0.15	0.22							
18-Jun	0.13	0							
19-Jun	0.11	0							
20-Jun	0.12	0.1							
21-Jun	0.17	0							
22-Jun	0.2	0							
SUM	1.03	0.53						0.5	
23-Jun	0.19	0							
24-Jun	0.25	0							
25-Jun	0.26	0							
26-Jun	0.27	0							
27-Jun	0.25	0							
28-Jun	0.26	1.56							
29-Jun	0.23	0.06							
SUM	1.71	1.62						0.09	
30-Jun	0.24	0							
1-Jul	0.27	0							
2-Jul	0.31	0	0.357955		0.22670484	0.312776	0.44988882		
3-Jul	0.34	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
4-Jul	0.34	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
5-Jul	0.35	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
6-Jul	0.38	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
SUM	2.23	0	1.789775	0.709993	1.13352422	1.563881	2.24944409	2.23	1.48932359
7-Jul	0.39	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
8-Jul	0.42	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
9-Jul	0.43	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
10-Jul	0.44	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
11-Jul	0.43	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
12-Jul	0.41	0.01	0.357955	0.177498	0.22670484	0.312776	0.44988882		
13-Jul	0.42	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
SUM	2.94	0.01	2.505685	1.242488	1.58693391	2.189434	3.14922173	2.93	2.134752565
14-Jul	0.43	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		

15-Jul	0.46	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
16-Jul	0.48	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
17-Jul	0.49	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
18-Jul	0.49	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
19-Jul	0.43	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
20-Jul	0.39	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
SUM	3.17	0	2.505685	1.242488	1.58693391	2.189434	3.14922173	3.17	2.134752565
21-Jul	0.29	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
22-Jul	0.3	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
23-Jul	0.15	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
24-Jul	0.32	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
25-Jul	0.49	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
26-Jul	0.46	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
27-Jul	0.38	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
SUM	2.39	0	2.505685	1.242488	1.58693391	2.189434	3.14922173	2.39	2.134752565
28-Jul	0.3	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
29-Jul	0.28	0.03	0.357955	0.177498	0.22670484	0.312776	0.44988882		
30-Jul	0.28	0.01	0.357955	0.177498	0.22670484	0.312776	0.44988882		
31-Jul	0.32	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
1-Aug	0.33	0.01	0.357955	0.177498	0.22670484	0.312776	0.44988882		
2-Aug	0.33	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
3-Aug	0.33	0.03	0.357955	0.177498	0.22670484	0.312776	0.44988882		
SUM	2.17	0.08	2.505685	1.242488	1.58693391	2.189434	3.14922173	2.09	2.134752565
4-Aug	0.31	0.05	0.357955	0.177498	0.22670484	0.312776	0.44988882		
5-Aug	0.31	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
6-Aug	0.32	0.01	0.357955	0.177498	0.22670484	0.312776	0.44988882		
7-Aug	0.35	0.07	0.357955	0.177498	0.22670484	0.312776	0.44988882		
8-Aug	0.31	0.01	0.357955	0.177498	0.22670484	0.312776	0.44988882		
9-Aug	0.28	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
10-Aug	0.26	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
SUM	2.14	0.14	2.505685	1.242488	1.58693391	2.189434	3.14922173	2	2.134752565
11-Aug	0.28	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
12-Aug	0.27	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
13-Aug	0.27	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
14-Aug	0.28	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
15-Aug	0.29	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
16-Aug	0.3	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		

17-Aug	0.27	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
SUM	1.96	0	2.505685	1.242488	1.58693391	2.189434	3.14922173	1.96	2.134752565
18-Aug	0.24	1.17	0.357955	0.177498	0.22670484	0.312776	0.44988882		
19-Aug	0.19	0	0	0	0	0	0.44988882		
20-Aug	0.18	0	0	0	0	0	0.44988882		
21-Aug	0.17	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
22-Aug	0.18	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
23-Aug	0.19	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
24-Aug	0.19	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
SUM	1.34	1.17	1.789775	0.887492	1.13352422	1.563881	3.14922173	0.17	1.704778788
25-Aug	0.15	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
26-Aug	0.08	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
27-Aug	0.12	0.16	0.357955	0.177498	0.22670484	0.312776	0.44988882		
28-Aug	0.02	0.03	0.357955	0.177498	0.22670484	0.312776	0.44988882		
29-Aug	0.04	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
30-Aug	0.06	0.2	0.357955	0.177498	0.22670484	0.312776	0.44988882		
31-Aug	0.09	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
SUM	0.56	0.39	2.505685	1.242488	1.58693391	2.189434	3.14922173	0.17	2.134752565
1-Sep	0.08	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
2-Sep	0.02	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
3-Sep	0.03	0.01	0.357955	0.177498	0.22670484	0.312776	0.44988882		
4-Sep	0.13	0	0.357955	0.177498	0.22670484	0.312776	0.44988882		
5-Sep	0.21	0	0	0	0.22670484	0	0		
6-Sep	0.3	0	0	0	0.22670484	0	0		
7-Sep	0.26	0.51	0	0	0.22670484	0	0		
SUM	1.03	0.52	1.43182	0.709993	1.58693391	1.251105	1.79955527	0.51	1.355881515
8-Sep	0.22	0			0.22670484				
9-Sep	0.19	0			0.22670484				
10-Sep	0.23	0			0.22670484				
11-Sep	0.24	0			0.22670484				
12-Sep	0.3	0			0.22670484				
13-Sep	0.26	0			0.22670484				
14-Sep	0.25	0			0				
SUM	1.69	0			1.36022906			1.69	1.360229062
15-Sep	0.2	0							
16-Sep	0.25	0							
17-Sep	0.35	0							

18-Sep	0.35	0							
19-Sep	0.34	0							
20-Sep	0.25	0							
21-Sep	0.21	0							
Yields:			173 bu/ac	148 bu/ac	173.5 bu/ac	228 bu/ac	188 bu/ac		
							Total		
							Crop Need	19.31	
							Irrigation		
							Total		20.85348091

APPENDIX B2 – PINTO BEAN, FARMERS A AND B

			Well 2		
		GPM	900		
		Acres	242		
		Feet per day	0.177498355	**Weekly**	**Avg. Irrigation**
				Crop Need	**For Week**
Date	**ET bean (in.)**	**Precipitation (in.)**		**(ET-p)**	
26-May		0			
27-May		0			
28-May		0			
29-May		0			
30-May		0.48			
31-May	0.02	0.01			
1-Jun	0.03	0.3			
SUM	0.05	0.79		-0.74	
2-Jun	0.05	0.28			
3-Jun	0.05	0.04			
4-Jun	0.04	0.09			
5-Jun	0.03	0.07			
6-Jun	0.03	0.49			
7-Jun	0.08	0			
8-Jun	0.05	0			
SUM	0.33	0.97		-0.64	
9-Jun	0.06	0			
10-Jun	0.07	0.75			
11-Jun	0.07	0.01			
12-Jun	0.07	0.09			
13-Jun	0.07	0.02			
14-Jun	0.06	0			
15-Jun	0.07	0			
SUM	0.47	0.87		-0.4	
16-Jun	0.08	0.21			
17-Jun	0.08	0.22			
18-Jun	0.07	0			
19-Jun	0.07	0			

20-Jun	0.07	0.1			
21-Jun	0.1	0			
22-Jun	0.13	0			
SUM	0.6	0.53		0.07	
23-Jun	0.15	0			
24-Jun	0.17	0			
25-Jun	0.18	0			
26-Jun	0.2	0			
27-Jun	0.19	0			
28-Jun	0.2	1.56			
29-Jun	0.19	0.06			
SUM	1.28	1.62		-0.34	
30-Jun	0.2	0			
1-Jul	0.23	0			
2-Jul	0.27	0			
3-Jul	0.3	0			
4-Jul	0.31	0			
5-Jul	0.33	0			
6-Jul	0.36	0			
SUM	2	0		2	
7-Jul	0.39	0			
8-Jul	0.42	0			
9-Jul	0.44	0	0.177498355		
10-Jul	0.46	0	0.177498355		
11-Jul	0.46	0	0.177498355		
12-Jul	0.44	0.01	0.177498355		
13-Jul	0.44	0	0.177498355		
SUM	3.05	0.01	0.887491776	3.04	0.887491776
14-Jul	0.45	0	0.177498355		
15-Jul	0.48	0	0.177498355		
16-Jul	0.5	0	0.177498355		
17-Jul	0.51	0	0.177498355		
18-Jul	0.51	0	0.177498355		
19-Jul	0.45	0	0.177498355		

20-Jul	0.41	0	0.177498355		
SUM	3.31	0	1.242488486	3.31	1.242488486
21-Jul	0.38	0	0.177498355		
22-Jul	0.31	0	0.177498355		
23-Jul	0.16	0	0.177498355		
24-Jul	0.34	0	0.177498355		
25-Jul	0.51	0	0.177498355		
26-Jul	0.48	0	0.177498355		
27-Jul	0.4	0	0.177498355		
SUM	2.58	0	1.242488486	2.58	1.242488486
28-Jul	0.31	0	0.177498355		
29-Jul	0.29	0.03	0.177498355		
30-Jul	0.29	0.01	0.177498355		
31-Jul	0.34	0	0.177498355		
1-Aug	0.35	0.01	0.177498355		
2-Aug	0.35	0	0.177498355		
3-Aug	0.35	0.03	0.177498355		
SUM	2.28	0.08	1.242488486	2.2	1.242488486
4-Aug	0.34	0.05	0.177498355		
5-Aug	0.35	0	0.177498355		
6-Aug	0.37	0.01	0.177498355		
7-Aug	0.4	0.07	0.177498355		
8-Aug	0.37	0.01	0.177498355		
9-Aug	0.34	0	0.177498355		
10-Aug	0.33	0	0.177498355		
SUM	2.5	0.14	1.242488486	2.36	1.242488486
11-Aug	0.35	0	0.177498355		
12-Aug	0.35	0	0.177498355		
13-Aug	0.36	0	0.177498355		
14-Aug	0.4	0	0.177498355		
15-Aug	0.42	0	0.177498355		
16-Aug	0.46	0	0.177498355		
17-Aug	0.44	0	0.177498355		
SUM	2.78	0	1.242488486	2.78	1.242488486

18-Aug	0.4	1.17	0.177498355		
19-Aug	0.33	0	0.177498355		
20-Aug	0.33	0	0.177498355		
21-Aug	0.33	0	0.177498355		
22-Aug	0.38	0	0.177498355		
23-Aug	0.44	0	0.177498355		
24-Aug	0.46	0	0.177498355		
SUM	2.67	1.17	1.242488486	1.5	1.242488486
25-Aug	0.42	0	0.177498355		
26-Aug	0.24	0	0.177498355		
27-Aug	0.23	0.16	0.177498355		
28-Aug	0.07	0.03	0.177498355		
29-Aug	0.15	0	0.177498355		
30-Aug	0.21	0.2	0.177498355		
31-Aug	0.19	0	0.177498355		
SUM	1.51	0.39	1.242488486	1.12	1.242488486
1-Sep	0.18	0	0.177498355		
2-Sep	0.1	0	0.177498355		
3-Sep	0.15	0.01	0.177498355		
4-Sep	0.25	0	0.177498355		
Yield			19 cwt/ac		
			Total		
			Crop Need	18.89	
				Irrigation	
				Total	9.584911179

APPENDIX B3 – SUNFLOWER, FARMER B

			Well 2	**Well 4**		
		GPM	900	1350		
		Acres	242	206		
		Feet per day	0.17749836	0.3127762	**Weekly**	**Avg. Irrigation**
					Crop Need	**For Week**
Date	**ET snflwr (in.)**	**Precipitation (in.)**			**(ET-p)**	
16-Jun	0.066122099	0.21				
17-Jun	0.047209561	0.22				
18-Jun	0.035101246	0				
19-Jun	0.041217369	0				
20-Jun	0.064544524	0.1				
21-Jun	0.074366243	0				
22-Jun	0.075678711	0				
SUM	0.404239754	0.53			-0.1257602	
23-Jun	0.074656303	0				
24-Jun	0.078922512	0				
25-Jun	0.073625105	0				
26-Jun	0.069812487	0				
27-Jun	0.078094432	0				
28-Jun	0.088779803	1.56				
29-Jun	0.052766934	0.06				
SUM	0.516657575	1.62			-1.1033424	
30-Jun	0.083185925	0				
1-Jul	0.108359309	0				
2-Jul	0.100305241	0				
3-Jul	0.115137543	0				
4-Jul	0.12512082	0				
5-Jul	0.129132059	0				
6-Jul	0.158212466	0				
SUM	0.819453362	0			0.81945336	
7-Jul	0.147851423	0				
8-Jul	0.171501692	0				
9-Jul	0.1717236	0				
10-Jul	0.167493715	0				

11-Jul	0.192382772	0				
12-Jul	0.181587194	0.01				
13-Jul	0.197407365	0				
SUM	1.229947761	0.01			1.21994776	
14-Jul	0.229109699	0	0.17749836			
15-Jul	0.25398835	0	0.17749836			
16-Jul	0.242494778	0	0.17749836			
17-Jul	0.25167481	0	0.17749836			
18-Jul	0.270780357	0	0.17749836			
19-Jul	0.203778518	0	0.17749836			
20-Jul	0.212549766	0	0.17749836			
SUM	1.664376279	0	1.24248849		1.66437628	1.242488486
21-Jul	0.279675792	0	0.17749836			
22-Jul	0.235427911	0	0.17749836			
23-Jul	0.294997274	0	0.17749836	0.3127762		
24-Jul	0.309103461	0	0.17749836	0.3127762		
25-Jul	0.302916837	0	0.17749836	0.3127762		
26-Jul	0.280338983	0	0.17749836	0.3127762		
27-Jul	0.220672206	0	0.17749836	0.3127762		
SUM	1.923132464	0	1.24248849	1.5638811	1.92313246	1.403184813
28-Jul	0.202590753	0	0.17749836	0.3127762		
29-Jul	0.240049495	0.03	0.17749836	0.3127762		
30-Jul	0.254108775	0.01	0.17749836	0.3127762		
31-Jul	0.314321648	0	0.17749836	0.3127762		
1-Aug	0.303909852	0.01	0.17749836	0.3127762		
2-Aug	0.290965192	0	0.17749836	0.3127762		
3-Aug	0.340069412	0.03	0.17749836	0.3127762		
SUM	1.946015126	0.08	1.24248849	2.1894336	1.86601513	1.71596104
4-Aug	0.266593889	0.05	0.17749836	0.3127762		
5-Aug	0.323984117	0	0.17749836	0.3127762		
6-Aug	0.388962523	0.01	0.17749836	0.3127762		
7-Aug	0.388281052	0.07	0.17749836	0.3127762		
8-Aug	0.219376146	0.01	0.17749836	0.3127762		
9-Aug	0.322969085	0	0.17749836	0.3127762		

