

THESIS

ANALYSIS OF THE GROUNDWATER/SURFACE WATER
INTERACTIONS IN THE ARIKAREE RIVER BASIN OF
EASTERN COLORADO

Submitted By:

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY RYAN OLIVER BAILEY BANNING ENTITLED ANALYSIS OF THE GROUNDWATER/SURFACE WATER INTERACTIONS IN THE ARIKAREE RIVER BASIN OF EASTERN COLORADO, BE ACCEPTED AS FULFILLING IN PART THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

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COLORADO

The decline of stream baseflows along Colorado's high plains streams is degrading aquatic and riparian habitat. Historic strongholds for many plains fish species no longer exist. In Eastern Colorado, center-pivot irrigation is common and clearly contributing to the decline of baseflow in some stream basins. The purpose of this study is to develop a defensible conceptualization of the stream-aquifer system in the Arikaree River basin of eastern Colorado, in part using the results of a preliminary groundwater model developed to predict groundwater levels, analyze stream depletion and examine the effects of irrigation well retirements on groundwater and stream levels.

The groundwater conceptualization and model represent the Arikaree River groundwater system of Southern Yuma County where there is significant hydrogeological connection between the Ogallala and alluvial aquifers. Analytical and numerical models presented in this thesis calculate seasonal stream-depletion of the Arikaree River due to nearby wells and similar potential effects of riparian vegetation.

Finally, the author examines the river basin water budget in Southern Yuma County to determine possible pumping effects on the amount of available water for streamflow and habitat.

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To my loving and patient wife for all of your support.
To my family for all of your encouragement throughout my college career.

I love you and thank you.

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I appreciate the guidance that all of the Civil Engineering Department faculty and staff have provided me during my studies. I thank Dr. Deanna Durnford for introducing me to groundwater engineering and for her patience during the writing of this thesis. Thank you to Dr. James Warner for introducing me to groundwater modeling using Visual Modflow and Calvin Miller for providing me with his library of research articles.

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PREFACE

PLS Notes

Many figures and well descriptions presented in this text were developed using the Public Land Survey (PLS) coordinate system. Boundaries of townships with section line divisions are shown in these figures to indicate scale. The PLS coordinate system is explained in appendix A.

Evapotranspiration (ET) Notes

According to the USGS, the definition of evapotranspiration (ET) varies depending upon the needs of an author of a study using the term (USGS 2010). The word is composed of and derived from “evaporation”, the process of water vaporizing into the atmosphere, and “transpiration”, the process by which water is expelled into the atmosphere by physiological functions of the plant. Evaporation includes water lost to the atmosphere from the ground surface, from the capillary fringe of the groundwater table and from surface-water bodies. Transpiration can occur from any part of the root zone, including from the aquifer or the capillary fringe.

Unless otherwise noted, ET is from all possible water sources at a given location. The initial abstraction is generally not included when ET is referenced except as explained in chapter 6 to determine probable infiltration at the ground level, using precipitation. In chapter 4, model input ET rates are always the maximum possible, occurring when the calculated water table is at the ground surface. This rate is reduced linearly with the extinction depth, to zero as described in the chapter.

CHAPTER 1 INTRODUCTION

1.1 STUDY BACKGROUND

Much of the western United States is semi-arid, requiring significant irrigation to grow common crops. Improvements in pump technology during the 1960s made groundwater wells an easy solution for satisfying crop requirements. However, by 1989 significant groundwater level reductions of up to 30.5-m (100-ft) were observed in parts of the High Plains aquifer (also referred to as the Ogallala aquifer for its geologic formation) underlying the states from South Dakota to Texas (Dugan et al. 1990).

Reductions in streamflow have had negative impacts on aquatic habitat resulting, in some cases, in the extirpation of fish species from western rivers (Labbe & Fausch 2000). In Colorado, the disappearance of habitat is threatening the Brass Minnow (*Hybognathus hankinsoni*), throughout the Arikaree River which is a stronghold for this species (Scheurer et al. 2003; Falke 2009) particularly along The Nature Conservancy's Fox Ranch property (Figure 1-1, Figure 1-2) along the Arikaree River.

Groundwater models often are used to investigate water rights or to estimate habitat recovery. The assumptions made during the modeling process are very different depending on which of these goals the modeler is trying to achieve. Modeling for habitat recovery projections requires the modeler to assume conservative estimates of flow

recovery (underestimation) because over estimation could mean habitat is actually not available where projected. If a given species were to require the area of habitat recovery projected in the model for survival and it were not available, there may not be enough time to remedy the situation. Conversely, underestimation of stream depletion causes legal problems when modeling to establish water rights because a user may be imposing on a senior right held by another user. The distinction is important and the purpose of a model must be established before it is used for any work.