10-Aug	0.359001037	0	0.17749836	0.3127762		
SUM	2.269167848	0.14	1.24248849	2.1894336	2.12916785	1.71596104
11-Aug	0.334453799	0	0.17749836	0.3127762		
12-Aug	0.373300353	0	0.17749836	0.3127762		
13-Aug	0.407568871	0	0.17749836	0.3127762		
14-Aug	0.412112	0	0.17749836	0.3127762		
15-Aug	0.408579422	0	0.17749836	0.3127762		
16-Aug	0.429167434	0	0.17749836	0.3127762		
17-Aug	0.298212091	0	0.17749836	0.3127762		
SUM	2.66339397	0	1.24248849	2.1894336	2.66339397	1.71596104
18-Aug	0.321995142	1.17	0.17749836	0.3127762		
19-Aug	0.260110913	0	0.17749836	0.3127762		
20-Aug	0.329941848	0	0.17749836	0.3127762		
21-Aug	0.340841095	0	0.17749836	0.3127762		
22-Aug	0.414406026	0	0.17749836	0.3127762		
23-Aug	0.471586172	0	0.17749836	0.3127762		
24-Aug	0.34167765	0	0.17749836	0.3127762		
SUM	2.480558846	1.17	1.24248849	2.1894336	1.31055885	1.71596104
25-Aug	0.276161155	0	0.17749836	0.3127762		
26-Aug	0.319601981	0	0.17749836	0.3127762		
27-Aug	0.319092656	0.16	0.17749836	0.3127762		
28-Aug	0.200590201	0.03	0.17749836	0.3127762		
29-Aug	0.254503069	0	0.17749836	0.3127762		
30-Aug	0.208467301	0.2	0.17749836	0.3127762		
31-Aug	0.170346361	0	0.17749836	0.3127762		
SUM	1.748762724	0.39	1.24248849	2.1894336	1.35876272	1.71596104
1-Sep	0.250550194	0	0.17749836	0.3127762		
2-Sep	0.278660801	0	0.17749836	0.3127762		
3-Sep	0.12751392	0.01	0.17749836	0.3127762		
4-Sep	0.272755515	0	0.17749836	0.3127762		
Yields			2062 lb/ac	3094 lb/ac		
				Total		

				Crop Need	14.9548084	
					Irrigation	
					Total	11.2254785

APPENDIX B4 – MILLET, FARMER B

			Well 1		
		GPM	500		
		Acres	120		
		Feet per day	0.1988639	**Weekly**	**Avg. Irrigation**
				Crop Need	**For Week**
Date	**ET millet (in.)**	**Precipitation (in.)**		**(ET-p)**	
23-May	0.033887576	0.01			
24-May	0.038130799	0			
25-May	0.031928252	0.14			
SUM	0.103946627	0.15		-0.0460534	
26-May	0.03081489	0			
27-May	0.057112125	0			
28-May	0.052782373	0			
29-May	0.08320696	0			
30-May	0.074857532	0.48			
31-May	0.048915515	0.01			
1-Jun	0.043879719	0.3			
SUM	0.391569114	0.79		-0.3984309	
2-Jun	0.066332737	0.28			
3-Jun	0.050862656	0.04			
4-Jun	0.033642873	0.09			
5-Jun	0.035988508	0.07			
6-Jun	0.062643059	0.49			
7-Jun	0.067029108	0			
8-Jun	0.0809092	0			
SUM	0.397408141	0.97		-0.5725919	
9-Jun	0.095126232	0			
10-Jun	0.088374171	0.75			
11-Jun	0.102733141	0.01			
12-Jun	0.103920609	0.09			
13-Jun	0.074274417	0.02			
14-Jun	0.096332865	0			
15-Jun	0.11829848	0			
SUM	0.679059916	0.87		-0.1909401	

16-Jun	0.127614259	0.21			
17-Jun	0.097440625	0.22			
18-Jun	0.076892185	0			
19-Jun	0.095081529	0			
20-Jun	0.155568314	0.1			
21-Jun	0.185833175	0			
22-Jun	0.194607153	0			
SUM	0.933037241	0.53		0.40303724	
23-Jun	0.196158308	0			
24-Jun	0.210485136	0			
25-Jun	0.198102237	0			
26-Jun	0.18847645	0			
27-Jun	0.210515184	0			
28-Jun	0.237932463	1.56			
29-Jun	0.140075292	0.06			
SUM	1.38174507	1.62		-0.2382549	
30-Jun	0.218034269	0			
1-Jul	0.279668141	0			
2-Jul	0.254342636	0			
3-Jul	0.286296947	0			
4-Jul	0.304625512	0			
5-Jul	0.307445094	0			
6-Jul	0.367992891	0			
SUM	2.018405489	0	0	2.01840549	0
7-Jul	0.335698687	0			
8-Jul	0.379887316	0			
9-Jul	0.3709188	0			
10-Jul	0.352664575	0			
11-Jul	0.394764028	0			
12-Jul	0.363070672	0.01			
13-Jul	0.384552517	0			
SUM	2.581556594	0.01	0	2.57155659	0
14-Jul	0.434803205	0			
15-Jul	0.469573734	0			

16-Jul	0.436742286	0			
17-Jul	0.441561999	0			
18-Jul	0.462801615	0			
19-Jul	0.339278042	0			
20-Jul	0.344719466	0			
SUM	2.929480348	0	0	2.92948035	0
21-Jul	0.4418224	0			
22-Jul	0.348357965	0			
23-Jul	0.428230388	0			
24-Jul	0.440217848	0			
25-Jul	0.423275514	0			
26-Jul	0.384386126	0			
27-Jul	0.296947663	0			
SUM	2.763237904	0	0	2.7632379	0
28-Jul	0.267594442	0			
29-Jul	0.311295522	0.03			
30-Jul	0.32359888	0.01			
31-Jul	0.39317689	0			
1-Aug	0.373512929	0.01			
2-Aug	0.351462614	0			
3-Aug	0.403851643	0.03	0.1988639		
SUM	2.424492919	0.08	0.1988639	2.34449292	0.198863898
4-Aug	0.311363894	0.05	0.1988639		
5-Aug	0.372273116	0	0.1988639		
6-Aug	0.439875979	0.01	0.1988639		
7-Aug	0.432341057	0.07	0.1988639		
8-Aug	0.240607726	0.01	0.1988639		
9-Aug	0.349069758	0	0.1988639		
10-Aug	0.38254176	0	0.1988639		
SUM	2.528073291	0.14	1.39204729	2.38807329	1.392047285
11-Aug	0.351529671	0	0.1988639		
12-Aug	0.387211706	0	0.1988639		
13-Aug	0.417434413	0	0.1988639		
14-Aug	0.417008496	0	0.1988639		

15-Aug	0.424999969	0	0.1988639		
16-Aug	0.438363342	0	0.1988639		
17-Aug	0.299257261	0	0.1988639		
SUM	2.735804858	0	1.39204729	2.73580486	1.392047285
18-Aug	0.317598506	1.17	0.1988639		
19-Aug	0.252276917	0	0		
20-Aug	0.3147822	0	0		
21-Aug	0.319983599	0	0.1988639		
22-Aug	0.382948458	0	0.1988639		
23-Aug	0.429078397	0	0.1988639		
24-Aug	0.306171354	0	0.1988639		
SUM	2.32283943	1.17	0.99431949	1.15283943	0.99431949
25-Aug	0.243771598	0	0.1988639		
26-Aug	0.277966483	0	0.1988639		
27-Aug	0.273490736	0.16	0.1988639		
28-Aug	0.169453211	0.03	0.1988639		
29-Aug	0.211938775	0	0.1988639		
30-Aug	0.17115428	0.2	0.1988639		
31-Aug	0.137899521	0	0.1988639		
SUM	1.485674604	0.39	1.39204729	1.0956746	1.392047285
1-Sep	0.200007058	0	0.1988639		
2-Sep	0.219371937	0	0.1988639		
3-Sep	0.099002237	0.01	0.1988639		
4-Sep	0.208864579	0	0.1988639		
5-Sep	0.232483465	0	0.1988639		
6-Sep	0.198357446	0	0.1988639		
7-Sep	0.091214438	0.51	0.1988639		
SUM	1.249301159	0.52	1.39204729	0.72930116	1.392047285
8-Sep	0.163448052	0	0.1988639		
9-Sep	0.1245335	0	0.1988639		
10-Sep	0.217714721	0	0.1988639		
11-Sep	0.172379878	0	0.1988639		
12-Sep	0.221752282	0	0.1988639		
13-Sep	0.100208832	0	0.1988639		

14-Sep	0.129672185	0	0.1988639		
SUM	1.129709451	0	1.39204729	1.12970945	1.392047285
15-Sep	0.159395582	0	0.1988639		
16-Sep	0.160714676	0	0.1988639		
17-Sep	0.252020971	0	0.1988639		
18-Sep	0.146531604	0	0.1988639		
19-Sep	0.12542856	0	0.1988639		
20-Sep	0.11888965	0	0.1988639		
21-Sep	0.112031656	0	0.1988639		
SUM	1.075012699	0	1.39204729	1.0750127	1.392047285
22-Sep	0.107869027	0	0.1988639		
23-Sep	0.117720344	0	0.1988639		
24-Sep	0.113774455	0	0.1988639		
		0	0.1988639		
Yield			2.2 tons/ac		
			Total		
			Crop Need	12.6509084	
				Irrigation	9.5454671
				Total	

APPENDIX B5 – CORN, FARMER C

			Well 1		
		GPM	800		
		Acres	300		
		Feet per day	0.127272895	**Weekly**	**Avg. Irrigation**
				Crop Need	**For Week**
Date	**ET corn (in.)**	**Precipitation (in.)**		**(ET-p)**	
14-Apr		0			
15-Apr		0.04			
16-Apr		0.23			
17-Apr		0			
18-Apr		0			
19-Apr		0.26			
20-Apr	0.01	0			
SUM	0.01	0.53		-0.52	
21-Apr	0.03	0			
22-Apr	0.04	0			
23-Apr	0.04	0.67			
24-Apr	0.03	0.33			
25-Apr	0.02	0			
26-Apr	0.03	0			
27-Apr	0.04	0			
SUM	0.23	1		-0.77	
28-Apr	0.03	0			
29-Apr	0.03	0.36			
30-Apr	0.03	0			
1-May	0.03	0.04			
2-May	0.03	0.01			
3-May	0.04	0			
4-May	0.04	0			
SUM	0.23	0.41		-0.18	
5-May	0.05	0			
6-May	0.04	0.05			
7-May	0.04	0			
8-May	0.04	0			

9-May	0.04	0			
10-May	0.03	0.89			
11-May	0.04	0			
SUM	0.28	0.94		-0.66	
12-May	0.04	0			
13-May	0.05	0			
14-May	0.04	0			
15-May	0.03	0.89			
16-May	0.04	0.01			
17-May	0.04	0			
18-May	0.04	0.17			
SUM	0.28	1.07		-0.79	
19-May	0.05	0			
20-May	0.04	0			
21-May	0.06	0			
22-May	0.06	0			
23-May	0.06	0.01			
24-May	0.05	0			
25-May	0.05	0.14			
SUM	0.37	0.15		0.22	
26-May	0.05	0			
27-May	0.07	0			
28-May	0.09	0			
29-May	0.05	0	0.127272895		
30-May	0.09	0.48	0.127272895		
31-May	0.12	0.01	0.127272895		
1-Jun	0.09	0.3	0.127272895		
SUM	0.56	0.79	0.509091579	-0.23	0.509091579
2-Jun	0.09	0.28	0.127272895		
3-Jun	0.09	0.04	0.127272895		
4-Jun	0.09	0.09	0.127272895		
5-Jun	0.06	0.07	0.127272895		
6-Jun	0.06	0.49	0.127272895		
7-Jun	0.08	0	0.127272895		

8-Jun	0.11	0			
SUM	0.58	0.97	0.763637368	-0.39	0.763637368
9-Jun	0.13	0			
10-Jun	0.14	0.75			
11-Jun	0.14	0.01			
12-Jun	0.14	0.09			
13-Jun	0.13	0.02			
14-Jun	0.12	0			
15-Jun	0.13	0			
SUM	0.93	0.87		0.06	
16-Jun	0.15	0.21			
17-Jun	0.15	0.22			
18-Jun	0.13	0			
19-Jun	0.11	0			
20-Jun	0.12	0.1			
21-Jun	0.17	0			
22-Jun	0.2	0			
SUM	1.03	0.53		0.5	
23-Jun	0.19	0			
24-Jun	0.25	0			
25-Jun	0.26	0			
26-Jun	0.27	0			
27-Jun	0.25	0			
28-Jun	0.26	1.56			
29-Jun	0.23	0.06			
SUM	1.71	1.62		0.09	
30-Jun	0.24	0			
1-Jul	0.27	0	0.127272895		
2-Jul	0.31	0	0.127272895		
3-Jul	0.34	0	0.127272895		
4-Jul	0.34	0	0.127272895		
5-Jul	0.35	0	0.127272895		
6-Jul	0.38	0	0.127272895		
SUM	2.23	0	0.636364473	2.23	0.636364473

7-Jul	0.39	0	0.127272895		
8-Jul	0.42	0	0.127272895		
9-Jul	0.43	0	0.127272895		
10-Jul	0.44	0	0.127272895		
11-Jul	0.43	0	0.127272895		
12-Jul	0.41	0.01	0.127272895		
13-Jul	0.42	0	0.127272895		
SUM	2.94	0.01	0.890910263	2.93	0.890910263
14-Jul	0.43	0	0.127272895		
15-Jul	0.46	0	0.127272895		
16-Jul	0.48	0	0.127272895		
17-Jul	0.49	0	0.127272895		
18-Jul	0.49	0	0.127272895		
19-Jul	0.43	0	0.127272895		
20-Jul	0.39	0	0.127272895		
SUM	3.17	0	0.890910263	3.17	0.890910263
21-Jul	0.29	0	0.127272895		
22-Jul	0.3	0	0.127272895		
23-Jul	0.15	0	0.127272895		
24-Jul	0.32	0	0.127272895		
25-Jul	0.49	0	0.127272895		
26-Jul	0.46	0	0.127272895		
27-Jul	0.38	0	0.127272895		
SUM	2.39	0	0.890910263	2.39	0.890910263
28-Jul	0.3	0	0.127272895		
29-Jul	0.28	0.03	0.127272895		
30-Jul	0.28	0.01	0.127272895		
31-Jul	0.32	0	0.127272895		
1-Aug	0.33	0.01	0.127272895		
2-Aug	0.33	0	0.127272895		
3-Aug	0.33	0.03	0.127272895		
SUM	2.17	0.08	0.890910263	2.09	0.890910263
4-Aug	0.31	0.05	0.127272895		
5-Aug	0.31	0	0.127272895		

6-Aug	0.32	0.01	0.127272895		
7-Aug	0.35	0.07	0.127272895		
8-Aug	0.31	0.01	0.127272895		
9-Aug	0.28	0	0.127272895		
10-Aug	0.26	0	0.127272895		
SUM	2.14	0.14	0.890910263	2	0.890910263
11-Aug	0.28	0	0.127272895		
12-Aug	0.27	0	0.127272895		
13-Aug	0.27	0	0.127272895		
14-Aug	0.28	0	0.127272895		
15-Aug	0.29	0	0.127272895		
16-Aug	0.3	0	0.127272895		
17-Aug	0.27	0	0.127272895		
SUM	1.96	0	0.890910263	1.96	0.890910263
18-Aug	0.24	1.17	0.127272895		
19-Aug	0.19	0	0.127272895		
20-Aug	0.18	0	0.127272895		
21-Aug	0.17	0	0.127272895		
22-Aug	0.18	0	0.127272895		
23-Aug	0.19	0	0.127272895		
24-Aug	0.19	0	0.127272895		
SUM	1.34	1.17	0.890910263	0.17	0.890910263
25-Aug	0.15	0	0.127272895		
26-Aug	0.08	0	0.127272895		
27-Aug	0.12	0.16	0.127272895		
28-Aug	0.02	0.03	0.127272895		
29-Aug	0.04	0	0.127272895		
30-Aug	0.06	0.2	0.127272895		
31-Aug	0.09	0	0.127272895		
SUM	0.56	0.39	0.890910263	0.17	0.890910263
1-Sep	0.08	0	0.127272895		
2-Sep	0.02	0	0.127272895		
3-Sep	0.03	0.01	0.127272895		
4-Sep	0.13	0	0.127272895		

5-Sep	0.21	0	0.127272895		
6-Sep	0.3	0	0.127272895		
7-Sep	0.26	0.51	0.127272895		
SUM	1.03	0.52	0.890910263	0.51	0.890910263
8-Sep	0.22	0	0.127272895		
9-Sep	0.19	0	0.127272895		
10-Sep	0.23	0	0.127272895		
11-Sep	0.24	0	0.127272895		
12-Sep	0.3	0	0		
13-Sep	0.26	0	0		
14-Sep	0.25	0	0		
SUM	1.69	0	0.509091579	1.69	0.509091579
15-Sep	0.2	0			
16-Sep	0.25	0			
17-Sep	0.35	0			
18-Sep	0.35	0			
19-Sep	0.34	0			
20-Sep	0.25	0			
21-Sep	0.21	0			
Yield			180 bu/ac		
			Total		
			Crop Need	18.69	
			Irrigation		
			Total		10.43637736

APPENDIX B6 – ALFALFA, FARMER C

			Well 2		
		GPM	500		
		Acres	125		
		Feet per day	0.190909342	Weekly	Avg. Irrigation
				Crop Need	For Week
Date	ET alfalfa (in.)	Precipitation (in.)		(ET-p)	
25-Apr	0.03	0	0.190909342		
26-Apr	0.06	0	0.190909342		
27-Apr	0.06	0	0.190909342		
SUM	0.15	0	0.572728026	0.15	0.572728026
28-Apr	0.06	0	0.190909342		
29-Apr	0.1	0.36	0.190909342		
30-Apr	0.04	0	0.190909342		
1-May	0.05	0.04	0.190909342		
2-May	0.06	0.01	0.190909342		
3-May	0.07	0	0.190909342		
4-May	0.1	0	0.190909342		
SUM	0.48	0.41	1.336365394	0.07	1.336365394
5-May	0.1	0	0.190909342		
6-May	0.1	0.05	0.190909342		
7-May	0.11	0	0.190909342		
8-May	0.11	0	0.190909342		
9-May	0.11	0	0.190909342		
10-May	0.09	0.89	0.190909342		
11-May	0.11	0	0.190909342		
SUM	0.73	0.94	1.336365394	-0.21	1.336365394
12-May	0.12	0	0.190909342		
13-May	0.14	0	0.190909342		
14-May	0.12	0	0.190909342		
15-May	0.09	0.89	0.190909342		
16-May	0.13	0.01	0.190909342		
17-May	0.15	0	0.190909342		
18-May	0.15	0.17	0.190909342		

SUM	0.9	1.07	1.336365394	-0.17	1.336365394
19-May	0.16	0	0.190909342		
20-May	0.16	0	0.190909342		
21-May	0.2	0	0.190909342		
22-May	0.23	0	0.190909342		
23-May	0.21	0.01	0.190909342		
24-May	0.18	0	0.190909342		
25-May	0.17	0.14	0.190909342		
SUM	1.31	0.15	1.336365394	1.16	1.336365394
26-May	0.15	0	0.190909342		
27-May	0.22	0	0.190909342		
28-May	0.22	0	0.190909342		
29-May	0.14	0	0.190909342		
30-May	0.27	0.48	0.190909342		
31-May	0.35	0.01	0.190909342		
1-Jun	0.27	0.3	0.190909342		
SUM	1.62	0.79	1.336365394	0.83	1.336365394
2-Jun	0.25	0.28	0.190909342		
3-Jun	0.25	0.04	0.190909342		
4-Jun	0.22	0.09	0.190909342		
5-Jun	0.16	0.07	0.190909342		
6-Jun	0.16	0.49	0.190909342		
7-Jun	0.2	0	0.190909342		
8-Jun	0.25	0	0.190909342		
SUM	1.49	0.97	1.336365394	0.52	1.336365394
9-Jun	0.28	0	0.190909342		
10-Jun	0.3	0.75	0.190909342		
11-Jun	0.3	0.01	0.190909342		
12-Jun	0.29	0.09	0.190909342		
13-Jun	0.26	0.02	0.190909342		
14-Jun	0.24	0	0.190909342		
15-Jun	0.24	0	0.190909342		
SUM	1.91	0.87	1.336365394	1.04	1.336365394
16-Jun	0.28	0.21	0.190909342		

17-Jun	0.27	0.22	0.190909342		
18-Jun	0.23	0	0.190909342		
19-Jun	0.19	0	0.190909342		
20-Jun	0.21	0.1	0.190909342		
21-Jun	0.28	0	0.190909342		
22-Jun	0.32	0	0.190909342		
SUM	1.78	0.53	1.336365394	1.25	1.336365394
23-Jun	0.35	0	0.190909342		
24-Jun	0.38	0	0.190909342		
25-Jun	0.38	0	0.190909342		
26-Jun	0.38	0	0.190909342		
27-Jun	0.35	0	0.190909342		
28-Jun	0.35	1.56	0.190909342		
29-Jun	0.31	0.06	0.190909342		
SUM	2.5	1.62	1.336365394	0.88	1.336365394
30-Jun	0.31	0	0.190909342		
1-Jul	0.34	0	0.190909342		
2-Jul	0.39	0	0.190909342		
3-Jul	0.41	0	0.190909342		
4-Jul	0.4	0	0.190909342		
5-Jul	0.41	0	0.190909342		
6-Jul	0.43	0	0.190909342		
SUM	2.69	0	1.336365394	2.69	1.336365394
7-Jul	0.44	0	0.190909342		
8-Jul	0.46	0	0.190909342		
9-Jul	0.47	0	0.190909342		
10-Jul	0.47	0	0.190909342		
11-Jul	0.46	0	0.190909342		
12-Jul	0.44	0.01	0.190909342		
13-Jul	0.44	0	0.190909342		
SUM	3.18	0.01	1.336365394	3.17	1.336365394
14-Jul	0.45	0	0.190909342		
15-Jul	0.48	0	0.190909342		
16-Jul	0.5	0	0.190909342		

17-Jul	0.51	0	0.190909342		
18-Jul	0.51	0	0.190909342		
19-Jul	0.45	0	0.190909342		
20-Jul	0.41	0	0.190909342		
SUM	3.31	0	1.336365394	3.31	1.336365394
21-Jul	0.32	0	0.190909342		
22-Jul	0.33	0	0.190909342		
23-Jul	0.34	0	0.190909342		
24-Jul	0.34	0	0.190909342		
25-Jul	0.51	0	0.190909342		
26-Jul	0.48	0	0.190909342		
27-Jul	0.4	0	0.190909342		
SUM	2.72	0	1.336365394	2.72	1.336365394
28-Jul	0.31	0	0.190909342		
29-Jul	0.29	0.03	0.190909342		
30-Jul	0.29	0.01	0.190909342		
31-Jul	0.34	0	0.190909342		
1-Aug	0.35	0.01	0.190909342		
2-Aug	0.35	0	0.190909342		
3-Aug	0.35	0.03	0.190909342		
SUM	2.28	0.08	1.336365394	2.2	1.336365394
4-Aug	0.34	0.05	0.190909342		
5-Aug	0.35	0	0.190909342		
6-Aug	0.37	0.01	0.190909342		
7-Aug	0.4	0.07	0.190909342		
8-Aug	0.37	0.01	0.190909342		
9-Aug	0.34	0	0.190909342		
10-Aug	0.33	0	0.190909342		
SUM	2.5	0.14	1.336365394	2.36	1.336365394
11-Aug	0.35	0	0.190909342		
12-Aug	0.35	0	0.190909342		
13-Aug	0.36	0	0.190909342		
14-Aug	0.4	0	0.190909342		
15-Aug	0.42	0	0.190909342		

16-Aug	0.46	0	0.190909342		
17-Aug	0.44	0	0.190909342		
SUM	2.78	0	1.336365394	2.78	1.336365394
18-Aug	0.4	1.17	0.190909342		
19-Aug	0.33	0	0.190909342		
20-Aug	0.33	0	0.190909342		
21-Aug	0.33	0	0.190909342		
22-Aug	0.38	0	0.190909342		
23-Aug	0.44	0	0.190909342		
24-Aug	0.46	0	0.190909342		
SUM	2.67	1.17	1.336365394	1.5	1.336365394
25-Aug	0.42	0	0.190909342		
26-Aug	0.24	0	0.190909342		
27-Aug	0.23	0.16	0.190909342		
28-Aug	0.07	0.03	0.190909342		
29-Aug	0.15	0	0.190909342		
30-Aug	0.21	0.2	0.190909342		
31-Aug	0.19	0	0.190909342		
SUM	1.51	0.39	1.336365394	1.12	1.336365394
1-Sep	0.18	0	0.190909342		
2-Sep	0.1	0	0.190909342		
3-Sep	0.15	0.01	0.190909342		
4-Sep	0.25	0	0.190909342		
Yield			4 ton/acre		
			Total		
			Crop Need	27.37	
				Irrigation	
				Total	24.62730512

APPENDIX B7 – SUNFLOWER, FARMER C

			Well 2		
		GPM	800		
		Acres	130		
		Feet per day	0.29370668	**Weekly**	**Avg. Irrigation**
				Crop Need	**For Week**
Date	**ET snflwr (in.)**	**Precipitation (in.)**		**(ET-p)**	
16-Jun	0.066122099	0.21			
17-Jun	0.047209561	0.22			
18-Jun	0.035101246	0			
19-Jun	0.041217369	0			
20-Jun	0.064544524	0.1			
21-Jun	0.074366243	0			
22-Jun	0.075678711	0			
SUM	0.404239754	0.53		-0.1257602	
23-Jun	0.074656303	0			
24-Jun	0.078922512	0			
25-Jun	0.073625105	0			
26-Jun	0.069812487	0			
27-Jun	0.078094432	0			
28-Jun	0.088779803	1.56			
29-Jun	0.052766934	0.06			
SUM	0.516657575	1.62		-1.1033424	
30-Jun	0.083185925	0			
1-Jul	0.108359309	0	0.29370668		
2-Jul	0.100305241	0	0.29370668		
3-Jul	0.115137543	0	0.29370668		
4-Jul	0.12512082	0	0.29370668		
5-Jul	0.129132059	0	0.29370668		
6-Jul	0.158212466	0	0.29370668		
SUM	0.819453362	0	1.76224008	0.81945336	1.76224008
7-Jul	0.147851423	0	0.29370668		
8-Jul	0.171501692	0	0.29370668		
9-Jul	0.1717236	0	0.29370668		
10-Jul	0.167493715	0	0.29370668		

11-Jul	0.192382772	0	0.29370668		
12-Jul	0.181587194	0.01	0.29370668		
13-Jul	0.197407365	0	0.29370668		
SUM	1.229947761	0.01	2.05594676	1.21994776	2.05594676
14-Jul	0.229109699	0	0.29370668		
15-Jul	0.25398835	0	0.29370668		
16-Jul	0.242494778	0	0.29370668		
17-Jul	0.25167481	0	0.29370668		
18-Jul	0.270780357	0	0.29370668		
19-Jul	0.203778518	0	0.29370668		
20-Jul	0.212549766	0	0.29370668		
SUM	1.664376279	0	2.05594676	1.66437628	2.05594676
21-Jul	0.279675792	0	0.29370668		
22-Jul	0.235427911	0	0.29370668		
23-Jul	0.294997274	0	0.29370668		
24-Jul	0.309103461	0	0.29370668		
25-Jul	0.302916837	0	0.29370668		
26-Jul	0.280338983	0	0.29370668		
27-Jul	0.220672206	0	0.29370668		
SUM	1.923132464	0	2.05594676	1.92313246	2.05594676
28-Jul	0.202590753	0	0.29370668		
29-Jul	0.240049495	0.03	0.29370668		
30-Jul	0.254108775	0.01	0.29370668		
31-Jul	0.314321648	0	0.29370668		
1-Aug	0.303909852	0.01	0.29370668		
2-Aug	0.290965192	0	0.29370668		
3-Aug	0.340069412	0.03	0.29370668		
SUM	1.946015126	0.08	2.05594676	1.86601513	2.05594676
4-Aug	0.266593889	0.05	0.29370668		
5-Aug	0.323984117	0	0.29370668		
6-Aug	0.388962523	0.01	0.29370668		
7-Aug	0.388281052	0.07	0.29370668		
8-Aug	0.219376146	0.01	0.29370668		
9-Aug	0.322969085	0	0.29370668		

10-Aug	0.359001037	0	0.29370668		
SUM	2.269167848	0.14	2.05594676	2.12916785	2.05594676
11-Aug	0.334453799	0	0.29370668		
12-Aug	0.373300353	0	0.29370668		
13-Aug	0.407568871	0	0.29370668		
14-Aug	0.412112	0	0.29370668		
15-Aug	0.408579422	0	0.29370668		
16-Aug	0.429167434	0	0.29370668		
17-Aug	0.298212091	0	0.29370668		
SUM	2.66339397	0	2.05594676	2.66339397	2.05594676
18-Aug	0.321995142	1.17	0.29370668		
19-Aug	0.260110913	0	0.29370668		
20-Aug	0.329941848	0	0.29370668		
21-Aug	0.340841095	0	0.29370668		
22-Aug	0.414406026	0	0.29370668		
23-Aug	0.471586172	0	0.29370668		
24-Aug	0.34167765	0	0.29370668		
SUM	2.480558846	1.17	2.05594676	1.31055885	2.05594676
25-Aug	0.276161155	0	0.29370668		
26-Aug	0.319601981	0	0.29370668		
27-Aug	0.319092656	0.16	0.29370668		
28-Aug	0.200590201	0.03	0.29370668		
29-Aug	0.254503069	0	0.29370668		
30-Aug	0.208467301	0.2	0.29370668		
31-Aug	0.170346361	0	0.29370668		
SUM	1.748762724	0.39	2.05594676	1.35876272	2.05594676
1-Sep	0.250550194	0	0.29370668		
2-Sep	0.278660801	0	0.29370668		
3-Sep	0.12751392	0.01	0.29370668		
4-Sep	0.272755515	0	0.29370668		
Yield			1500 lb/ac		
			Total		

			Crop Need	14.9548084	
			Irrigation		
			Total		14.39162732

APPENDIX B8 – HERSHEY (PROSO MILLET), FARMER C

			Well 1		
		GPM	600		
		Acres	100		
		Feet per day	0.28636401	**Weekly**	**Avg. Irrigation**
				Crop Need	**For Week**
Date	**ET millet (in.)**	**Precipitation (in.)**		**(ET-p)**	
23-May	0.033887576	0.01			
24-May	0.038130799	0			
25-May	0.031928252	0.14			
SUM	0.103946627	0.15		-0.0460534	
26-May	0.03081489	0			
27-May	0.057112125	0			
28-May	0.052782373	0			
29-May	0.08320696	0			
30-May	0.074857532	0.48			
31-May	0.048915515	0.01			
1-Jun	0.043879719	0.3			
SUM	0.391569114	0.79		-0.3984309	
2-Jun	0.066332737	0.28			
3-Jun	0.050862656	0.04			
4-Jun	0.033642873	0.09			
5-Jun	0.035988508	0.07			
6-Jun	0.062643059	0.49			
7-Jun	0.067029108	0			
8-Jun	0.0809092	0			
SUM	0.397408141	0.97		-0.5725919	
9-Jun	0.095126232	0			
10-Jun	0.088374171	0.75			
11-Jun	0.102733141	0.01			
12-Jun	0.103920609	0.09			
13-Jun	0.074274417	0.02			
14-Jun	0.096332865	0			
15-Jun	0.11829848	0			
SUM	0.679059916	0.87		-0.1909401	

16-Jun	0.127614259	0.21			
17-Jun	0.097440625	0.22			
18-Jun	0.076892185	0			
19-Jun	0.095081529	0			
20-Jun	0.155568314	0.1			
21-Jun	0.185833175	0			
22-Jun	0.194607153	0			
SUM	0.933037241	0.53		0.40303724	
23-Jun	0.196158308	0			
24-Jun	0.210485136	0			
25-Jun	0.198102237	0			
26-Jun	0.18847645	0			
27-Jun	0.210515184	0			
28-Jun	0.237932463	1.56			
29-Jun	0.140075292	0.06			
SUM	1.38174507	1.62		-0.2382549	
30-Jun	0.218034269	0			
1-Jul	0.279668141	0			
2-Jul	0.254342636	0			
3-Jul	0.286296947	0			
4-Jul	0.304625512	0			
5-Jul	0.307445094	0			
6-Jul	0.367992891	0			
SUM	2.018405489	0	0	2.01840549	0
7-Jul	0.335698687	0			
8-Jul	0.379887316	0			
9-Jul	0.3709188	0			
10-Jul	0.352664575	0			
11-Jul	0.394764028	0			
12-Jul	0.363070672	0.01			
13-Jul	0.384552517	0			
SUM	2.581556594	0.01	0	2.57155659	0
14-Jul	0.434803205	0			
15-Jul	0.469573734	0			

16-Jul	0.436742286	0			
17-Jul	0.441561999	0			
18-Jul	0.462801615	0			
19-Jul	0.339278042	0			
20-Jul	0.344719466	0			
SUM	2.929480348	0	0	2.92948035	0
21-Jul	0.4418224	0			
22-Jul	0.348357965	0	0.28636401		
23-Jul	0.428230388	0	0.28636401		
24-Jul	0.440217848	0	0.28636401		
25-Jul	0.423275514	0	0.28636401		
26-Jul	0.384386126	0	0.28636401		
27-Jul	0.296947663	0	0.28636401		
SUM	2.763237904	0	1.71818408	2.7632379	1.718184078
28-Jul	0.267594442	0	0.28636401		
29-Jul	0.311295522	0.03	0.28636401		
30-Jul	0.32359888	0.01	0.28636401		
31-Jul	0.39317689	0	0.28636401		
1-Aug	0.373512929	0.01	0.28636401		
2-Aug	0.351462614	0	0.28636401		
3-Aug	0.403851643	0.03	0.28636401		
SUM	2.424492919	0.08	2.00454809	2.34449292	2.004548091
4-Aug	0.311363894	0.05	0.28636401		
5-Aug	0.372273116	0	0.28636401		
6-Aug	0.439875979	0.01	0.28636401		
7-Aug	0.432341057	0.07	0.28636401		
8-Aug	0.240607726	0.01	0.28636401		
9-Aug	0.349069758	0	0.28636401		
10-Aug	0.38254176	0	0.28636401		
SUM	2.528073291	0.14	2.00454809	2.38807329	2.004548091
11-Aug	0.351529671	0	0.28636401		
12-Aug	0.387211706	0	0.28636401		
13-Aug	0.417434413	0	0.28636401		
14-Aug	0.417008496	0	0.28636401		

15-Aug	0.424999969	0	0.28636401		
16-Aug	0.438363342	0	0.28636401		
17-Aug	0.299257261	0	0.28636401		
SUM	2.735804858	0	2.00454809	2.73580486	2.004548091
18-Aug	0.317598506	1.17	0.28636401		
19-Aug	0.252276917	0	0.28636401		
20-Aug	0.3147822	0	0.28636401		
21-Aug	0.319983599	0	0.28636401		
22-Aug	0.382948458	0	0.28636401		
23-Aug	0.429078397	0	0.28636401		
24-Aug	0.306171354	0	0.28636401		
SUM	2.32283943	1.17	2.00454809	1.15283943	2.004548091
25-Aug	0.243771598	0	0.28636401		
26-Aug	0.277966483	0	0.28636401		
27-Aug	0.273490736	0.16	0.28636401		
28-Aug	0.169453211	0.03	0.28636401		
29-Aug	0.211938775	0	0.28636401		
30-Aug	0.17115428	0.2	0.28636401		
31-Aug	0.137899521	0	0.28636401		
SUM	1.485674604	0.39	2.00454809	1.0956746	2.004548091
1-Sep	0.200007058	0	0.28636401		
2-Sep	0.219371937	0	0.28636401		
3-Sep	0.099002237	0.01	0.28636401		
4-Sep	0.208864579	0	0.28636401		
5-Sep	0.232483465	0	0.28636401		
6-Sep	0.198357446	0	0.28636401		
7-Sep	0.091214438	0.51	0.28636401		
SUM	1.249301159	0.52	2.00454809	0.72930116	2.004548091
8-Sep	0.163448052	0	0.28636401		
9-Sep	0.1245335	0	0.28636401		
10-Sep	0.217714721	0	0.28636401		
11-Sep	0.172379878	0	0.28636401		
12-Sep	0.221752282	0	0.28636401		
13-Sep	0.100208832	0	0.28636401		

14-Sep	0.129672185	0	0.28636401		
SUM	1.129709451	0	2.00454809	1.12970945	2.004548091
15-Sep	0.159395582	0	0.28636401		
16-Sep	0.160714676	0	0.28636401		
17-Sep	0.252020971	0	0.28636401		
18-Sep	0.146531604	0	0.28636401		
19-Sep	0.12542856	0	0.28636401		
20-Sep	0.11888965	0	0.28636401		
21-Sep	0.112031656	0			
SUM	1.075012699	0	1.71818408	1.0750127	1.718184078
22-Sep	0.107869027	0			
23-Sep	0.117720344	0			
24-Sep	0.113774455	0			
		0			
Yield			50 bu/ac		
			Total		
			Crop Need	15.4141463	
				Irrigation	17.46820479
				Total	

APPENDIX B9 – CORN, FARMER D

			Well 1	**Well 2**		
		GPM	850	1200		
		Acres	165	250		
		Feet per day	0.245868	0.229091	**Weekly**	**Avg. Irrigation**
					Crop Need	**For Week**
Date	**ET corn (in.)**	**Precipitation (in.)**			**(ET-p)**	
14-Apr		0				
15-Apr		0.04				
16-Apr		0.23				
17-Apr		0				
18-Apr		0				
19-Apr		0.26				
20-Apr	0.01	0				
SUM	0.01	0.53			-0.52	
21-Apr	0.03	0				
22-Apr	0.04	0				
23-Apr	0.04	0.67				
24-Apr	0.03	0.33				
25-Apr	0.02	0				
26-Apr	0.03	0				
27-Apr	0.04	0				
SUM	0.23	1			-0.77	
28-Apr	0.03	0				
29-Apr	0.03	0.36				
30-Apr	0.03	0				
1-May	0.03	0.04				
2-May	0.03	0.01				
3-May	0.04	0				
4-May	0.04	0				
SUM	0.23	0.41			-0.18	
5-May	0.05	0				
6-May	0.04	0.05				
7-May	0.04	0				
8-May	0.04	0				

9-May	0.04	0				
10-May	0.03	0.89				
11-May	0.04	0				
SUM	0.28	0.94			-0.66	
12-May	0.04	0				
13-May	0.05	0				
14-May	0.04	0				
15-May	0.03	0.89				
16-May	0.04	0.01				
17-May	0.04	0				
18-May	0.04	0.17				
SUM	0.28	1.07			-0.79	
19-May	0.05	0				
20-May	0.04	0				
21-May	0.06	0				
22-May	0.06	0				
23-May	0.06	0.01				
24-May	0.05	0				
25-May	0.05	0.14				
SUM	0.37	0.15			0.22	
26-May	0.05	0				
27-May	0.07	0				
28-May	0.09	0				
29-May	0.05	0				
30-May	0.09	0.48				
31-May	0.12	0.01				
1-Jun	0.09	0.3				
SUM	0.56	0.79			-0.23	
2-Jun	0.09	0.28				
3-Jun	0.09	0.04				
4-Jun	0.09	0.09				
5-Jun	0.06	0.07				
6-Jun	0.06	0.49				
7-Jun	0.08	0				

8-Jun	0.11	0				
SUM	0.58	0.97			-0.39	
9-Jun	0.13	0				
10-Jun	0.14	0.75				
11-Jun	0.14	0.01				
12-Jun	0.14	0.09				
13-Jun	0.13	0.02				
14-Jun	0.12	0				
15-Jun	0.13	0				
SUM	0.93	0.87			0.06	
16-Jun	0.15	0.21				
17-Jun	0.15	0.22				
18-Jun	0.13	0				
19-Jun	0.11	0				
20-Jun	0.12	0.1				
21-Jun	0.17	0				
22-Jun	0.2	0				
SUM	1.03	0.53			0.5	
23-Jun	0.19	0				
24-Jun	0.25	0				
25-Jun	0.26	0				
26-Jun	0.27	0				
27-Jun	0.25	0				
28-Jun	0.26	1.56				
29-Jun	0.23	0.06				
SUM	1.71	1.62			0.09	
30-Jun	0.24	0				
1-Jul	0.27	0				
2-Jul	0.31	0	0.245868			
3-Jul	0.34	0	0.245868			
4-Jul	0.34	0	0.245868	0.229091		
5-Jul	0.35	0	0.245868	0.229091		
6-Jul	0.38	0	0.245868	0.229091		
SUM	2.23	0	1.22934	0.687274	2.23	0.958307046

7-Jul	0.39	0	0.245868	0.229091		
8-Jul	0.42	0	0.245868	0.229091		
9-Jul	0.43	0	0.245868	0.229091		
10-Jul	0.44	0	0.245868	0.229091		
11-Jul	0.43	0	0.245868	0.229091		
12-Jul	0.41	0.01	0.245868	0.229091		
13-Jul	0.42	0	0.245868	0.229091		
SUM	2.94	0.01	1.721077	1.603638	2.93	1.662357558
14-Jul	0.43	0	0.245868	0.229091		
15-Jul	0.46	0	0.245868	0.229091		
16-Jul	0.48	0	0.245868	0.229091		
17-Jul	0.49	0	0.245868	0.229091		
18-Jul	0.49	0	0.245868	0.229091		
19-Jul	0.43	0	0.245868	0.229091		
20-Jul	0.39	0	0.245868	0.229091		
SUM	3.17	0	1.721077	1.603638	3.17	1.662357558
21-Jul	0.29	0	0.245868	0.229091		
22-Jul	0.3	0	0.245868	0.229091		
23-Jul	0.15	0	0.245868	0.229091		
24-Jul	0.32	0	0.245868	0.229091		
25-Jul	0.49	0	0.245868	0.229091		
26-Jul	0.46	0	0.245868	0.229091		
27-Jul	0.38	0	0.245868	0.229091		
SUM	2.39	0	1.721077	1.603638	2.39	1.662357558
28-Jul	0.3	0	0.245868	0.229091		
29-Jul	0.28	0.03	0.245868	0.229091		
30-Jul	0.28	0.01	0.245868	0.229091		
31-Jul	0.32	0	0.245868	0.229091		
1-Aug	0.33	0.01	0.245868	0.229091		
2-Aug	0.33	0	0.245868	0.229091		
3-Aug	0.33	0.03	0.245868	0.229091		
SUM	2.17	0.08	1.721077	1.603638	2.09	1.662357558
4-Aug	0.31	0.05	0.245868	0.229091		
5-Aug	0.31	0	0.245868	0.229091		

6-Aug	0.32	0.01	0.245868	0.229091		
7-Aug	0.35	0.07	0.245868	0.229091		
8-Aug	0.31	0.01	0.245868	0.229091		
9-Aug	0.28	0	0.245868	0.229091		
10-Aug	0.26	0	0.245868	0.229091		
SUM	2.14	0.14	1.721077	1.603638	2	1.662357558
11-Aug	0.28	0	0.245868	0.229091		
12-Aug	0.27	0	0.245868	0.229091		
13-Aug	0.27	0	0.245868	0.229091		
14-Aug	0.28	0	0.245868	0.229091		
15-Aug	0.29	0	0.245868	0.229091		
16-Aug	0.3	0	0.245868	0.229091		
17-Aug	0.27	0	0.245868	0.229091		
SUM	1.96	0	1.721077	1.603638	1.96	1.662357558
18-Aug	0.24	1.17	0.245868	0.229091		
19-Aug	0.19	0	0.245868	0.229091		
20-Aug	0.18	0	0.245868	0.229091		
21-Aug	0.17	0	0.245868	0.229091		
22-Aug	0.18	0	0.245868	0.229091		
23-Aug	0.19	0	0.245868	0.229091		
24-Aug	0.19	0	0.245868	0.229091		
SUM	1.34	1.17	1.721077	1.603638	0.17	1.662357558
25-Aug	0.15	0	0.245868	0.229091		
26-Aug	0.08	0	0.245868	0.229091		
27-Aug	0.12	0.16	0.245868	0.229091		
28-Aug	0.02	0.03	0.245868	0.229091		
29-Aug	0.04	0	0.245868	0.229091		
30-Aug	0.06	0.2	0.245868	0.229091		
31-Aug	0.09	0	0.245868	0.229091		
SUM	0.56	0.39	1.721077	1.603638	0.17	1.662357558
1-Sep	0.08	0	0.245868	0.229091		
2-Sep	0.02	0	0.245868	0.229091		
3-Sep	0.03	0.01	0.245868	0.229091		
4-Sep	0.13	0	0.245868	0.229091		

5-Sep	0.21	0	0.245868	0.229091		
6-Sep	0.3	0	0.245868	0.229091		
7-Sep	0.26	0.51	0.245868	0		
SUM	1.03	0.52	1.721077	1.374547	0.51	1.547811953
Yields			172 bu/ac	185 bu/ac		
				Total	17.62	
				Crop Need		
					Irrigation	15.80497946
					Total	

APPENDIX B10 – MILLET, FARMER D

			Well 1		
		GPM	750		
		Acres	140		
		Feet per day	0.25568215	**Weekly**	**Avg. Irrigation**
				Crop Need	**For Week**
Date	**ET millet (in.)**	**Precipitation (in.)**		**(ET-p)**	
23-May	0.033887576	0.01			
24-May	0.038130799	0			
25-May	0.031928252	0.14			
SUM	0.103946627	0.15		-0.0460534	
26-May	0.03081489	0			
27-May	0.057112125	0			
28-May	0.052782373	0			
29-May	0.08320696	0			
30-May	0.074857532	0.48			
31-May	0.048915515	0.01			
1-Jun	0.043879719	0.3			
SUM	0.391569114	0.79		-0.3984309	
2-Jun	0.066332737	0.28			
3-Jun	0.050862656	0.04			
4-Jun	0.033642873	0.09			
5-Jun	0.035988508	0.07			
6-Jun	0.062643059	0.49			
7-Jun	0.067029108	0			
8-Jun	0.0809092	0			
SUM	0.397408141	0.97		-0.5725919	
9-Jun	0.095126232	0			
10-Jun	0.088374171	0.75			
11-Jun	0.102733141	0.01			
12-Jun	0.103920609	0.09			
13-Jun	0.074274417	0.02			
14-Jun	0.096332865	0			
15-Jun	0.11829848	0			
SUM	0.679059916	0.87		-0.1909401	

			Well 1		
		GPM	750		
		Acres	140		
		Feet per day	0.25568215	**Weekly**	**Avg. Irrigation**
				Crop Need	**For Week**
Date	**ET millet (in.)**	**Precipitation (in.)**		**(ET-p)**	
23-May	0.033887576	0.01			
24-May	0.038130799	0			
25-May	0.031928252	0.14			
SUM	0.103946627	0.15		-0.0460534	
26-May	0.03081489	0			
27-May	0.057112125	0			
28-May	0.052782373	0			
29-May	0.08320696	0			
30-May	0.074857532	0.48			
31-May	0.048915515	0.01			
1-Jun	0.043879719	0.3			
SUM	0.391569114	0.79		-0.3984309	
2-Jun	0.066332737	0.28			
3-Jun	0.050862656	0.04			
4-Jun	0.033642873	0.09			
5-Jun	0.035988508	0.07			
6-Jun	0.062643059	0.49			
7-Jun	0.067029108	0			
8-Jun	0.0809092	0			
SUM	0.397408141	0.97		-0.5725919	
9-Jun	0.095126232	0			
10-Jun	0.088374171	0.75			
11-Jun	0.102733141	0.01			
12-Jun	0.103920609	0.09			
13-Jun	0.074274417	0.02			
14-Jun	0.096332865	0			
15-Jun	0.11829848	0			
SUM	0.679059916	0.87		-0.1909401	

16-Jun	0.127614259	0.21			
17-Jun	0.097440625	0.22			
18-Jun	0.076892185	0			
19-Jun	0.095081529	0			
20-Jun	0.155568314	0.1			
21-Jun	0.185833175	0			
22-Jun	0.194607153	0			
SUM	0.933037241	0.53		0.40303724	
23-Jun	0.196158308	0			
24-Jun	0.210485136	0			
25-Jun	0.198102237	0			
26-Jun	0.18847645	0			
27-Jun	0.210515184	0			
28-Jun	0.237932463	1.56			
29-Jun	0.140075292	0.06			
SUM	1.38174507	1.62		-0.2382549	
30-Jun	0.218034269	0			
1-Jul	0.279668141	0			
2-Jul	0.254342636	0			
3-Jul	0.286296947	0			
4-Jul	0.304625512	0			
5-Jul	0.307445094	0			
6-Jul	0.367992891	0			
SUM	2.018405489	0	0	2.01840549	0
7-Jul	0.335698687	0			
8-Jul	0.379887316	0			
9-Jul	0.3709188	0			
10-Jul	0.352664575	0			
11-Jul	0.394764028	0			
12-Jul	0.363070672	0.01			
13-Jul	0.384552517	0			
SUM	2.581556594	0.01	0	2.57155659	0
14-Jul	0.434803205	0			
15-Jul	0.469573734	0			

16-Jul	0.436742286	0			
17-Jul	0.441561999	0			
18-Jul	0.462801615	0			
19-Jul	0.339278042	0			
20-Jul	0.344719466	0			
SUM	2.929480348	0	0	2.92948035	0
21-Jul	0.4418224	0			
22-Jul	0.348357965	0			
23-Jul	0.428230388	0			
24-Jul	0.440217848	0			
25-Jul	0.423275514	0			
26-Jul	0.384386126	0			
27-Jul	0.296947663	0			
SUM	2.763237904	0	0	2.7632379	0
28-Jul	0.267594442	0			
29-Jul	0.311295522	0.03			
30-Jul	0.32359888	0.01			
31-Jul	0.39317689	0	0.25568215		
1-Aug	0.373512929	0.01	0.25568215		
2-Aug	0.351462614	0	0.25568215		
3-Aug	0.403851643	0.03	0.25568215		
SUM	2.424492919	0.08	1.02272862	2.34449292	1.022728618
4-Aug	0.311363894	0.05	0.25568215		
5-Aug	0.372273116	0	0.25568215		
6-Aug	0.439875979	0.01	0.25568215		
7-Aug	0.432341057	0.07	0.25568215		
8-Aug	0.240607726	0.01	0.25568215		
9-Aug	0.349069758	0	0.25568215		
10-Aug	0.38254176	0	0.25568215		
SUM	2.528073291	0.14	1.78977508	2.38807329	1.789775081
11-Aug	0.351529671	0	0.25568215		
12-Aug	0.387211706	0	0.25568215		
13-Aug	0.417434413	0	0.25568215		
14-Aug	0.417008496	0	0.25568215		

15-Aug	0.424999969	0	0.25568215		
16-Aug	0.438363342	0	0.25568215		
17-Aug	0.299257261	0	0.25568215		
SUM	2.735804858	0	1.78977508	2.73580486	1.789775081
18-Aug	0.317598506	1.17	0.25568215		
19-Aug	0.252276917	0	0.25568215		
20-Aug	0.3147822	0	0.25568215		
21-Aug	0.319983599	0	0.25568215		
22-Aug	0.382948458	0	0.25568215		
23-Aug	0.429078397	0	0.25568215		
24-Aug	0.306171354	0	0.25568215		
SUM	2.32283943	1.17	1.78977508	1.15283943	1.789775081
25-Aug	0.243771598	0	0.25568215		
26-Aug	0.277966483	0	0.25568215		
27-Aug	0.273490736	0.16	0.25568215		
28-Aug	0.169453211	0.03	0.25568215		
29-Aug	0.211938775	0	0.25568215		
30-Aug	0.17115428	0.2	0.25568215		
31-Aug	0.137899521	0	0.25568215		
SUM	1.485674604	0.39	1.78977508	1.0956746	1.789775081
1-Sep	0.200007058	0	0.25568215		
2-Sep	0.219371937	0	0.25568215		
3-Sep	0.099002237	0.01	0.25568215		
4-Sep	0.208864579	0	0.25568215		
5-Sep	0.232483465	0	0.25568215		
6-Sep	0.198357446	0	0.25568215		
7-Sep	0.091214438	0.51	0.25568215		
SUM	1.249301159	0.52	1.78977508	0.72930116	1.789775081
8-Sep	0.163448052	0	0.25568215		
9-Sep	0.1245335	0	0.25568215		
10-Sep	0.217714721	0	0.25568215		
11-Sep	0.172379878	0	0.25568215		
12-Sep	0.221752282	0	0.25568215		
13-Sep	0.100208832	0	0.25568215		

14-Sep	0.129672185	0	0.25568215		
SUM	1.129709451	0	1.78977508	1.12970945	1.789775081
15-Sep	0.159395582	0	0.25568215		
16-Sep	0.160714676	0	0.25568215		
17-Sep	0.252020971	0			
18-Sep	0.146531604	0			
19-Sep	0.12542856	0			
20-Sep	0.11888965	0			
21-Sep	0.112031656	0			
SUM	1.075012699	0	0.51136431	1.0750127	0.511364309
22-Sep	0.107869027	0			
23-Sep	0.117720344	0			
24-Sep	0.113774455	0			
		0			
Yield			1.8 tons/ac		
			Total		
			Crop Need	12.6509084	
				Irrigation	12.27274341
				Total	

APPENDIX C1 – GAGE HEIGHTS 2003

	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6
3/30/2003		480			390	540
4/10/2003		480		350	395	565
4/24/2003		460		330	410	580
5/29/2003	495	410		310	390	535
6/6/2003		395		360	430	500
6/11/2003		435		380	450	500
6/20/2003	450	430		317.5	385	475
6/25/2003	440	335		255	320	450
7/3/2003	440	300	175	175	220	410
7/10/2003	440	300	155	80	120	385
7/24/2003	435	0	0	0	0	300
8/4/2003	440	0	0	0	0	270
8/21/2003	450	0	0	0	0	185
9/20/2003	460	0	0	0	0	160
10/18/2003	470	75	0	0	0	545
11/8/2003	480	380	90	0	0	565
12/19/2003	500	510	200	255	320	580
1/16/2004	500	500	240	320	390	570
2/13/2004	400	485	485	330	455	575

All depths in millimeters.

APPENDIX C2 – GAGE HEIGHTS 2002

	East Ranch (~Gage 6)	U-Road (~Gage 2)	West Ranch (~Gage 1)
6/5/2002	152.4	800.1	304.8
6/7/2002	101.6	736.6	304.8
6/10/2002	76.2	736.6	304.8
6/12/2002	50.8	711.2	304.8
6/14/2002	50.8	711.2	304.8
6/17/2002	25.4	711.2	304.8
6/19/2002	25.4	711.2	304.8
6/21/2002	25.4	609.6	304.8
6/24/2002	0	457.2	292.1
6/27/2002	0	317.5	292.1
6/28/2002	0	254	292.1
7/1/2002	0	152.4	292.1
7/3/2002	0	101.6	292.1
7/5/2002	0	50.8	292.1
7/8/2002	0	0	292.1
7/10/2002	0	0	292.1
7/12/2002	0	0	292.1
7/15/2002	0	0	292.1
7/17/2002	0	0	279.4
7/19/2002	0	0	279.4
7/22/2002	0	0	279.4
7/24/2002	0	0	279.4
7/26/2002	0	0	279.4
7/29/2002	0	0	279.4
7/31/2002	0	0	279.4
8/2/2002	0	0	279.4
8/5/2002	0	0	279.4
8/7/2002	0	0	279.4
8/9/2002	0	0	279.4
8/12/2002	0	0	279.4
8/14/2002	0	0	304.8
8/16/2002	0	0	304.8
8/29/2002	0	0	355.6
9/12/2002	63.5	0	355.6
9/18/2002	203.2	0	355.6
9/26/2002	279.4	25.4	355.6
10/4/2002	279.4	25.4	355.6
10/13/2002	152.4	0	355.6
10/21/2002	228.6	228.6	355.6
11/07/02	304.8	736.6	368.3

All depths in millimeters.

APPENDIX D – MONITORING WELL DATA

	Well A	Well B	Well C	Well D	Well E	Well F
8/21/2003	-17.5			-14.5		
9/20/2003	-17		-12	-17.5	-25.5	
10/18/2003	-9.5	-43.5	-4	-13	-18.5	
11/8/2003	6.5	-29.5	3	-8.5	-13.5	
12/19/2003	11.75	-25.5	8	9.5	7.5	
1/16/2004	11.5	-25	10	11.5	4	-45
2/13/2004	11	-24	10.5	12.5	6	-42.5

All depths in inches.

Negative values correspond to depths below the surface.
Positive values correspond to depths above the surface (in the streambed).

All depths are relative to the ground elevation of individual wells.

Ground elevation of Well A is 35.28 inches below ground elevation of Well B.
Ground elevation of Well D is 48.24 inches below ground elevation of Well F.
Ground elevation of Well E is 52.92 inches below ground elevation of Well F.

APPENDIX E – STREAMBED HYDRAULIC CONDUCTIVITY DATA

Gage 1

	Date														
	7/10/03	**7/10/03**	**7/10/03**	**7/10/03**	**7/10/03**	**10/18/03**	**10/18/03**	**10/18/03**	**10/18/03**	**10/18/03**	**10/18/03**	**10/18/03**	**10/18/03**	**10/18/03**	**10/18/03**
L (m)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
t2-t1 (min.)	52	52.75	53	54	55	25	25.25	26	26.25	26.75	18.25	18.5	18.75	19	19.25
t2-t1 (day)	0.03611111	0.03663194	0.03680556	0.0375	0.03819444	0.01736111	0.01753472	0.01805556	0.01822917	0.01857639	0.01267361	0.01284722	0.01302083	0.01319444	0.01336806
H0 (m)	0.275	0.25	0.19	0.09	0.21	0.025	0.02	0.04	0.25	0.125	0.025	0.02	0.04	0.25	0.125
H1 (m)	0.26	0.244	0.155	0.088	0.195	0.025	0.015	0.04	0.242	0.105	0.025	0.02	0.04	0.242	0.105
Kv (m/day)	0.38831169	0.16578899	1.3829363	0.14981904	0.48507036	0	4.10160579	0	0.44603234	2.34643811	0	0	0	0.6162289	3.26063477

Gage 2

	Date													
	6/6/03	**6/11/03**	**6/11/03**	**6/11/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**
L (m)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
t2-t1 (min.)	40	38	39	40	16.5	17	17.5	18	18.5	15	15.5	15.5	16	16
t2-t1 (day)	0.02777778	0.02638889	0.02708333	0.02777778	0.01145833	0.01180556	0.01215278	0.0125	0.01284722	0.01041667	0.01076389	0.01076389	0.01111111	0.01111111
H0 (m)	0.217	0.203	0.92	0.145	0.08	0.225	0.265	0.1	0.15	0.08	0.225	0.265	0.1	0.15
H1 (m)	0.208	0.194	0.92	0.138	0.03	0.195	0.248	0.09	0.15	0.035	0.195	0.248	0.094	0.15
Kv (m/day)	0.38123346	0.42961093	0	0.44532052	21.399911	3.03037081	1.36390793	2.10721031	0	19.8402858	3.3236325	1.53989605	1.39219658	0

Gage 3

	Date											
	7/3/03	**7/3/03**	**7/3/03**	**7/3/03**	**7/3/03**	**1/16/04**	**1/16/04**	**1/16/04**	**1/16/04**	**1/16/04**	**1/16/04**	**1/16/04**
L (m)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
t2-t1 (min.)	19.5	20	20	20.5	20.75	20	20.5	21	21	21.5	21.75	21
t2-t1 (day)	0.01354167	0.01388889	0.01388889	0.01423611	0.01440972	0.01388889	0.01423611	0.01458333	0.01458333	0.01493056	0.01510417	0.01458333
H0 (m)	0.275	0.165	0.25	0.165	0.27	0.11	0.155	0.04	0.11	0.16	0.14	0.11
H1 (m)	0.26	0.145	0.241	0.165	0.26	0.103	0.155	0.04	0.104	0.16	0.085	0.11
Kv (m/day)	1.03549785	2.32581117	0.65995172	0	0.65477196	1.1835248	0	0	0.96153371	0	8.25916413	0
	Date											
	1/16/04	**1/16/04**	**1/16/04**									
L (m)	0.25	0.25	0.25									
t2-t1 (min.)	21.5	21.5	21.5									
t2-t1 (day)	0.01493056	0.01493056	0.01493056									
H0 (m)	0.04	0.14	0.14									
H1 (m)	0.04	0.088	0.14									
Kv (m/day)	0	7.77441948	0									

Gage 4

	Date											
	4/24/03	**4/24/03**	**7/3/03**	**7/3/03**	**7/3/03**	**7/3/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**
L (m)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
t2-t1 (min.)	30	26.5	16.5	20	30	30	19.5	20	21	22	27	28
t2-t1 (day)	0.02083333	0.01840278	0.01145833	0.01388889	0.02083333	0.02083333	0.01354167	0.01388889	0.01458333	0.01527778	0.01875	0.01944444
H0 (m)	0.282	0.282	0.035	0.035	0.215	0	0.125	0.055	0.11	0.04	0.155	0.055
H1 (m)	0.256	0.256	0.01	0.025	0.205	0	0.125	0.045	0.11	0.04	0.155	0.035
Kv (m/day)	1.16075552	1.31406285	27.3330102	6.05650026	0.57153659	0	0	3.61207252	0	0	0	5.81123731
	Date											
	12/19/03	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**	**12/19/03**						
L (m)	0.25	0.25	0.25	0.25	0.25	0.25						
t2-t1 (min.)	28.5	29	20	21.5	22	23						
t2-t1 (day)	0.01979167	0.02013889	0.01388889	0.01493056	0.01527778	0.01597222						
H0 (m)	0.11	0.04	0.155	0.055	0.11	0.04						
H1 (m)	0.109	0.034	0.155	0.045	0.11	0.04						
Kv (m/day)	0.11535769	2.01747637	0	3.36006746	0	0						

Gage 6

	Date											
	6/20/03	**6/20/03**	**6/20/03**	**6/20/03**	**6/20/03**	**6/20/03**	**6/20/03**	**6/20/03**	**7/3/03**	**7/3/03**	**7/3/03**	**7/3/03**
L (m)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
t2-t1 (min.)	20.75	21.25	21.75	22.25	22	21.75	21.166	20.5	10.5	11	11.5	14.25
t2-t1 (day)	0.01440972	0.01475694	0.01510417	0.01545139	0.01527778	0.01510417	0.01469861	0.01423611	0.00729167	0.00763889	0.00798611	0.00989583
H0 (m)	0.065	0.17	0.195	0.085	0.065	0.17	0.195	0.085	0.212	0.085	0.145	0.212
H1 (m)	0.035	0.145	0.187	0.03	0.03	0.15	0.191	0.033	0.18	0.055	0.13	0.162
Kv (m/day)	10.7399574	2.69474306	0.69336731	16.8504897	12.6521982	2.07166581	0.35251852	16.6152064	5.61015167	14.2467732	3.41841262	6.79553531
	Date											
	7/3/03	**7/3/03**										
L (m)	0.25	0.25										
t2-t1 (min.)	15.1666	15.5										
t2-t1 (day)	0.01053236	0.01076389										
H0 (m)	0.085	0.145										
H1 (m)	0.04	0.12										
Kv (m/day)	17.8918049	4.39529806										

APPENDIX F – STREAM-DEPLETION FACTOR TEST DATA

SDF Analysis on Eastern Boundary using Full Design Capacities

Transmissivity (gpd/ft)	200000
Transmissivity (ft^2/day)	26736
Specific Yield	0.15

T/S	178240

Township	Section	Well	Well	Distance from	Tp (days)	sdf (days)	Tp/sdf	q/Q	q (gpd)	q (cfs)
		(gpm)	(gpd)	River, a (ft)						
3S-44	19	718	1033920	22607	64	2867.34992	0.02232026	0.00073	754.7616	0.001162333
	35	1250	1800000	42595	64	10179.1631	0.00628735	0.00025	450	0.000693
	36	500	720000	47162	64	12478.9848	0.00512862	0.00022	158.4	0.000243936
4S-44	3	950	1368000	38770	64	8433.08404	0.00758916	0.0003	410.4	0.000632016
	3	1350	1944000	34847	64	6812.79965	0.00939408	0.00035	680.4	0.001047816
	4	1000	1440000	32547	64	5943.15086	0.0107687	0.0004	576	0.00088704
	4	1200	1728000	30109	64	5086.13039	0.01258324	0.00041	708.48	0.001091059
	5	1812	2609280	29359	64	4835.90036	0.01323435	0.00042	1095.8976	0.001687682
	7	1700	2448000	22440	64	2825.14363	0.02265372	0.00075	1836	0.00282744
	8	1500	2160000	28628	64	4598.08339	0.01391884	0.00042	907.2	0.001397088
	10	1250	1800000	37230	64	7776.44132	0.00822999	0.00032	576	0.00088704
	10	1250	1800000	38652	64	8381.82846	0.00763557	0.00032	576	0.00088704
	10	1500	2160000	40838	64	9356.72264	0.00684	0.0003	648	0.00099792
	24	1500	2160000	49310	64	13641.5849	0.00469154	0.0002	432	0.00066528
	14	1400	2016000	43250	64	10494.628	0.00609836	0.0003	604.8	0.000931392
	16	2000	2880000	34987	64	6867.65131	0.00931905	0.00038	1094.4	0.001685376
	17	1400	2016000	30737	64	5300.5115	0.01207431	0.00041	826.56	0.001272902
	18	1200	1728000	24400	64	3340.21544	0.01916044	0.0007	1209.6	0.001862784
	24	1092	1572480	53477	64	16044.6001	0.00398888	0.00015	235.872	0.000363243
	25	1200	1728000	53284	64	15928.9983	0.00401783	0.00015	259.2	0.000399168
	25	800	1152000	52537	64	15485.5048	0.0041329	0.00015	172.8	0.000266112
	25	600	864000	53760	64	16214.8654	0.003947	0.00015	129.6	0.000199584
	35	1198	1725120	49700	64	13858.2249	0.0046182	0.00016	276.0192	0.00042507
	27	1250	1800000	44829	64	11274.906	0.00567632	0.00025	450	0.000693

	27	950	1368000	42431	64	10100.93	0.00633605	0.00027	369.36	0.000568814
	28	1250	1800000	39524	64	8764.28734	0.00730236	0.00031	558	0.00085932
	28	800	1152000	39926	64	8943.47776	0.00715605	0.00031	357.12	0.000549965
	31	1980	2851200	38116	64	8150.97316	0.00785182	0.00034	969.408	0.001492888
	31	1000	1440000	38700	64	8402.65934	0.00761664	0.00033	475.2	0.000731808
	34	1850	2664000	47792	64	12814.6054	0.0049943	0.00021	559.44	0.000861538
	36	1200	1728000	56394	64	17842.7022	0.0035869	0.00017	293.76	0.00045239
			0							
3S-45	33	130	187200	2389	64	32.0204275	1.99872409	0.617	115502.4	*(Not Operating -*
	33	130	187200	2389	64	32.0204275	1.99872409	0.617	115502.4	*on TNC Property)*
			0							
4S-45	11	1200	1728000	15119	64	1282.45153	0.04990442	0.003	5184	0.00798336
	14	1750	2520000	18388	64	1896.98465	0.03373775	0.0015	3780	0.0058212
	15	1700	2448000	16612	64	1548.24138	0.04133722	0.002	4896	0.00753984
	21	1000	1440000	19155	64	2058.53919	0.03109001	0.0015	2160	0.0033264
	21	1400	2016000	21221	64	2526.54197	0.02533107	0.0025	5040	0.0077616
	21	1600	2304000	23926	64	3211.70038	0.01992714	0.0007	1612.8	0.002483712
	21	1600	2304000	22722	64	2896.59607	0.0220949	0.0007	1612.8	0.002483712
	23	1400	2016000	24371	64	3332.2803	0.01920607	0.0007	1411.2	0.002173248
	23	1400	2016000	26833	64	4039.55279	0.01584334	0.00055	1108.8	0.001707552
	24	1000	1440000	27363	64	4200.70562	0.01523554	0.00055	792	0.00121968
	25	1350	1944000	31797	64	5672.40355	0.0112827	0.00038	738.72	0.001137629
	35	1000	1440000	30030	64	5059.47543	0.01264953	0.00038	547.2	0.000842688
	27	1600	2304000	25456	64	3635.5921	0.01760374	0.0006	1382.4	0.002128896
	33	1800	2592000	29287	64	4812.21033	0.0132995	0.00045	1166.4	0.001796256
	31	1000	1440000	35588	64	7105.6202	0.00900695	0.0004	576	0.00088704
	31	1000	1440000	32216	64	5822.88294	0.01099112	0.0004	576	0.00088704
	31	1000	1440000	34418	64	6646.08799	0.00962973	0.00039	561.6	0.000864864
	32	1000	1440000	31713	64	5642.4729	0.01134254	0.00041	590.4	0.000909216
	32	1300	1872000	31061	64	5412.84628	0.01182372	0.00041	767.52	0.001181981
	36	1000	1440000	34960	64	6857.05566	0.00933345	0.00038	547.2	0.000842688
3S-46	12	600	864000	26666	64	3989.42749	0.0160424	0.00055	475.2	0.000731808

4S-46	8	1000	1440000	38936	64	8505.45386	0.00752458	0.00025	360	0.0005544
	10	1000	1440000	29085	64	4746.05714	0.01348488	0.00041	590.4	0.000909216
	11	1200	1728000	26080	64	3816.01436	0.01677143	0.00055	950.4	0.001463616
	11	1200	1728000	23732	64	3159.82846	0.02025426	0.0007	1209.6	0.001862784
	12	1200	1728000	19187	64	2065.42285	0.03098639	0.0015	2592	0.00399168
	12	1200	1728000	21949	64	2702.86468	0.02367858	0.0009	1555.2	0.002395008
	14	1100	1584000	27838	64	4347.81331	0.01472004	0.00055	871.2	0.001341648
	17	1200	1728000	42912	64	10331.2373	0.0061948	0.00025	432	0.00066528
	17	1000	1440000	42336	64	10055.7501	0.00636452	0.00025	360	0.0005544
	18	1600	2304000	46200	64	11975.0898	0.00534443	0.00022	506.88	0.000780595
	18	1000	1440000	47228	64	12513.9362	0.0051143	0.00022	316.8	0.000487872
	18	1200	1728000	45513	64	11621.5954	0.00550699	0.00023	397.44	0.000612058
	19	1000	1440000	45738	64	11736.7855	0.00545294	0.00023	331.2	0.000510048
	22	1000	1440000	32613	64	5967.27878	0.01072516	0.0004	576	0.00088704
	23	1200	1728000	33229	64	6194.82967	0.0103312	0.0004	691.2	0.001064448
	23	1500	2160000	31346	64	5512.63306	0.0116097	0.00041	885.6	0.001363824
	24	600	864000	29529	64	4892.06598	0.01308241	0.0005	432	0.00066528
	24	1600	2304000	25967	64	3783.01778	0.01691771	0.00055	1267.2	0.001951488
	24	1600	2304000	26947	64	4073.94978	0.01570957	0.00054	1244.16	0.001916006
	26	1500	2160000	33592	64	6330.91598	0.01010912	0.0004	864	0.00133056
	26	2200	3168000	35428	64	7041.87154	0.00908849	0.00038	1203.84	0.001853914
	27	1000	1440000	38175	64	8176.22658	0.00782757	0.00032	460.8	0.000709632
	28	1000	1440000	40933	64	9400.30571	0.00680829	0.00028	403.2	0.000620928
	28	1000	1440000	42264	64	10021.5759	0.00638622	0.00026	374.4	0.000576576
	29	1000	1440000	44352	64	11036.2427	0.00579908	0.00024	345.6	0.000532224
	29	1000	1440000	45988	64	11865.4407	0.00539382	0.00022	316.8	0.000487872
	30	1000	1440000	49203	64	13582.4462	0.00471196	0.0002	288	0.00044352
	31	2500	3600000	54050	64	16390.2743	0.00390475	0.00015	540	0.0008316
	33	1100	1584000	45350	64	11538.5015	0.00554665	0.00025	396	0.00060984
			0							
3S-47	4	1600	2304000		64	0	0		0	0
	5	1000	1440000		64	0	0		0	0
	5	1000	1440000		64	0	0		0	0

4S-47	12	300	432000	50456	64	14283.0338	0.00448084	0.0002	86.4	0.000133056	
	13	1200	1728000	49329	64	13652.0996	0.00468792	0.0002	345.6	0.000532224	
	13	1000	1440000	49573	64	13787.4906	0.00464189	0.0002	288	0.00044352	
	14	1000	1440000	55030	64	16990.0185	0.00376692	0.00017	244.8	0.000376992	
	15	1000	1440000	59875	64	20113.418	0.00318196	0.00013	187.2	0.000288288	
	17	650	936000		64	0	0		0	0	
	18	700	1008000		64	0	0		0	0	
	18	600	864000		64	0	0		0	0	
	19	550	792000		64	0	0		0	0	
	20	1000	1440000		64	0	0		0	0	
	23	1000	1440000	58000	64	18873.4291	0.00339101	0.00014	201.6	0.000310464	
	24	1000	1440000	53650	64	16148.5778	0.0039632	0.00017	244.8	0.000376992	
	25	1150	1656000	54445	64	16630.7115	0.0038483	0.00016	264.96	0.000408038	
	26	1200	1728000	58157	64	18975.7442	0.00337273	0.00014	241.92	0.000372557	
	26	1000	1440000		64	0	0		0	0	
	26	1000	1440000		64	0	0		0	0	
	27	1650	2376000		64	0	0		0	0	
	29	1200	1728000		64	0	0		0	0	
	30	1300	1872000		64	0	0		0	0	
	30	1600	2304000		64	0	0		0	0	
	31	1500	2160000		64	0	0		0	0	
	31	1500	2160000		64	0	0		0	0	
	34	1200	1728000		64	0	0		0	0	
	36	1200	1728000	55742	64	17432.5099	0.0036713	0.00015	259.2	0.000399168	
Total Stream Depletion by All Wells On Last Day of Irrigation										0.11904711	**cfs**
Baseflow in Winter (as recorded by USGS gaging site)										5.5	**cfs**
Percent Depletion on Last Day of Irrigation										2.164492915	**%**

SDF Analysis at U-Road using Full Design Capacities

Transmissivity (gpd/ft)	200000
Transmissivity (ft^2/day)	26736
Specific Yield	0.15

T/S	178240

Township	Section	Well (gpm)	Well (gpd)	Distance from River, a (ft)	Tp (days)	sdf (days)	Tp/sdf	q/Q	q (gpd)	q (cfs)
3S-44	19	718	1033920	33892	64	6444.49991	0.00993095	0.00073	754.7616	0.001162333
	35	1250	1800000		64	0	0	0	0	0
	36	500	720000		64	0	0	0	0	0
4S-44	3	950	1368000	53077	64	15805.4754	0.00404923	0.00017	232.56	0.000358142
	3	1350	1944000	48984	64	13461.8057	0.00475419	0.0002	388.8	0.000598752
	4	1000	1440000	45930	64	11835.5302	0.00540745	0.00025	360	0.0005544
	4	1200	1728000	44195	64	10958.2474	0.00584035	0.00027	466.56	0.000718502
	5	1812	2609280	42690	64	10224.6191	0.0062594	0.00028	730.5984	0.001125122
	7	1700	2448000	35719	64	7158.02828	0.00894101	0.00037	905.76	0.00139487
	8	1500	2160000	42058	64	9924.12121	0.00644893	0.00027	583.2	0.000898128
	10	1250	1800000	50585	64	14356.1615	0.00445802	0.0002	360	0.0005544
	10	1250	1800000	52189	64	15281.0352	0.0041882	0.00018	324	0.00049896
	10	1500	2160000	54309	64	16547.7305	0.0038676	0.00017	367.2	0.000565488
	24	1500	2160000		64	0	0	0	0	0
	14	1400	2016000		64	0	0	0	0	0
	16	2000	2880000	48609	64	13256.4794	0.00482783	0.00021	604.8	0.000931392
	17	1400	2016000	44063	64	10892.8858	0.00587539	0.00025	504	0.00077616
	18	1200	1728000	38075	64	8133.44718	0.00786874	0.00031	535.68	0.000824947
	24	1092	1572480		64	0	0	0	0	0
	25	1200	1728000		64	0	0	0	0	0
	25	800	1152000		64	0	0	0	0	0
	25	600	864000		64	0	0	0	0	0
	35	1198	1725120		64	0	0	0	0	0
	27	1250	1800000	58048	64	18904.6808	0.0033854	0.00012	216	0.00033264

	27	950	1368000	55408	64	17224.2284	0.0037157	0.00017	232.56	0.000358142
	28	1250	1800000	53083	64	15809.049	0.00404831	0.00017	306	0.00047124
	28	800	1152000	52924	64	15714.4848	0.00407268	0.00017	195.84	0.000301594
	31	1980	2851200	48938	64	13436.5341	0.00476313	0.00021	598.752	0.000922078
	31	1000	1440000	50272	64	14179.0506	0.0045137	0.0002	288	0.00044352
	34	1850	2664000		64	0	0	0	0	0
	36	1200	1728000		64	0	0	0	0	0
			0							
3S-45	33	130	187200	11811	64	782.651038	0.08177335	0.009	1684.8	(Not running -
	33	130	187200	11811	64	782.651038	0.08177335	0.009	1684.8	confirmed by TNC)
			0							
4S-45	11	1200	1728000	27784	64	4330.96194	0.01477732	0.0005	864	0.00133056
	14	1750	2520000	29233	64	4794.48098	0.01334868	0.00048	1209.6	0.001862784
	15	1700	2448000	26873	64	4051.6053	0.01579621	0.00058	1419.84	0.002186554
	21	1000	1440000	25763	64	3723.81154	0.01718669	0.0006	864	0.00133056
	21	1400	2016000	28357	64	4511.44215	0.01418615	0.00052	1048.32	0.001614413
	21	1600	2304000	29989	64	5045.66944	0.01268414	0.00042	967.68	0.001490227
	21	1600	2304000	27582	64	4268.21546	0.01499456	0.00052	1198.08	0.001845043
	23	1400	2016000	35112	64	6916.81185	0.00925282	0.00036	725.76	0.00111767
	23	1400	2016000	37484	64	7882.91212	0.00811883	0.00031	624.96	0.000962438
	24	1000	1440000	38907	64	8492.78865	0.00753581	0.00028	403.2	0.000620928
	25	1350	1944000	42500	64	10133.8083	0.00631549	0.00027	524.88	0.000808315
	35	1000	1440000	38666	64	8387.90146	0.00763004	0.00028	403.2	0.000620928
	27	1600	2304000	33266	64	6208.63306	0.01030823	0.0004	921.6	0.001419264
	33	1800	2592000	34919	64	6840.9816	0.00935538	0.00037	959.04	0.001476922
	31	1000	1440000	36020	64	7279.17639	0.0087922	0.00035	504	0.00077616
	31	1000	1440000	33686	64	6366.39697	0.01005278	0.0004	576	0.00088704
	31	1000	1440000	36345	64	7411.12559	0.00863567	0.00037	532.8	0.000820512
	32	1000	1440000	34585	64	6710.73959	0.00953695	0.00038	547.2	0.000842688
	32	1300	1872000	34834	64	6807.71744	0.0094011	0.00038	711.36	0.001095494
	36	1000	1440000	46239	64	11995.316	0.00533542	0.00024	345.6	0.000532224
3S-46	12	600	864000	17001	64	1621.6001	0.03946719	0.00019	164.16	0.000252806

4S-46	8	1000	1440000	27201	64	4151.11311	0.01541755	0.00051	734.4	0.001130976
	10	1000	1440000	19292	64	2088.09057	0.03065001	0.0015	2160	0.0033264
	11	1200	1728000	17719	64	1761.46185	0.03633346	0.0016	2764.8	0.004257792
	11	1200	1728000	16252	64	1481.86436	0.04318884	0.002	3456	0.00532224
	12	1200	1728000	14912	64	1247.57487	0.05129953	0.006	10368	0.01596672
	12	1200	1728000	15549	64	1356.43739	0.04718242	0.0055	9504	0.01463616
	14	1100	1584000	20375	64	2329.11033	0.0274783	0.001	1584	0.00243936
	17	1200	1728000	31873	64	5699.55189	0.01122895	0.0004	691.2	0.001064448
	17	1000	1440000	30811	64	5326.06441	0.01201638	0.00041	590.4	0.000909216
	18	1600	2304000	34149	64	6542.6066	0.00978203	0.0004	921.6	0.001419264
	18	1000	1440000	35882	64	7223.5072	0.00885996	0.00035	504	0.00077616
	18	1200	1728000	34047	64	6503.58062	0.00984073	0.0004	691.2	0.001064448
	19	1000	1440000	34813	64	6799.51172	0.00941244	0.00038	547.2	0.000842688
	22	1000	1440000	25550	64	3662.49158	0.01747444	0.00058	835.2	0.001286208
	23	1200	1728000	27200	64	4150.8079	0.01541869	0.00056	967.68	0.001490227
	23	1500	2160000	26262	64	3869.46053	0.01653977	0.00057	1231.2	0.001896048
	24	600	864000	25806	64	3736.25245	0.01712946	0.00058	501.12	0.000771725
	24	1600	2304000	22877	64	2936.2496	0.02179651	0.0007	1612.8	0.002483712
	24	1600	2304000	24619	64	3400.44413	0.01882107	0.0006	1382.4	0.002128896
	26	1500	2160000	29467	64	4871.54448	0.01313752	0.00045	972	0.00149688
	26	2200	3168000	30373	64	5175.71325	0.01236545	0.00044	1393.92	0.002146637
	27	1000	1440000	31304	64	5497.87038	0.01164087	0.0004	576	0.00088704
	28	1000	1440000	32957	64	6093.8277	0.01050243	0.0004	576	0.00088704
	28	1000	1440000	34218	64	6569.07273	0.00974262	0.00039	561.6	0.000864864
	29	1000	1440000	36113	64	7316.81311	0.00874698	0.00037	532.8	0.000820512
	29	1000	1440000	37658	64	7956.26663	0.00804397	0.00032	460.8	0.000709632
	30	1000	1440000	39504	64	8755.41975	0.00730976	0.0003	432	0.00066528
	31	2500	3600000	45986	64	11864.4086	0.00539428	0.00024	864	0.00133056
	33	1100	1584000	39558	64	8779.37255	0.00728981	0.00031	491.04	0.000756202
3S-47	4	1600	2304000	53494	64	16054.8027	0.00398635	0.00017	391.68	0.000603187
	5	1000	1440000	58517	64	19211.3964	0.00333136	0.00015	216	0.00033264
	5	1000	1440000	58517	64	19211.3964	0.00333136	0.00015	216	0.00033264

4S-47	12	300	432000	37720	64	7982.48654	0.00801755	0.00032	138.24	0.00021289	
	13	1200	1728000	37710	64	7978.2546	0.0080218	0.00032	552.96	0.000851558	
	13	1000	1440000	38484	64	8309.12397	0.00770238	0.00031	446.4	0.000687456	
	14	1000	1440000	42518	64	10142.3941	0.00631015	0.00028	403.2	0.000620928	
	15	1000	1440000	47855	64	12848.4124	0.00498116	0.00021	302.4	0.000465696	
	17	650	936000	59864	64	20106.0284	0.00318312	0.00015	140.4	0.000216216	
	18	700	1008000		64	0	0	0	0	0	
	18	600	864000		64	0	0	0	0	0	
	19	550	792000		64	0	0	0	0	0	
	20	1000	1440000		64	0	0	0	0	0	
	23	1000	1440000	46662	64	12215.7891	0.00523912	0.00014	201.6	0.000310464	
	24	1000	1440000	42786	64	10270.6564	0.00623134	0.00017	244.8	0.000376992	
	25	1150	1656000	45035	64	11378.7658	0.00562451	0.00016	264.96	0.000408038	
	26	1200	1728000	47449	64	12631.3263	0.00506677	0.00014	241.92	0.000372557	
	26	1000	1440000	51088	64	14643.0865	0.00437066	0.00019	273.6	0.000421344	
	26	1000	1440000	49493	64	13743.0265	0.00465691	0.0002	288	0.00044352	
	27	1650	2376000	53114	64	15827.5191	0.00404359	0.00018	427.68	0.000658627	
	29	1200	1728000		64	0	0	0	0	0	
	30	1300	1872000		64	0	0	0	0	0	
	30	1600	2304000		64	0	0	0	0	0	
	31	1500	2160000		64	0	0	0	0	0	
	31	1500	2160000		64	0	0	0	0	0	
	34	1200	1728000	55467	64	17260.9296	0.0037078	0.00017	293.76	0.00045239	
	36	1200	1728000	46913	64	12347.5627	0.00518321	0.00015	259.2	0.000399168	
Total Stream Depletion by All Wells On Last Day of Irrigation										0.119627988	**cfs**
Baseflow in Winter (as measured in March 2003 and January 2004)										1.34	**cfs**
Percent Depletion on Last Day of Irrigation										8.927461827	**%**

SDF Analysis on Western Boundary using Full Design Capacities

Transmissivity (gpd/ft)	200000
Transmissivity (ft^2/day)	26736
Specific Yield	0.15

T/S	178240

Township	Section	Well (gpm)	Well (gpd)	Distance from River, a (ft)	Tp (days)	sdf (days)	Tp/sdf	q/Q	q (gpd)	q (cfs)
3S-44	19	718	1033920		64	0	0	0	0	0
	35	1250	1800000		64	0	0	0	0	0
	36	500	720000		64	0	0	0	0	0
4S-44	3	950	1368000		64	0	0	0	0	0
	3	1350	1944000		64	0	0	0	0	0
	4	1000	1440000		64	0	0	0	0	0
	4	1200	1728000		64	0	0	0	0	0
	5	1812	2609280		64	0	0	0	0	0
	7	1700	2448000		64	0	0	0	0	0
	8	1500	2160000		64	0	0	0	0	0
	10	1250	1800000		64	0	0	0	0	0
	10	1250	1800000		64	0	0	0	0	0
	10	1500	2160000		64	0	0	0	0	0
	24	1500	2160000		64	0	0	0	0	0
	14	1400	2016000		64	0	0	0	0	0
	16	2000	2880000		64	0	0	0	0	0
	17	1400	2016000		64	0	0	0	0	0
	18	1200	1728000		64	0	0	0	0	0
	24	1092	1572480		64	0	0	0	0	0
	25	1200	1728000		64	0	0	0	0	0
	25	800	1152000		64	0	0	0	0	0
	25	600	864000		64	0	0	0	0	0
	35	1198	1725120		64	0	0	0	0	0
	27	1250	1800000		64	0	0	0	0	0

	27	950	1368000		64	0	0	0	0	0
	28	1250	1800000		64	0	0	0	0	0
	28	800	1152000		64	0	0	0	0	0
	31	1980	2851200		64	0	0	0	0	0
	31	1000	1440000		64	0	0	0	0	0
	34	1850	2664000		64	0	0	0	0	0
	36	1200	1728000		64	0	0	0	0	0
			0							
3S-45	33	130	187200	37652	64	7953.73151	0.00804654	0.00034	63.648	*(Not Operating -*
	33	130	187200	37652	64	7953.73151	0.00804654	0.00034	63.648	*on TNC Property)*
			0							
4S-45	11	1200	1728000	49948	64	13996.8733	0.00457245	0.0002	345.6	0.000532224
	14	1750	2520000	49903	64	13971.6641	0.0045807	0.0002	504	0.00077616
	15	1700	2448000	46930	64	12356.5131	0.00517945	0.00022	538.56	0.000829382
	21	1000	1440000	42495	64	10131.4241	0.00631698	0.00027	388.8	0.000598752
	21	1400	2016000	44332	64	11026.2917	0.00580431	0.00025	504	0.00077616
	21	1600	2304000	44581	64	11150.5025	0.00573965	0.00024	552.96	0.000851558
	21	1600	2304000	41611	64	9714.29152	0.00658823	0.00028	645.12	0.000993485
	23	1400	2016000	54432	64	16622.7706	0.00385014	0.00017	342.72	0.000527789
	23	1400	2016000	56509	64	17915.5469	0.00357232	0.00016	322.56	0.000496742
	24	1000	1440000	59345	64	19758.9151	0.00323904	0.00015	216	0.00033264
	25	1350	1944000		64			0	0	0
	35	1000	1440000	54795	64	16845.2201	0.0037993	0.00016	230.4	0.000354816
	27	1600	2304000	49211	64	13586.8633	0.00471043	0.0002	460.8	0.000709632
	33	1800	2592000	47727	64	12779.7718	0.00500791	0.00021	544.32	0.000838253
	31	1000	1440000	40518	64	9210.6616	0.00694847	0.00028	403.2	0.000620928
	31	1000	1440000	41527	64	9675.11069	0.00661491	0.00027	388.8	0.000598752
	31	1000	1440000	43320	64	10528.6266	0.00607867	0.00026	374.4	0.000576576
	32	1000	1440000	43939	64	10831.6636	0.0059086	0.00025	360	0.0005544
	32	1300	1872000	44881	64	11301.0781	0.00566318	0.00024	449.28	0.000691891
	36	1000	1440000		64	0	0	0	0	0
3S-46	12	600	864000	31042	64	5406.22623	0.0118382	0.00042	362.88	0.000558835

4S-46	8	1000	1440000	11099	64	691.134431	0.09260138	0.02	28800	0.044352
	10	1000	1440000	16127	64	1459.15692	0.04386094	0.002	2880	0.0044352
	11	1200	1728000	18997	64	2024.71953	0.03160932	0.001	1728	0.00266112
	11	1200	1728000	21462	64	2584.25406	0.02476537	0.00092	1589.76	0.00244823
	12	1200	1728000	26597	64	3968.8084	0.01612575	0.00055	950.4	0.001463616
	12	1200	1728000	23763	64	3168.08892	0.02020145	0.0007	1209.6	0.001862784
	14	1100	1584000	20852	64	2439.44066	0.02623552	0.00095	1504.8	0.002317392
	17	1200	1728000	14205	64	1132.08048	0.05653308	0.006	10368	0.01596672
	17	1000	1440000	10301	64	595.324287	0.10750443	0.026	37440	0.0576576
	18	1600	2304000	11309	64	717.535239	0.08919423	0.019	43776	0.06741504
	18	1000	1440000	14824	64	1232.89372	0.0519104	0.006	8640	0.0133056
	18	1200	1728000	14422	64	1166.9327	0.05484464	0.006	10368	0.01596672
	19	1000	1440000	17111	64	1642.65216	0.03896138	0.0015	2160	0.0033264
	22	1000	1440000	21902	64	2691.30164	0.02378031	0.00085	1224	0.00188496
	23	1200	1728000	24894	64	3476.83593	0.01840754	0.00065	1123.2	0.001729728
	23	1500	2160000	26907	64	4061.86405	0.01575631	0.00055	1188	0.00182952
	24	600	864000	28631	64	4599.04713	0.01391593	0.0005	432	0.00066528
	24	1600	2304000	28757	64	4639.6154	0.01379425	0.0005	1152	0.00177408
	24	1600	2304000	30493	64	5216.69125	0.01226831	0.00042	967.68	0.001490227
	26	1500	2160000	29670	64	4938.89643	0.01295836	0.00042	907.2	0.001397088
	26	2200	3168000	28178	64	4454.66609	0.01436696	0.00048	1520.64	0.002341786
	27	1000	1440000	25013	64	3510.1558	0.01823281	0.00065	936	0.00144144
	28	1000	1440000	24115	64	3262.64152	0.01961601	0.00067	964.8	0.001485792
	28	1000	1440000	23314	64	3049.49841	0.02098706	0.0007	1008	0.00155232
	29	1000	1440000	22738	64	2900.67686	0.02206382	0.00072	1036.8	0.001596672
	29	1000	1440000	25263	64	3580.67308	0.01787373	0.0006	864	0.00133056
	30	1000	1440000	23162	64	3009.86447	0.02126342	0.00071	1022.4	0.001574496
	31	2500	3600000	30273	64	5141.68834	0.01244727	0.00041	1476	0.00227304
	33	1100	1584000	31389	64	5527.76773	0.01157791	0.0004	633.6	0.000975744
3S-47	4	1600	2304000	36962	64	7664.88692	0.00834976	0.00032	737.28	0.001135411
	5	1000	1440000	41218	64	9531.6625	0.00671446	0.00027	388.8	0.000598752
	5	1000	1440000	41218	64	9531.6625	0.00671446	0.00027	388.8	0.000598752

4S-47	12	300	432000	12761	64	913.617151	0.07005122	0.008	3456	0.00532224	
	13	1200	1728000	14287	64	1145.18834	0.055886	0.006	10368	0.01596672	
	13	1000	1440000	16129	64	1459.51886	0.04385007	0.002	2880	0.0044352	
	14	1000	1440000	17232	64	1665.96625	0.03841614	0.0015	2160	0.0033264	
	15	1000	1440000	22728	64	2898.12603	0.02208324	0.00087	1252.8	0.001929312	
	17	650	936000	34114	64	6529.20218	0.00980212	0.0004	374.4	0.000576576	
	18	700	1008000	34811	64	6798.73048	0.00941352	0.00038	383.04	0.000589882	
	18	600	864000	37771	64	8004.08685	0.00799592	0.00035	302.4	0.000465696	
	19	550	792000	36893	64	7636.29628	0.00838103	0.00032	253.44	0.000390298	
	20	1000	1440000	36648	64	7535.21041	0.00849346	0.00033	475.2	0.000731808	
	23	1000	1440000	22641	64	2875.98115	0.02225328	0.0008	1152	0.00177408	
	24	1000	1440000	20756	64	2417.03061	0.02647877	0.00095	1368	0.00210672	
	25	1150	1656000	26481	64	3934.26482	0.01626733	0.00053	877.68	0.001351627	
	26	1200	1728000	25774	64	3726.99212	0.01717202	0.00055	950.4	0.001463616	
	26	1000	1440000	29734	64	4960.22641	0.01290264	0.00041	590.4	0.000909216	
	26	1000	1440000	27009	64	4092.71814	0.01563753	0.00055	792	0.00121968	
	27	1650	2376000	30725	64	5296.37357	0.01208374	0.00041	974.16	0.001500206	
	29	1200	1728000	38077	64	8134.30167	0.00786792	0.00033	570.24	0.00087817	
	30	1300	1872000	40118	64	9029.7011	0.00708772	0.00029	542.88	0.000836035	
	30	1600	2304000	44405	64	11062.6348	0.00578524	0.00025	576	0.00088704	
	31	1500	2160000	42932	64	10340.8697	0.00618903	0.00024	518.4	0.000798336	
	31	1500	2160000	46355	64	12055.5769	0.00530875	0.00022	475.2	0.000731808	
	34	1200	1728000	33408	64	6261.75081	0.01022078	0.0004	691.2	0.001064448	
	36	1200	1728000	28690	64	4618.02121	0.01385875	0.00046	794.88	0.001224115	
Total Stream Depletion by All Wells On Last Day of Irrigation										0.323552275	cfs
Baseflow in Winter (aveage of recorded discharges)										0.29	cfs
Percent Depletion on Last Day of Irrigation										111.5697501	%