It was determined that a study of the groundwater basin was required to understand the Arikaree River system. This thesis is part of the preliminary study in what is a collaborative effort between the Civil and Environmental Engineering and the Fish, Wildlife and Conservation Biology Departments at Colorado State University. By better understanding the river system through modeling and conceptualization it is hoped that future research will aid in the preservation of the Arikaree River basin habitat.

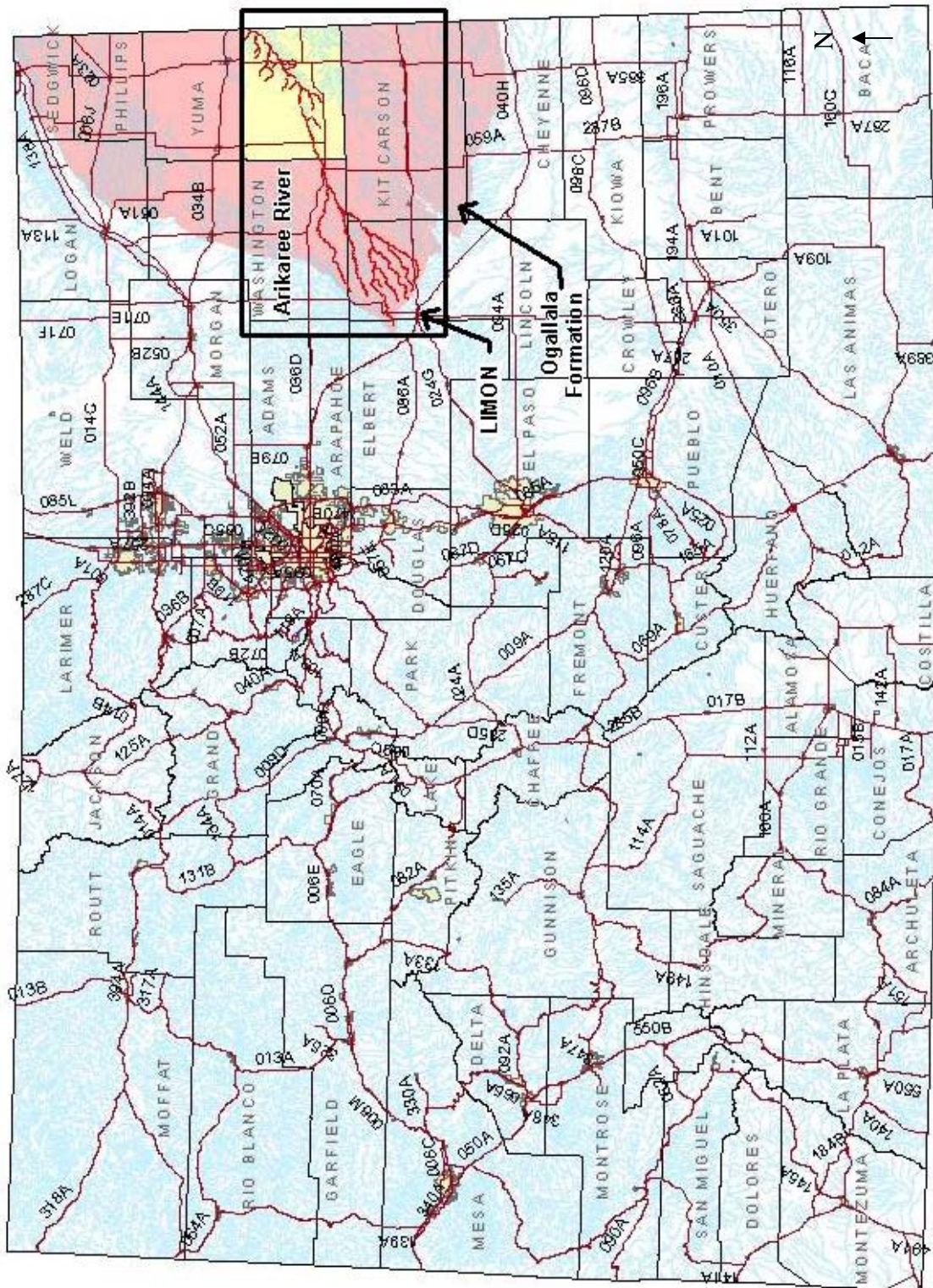
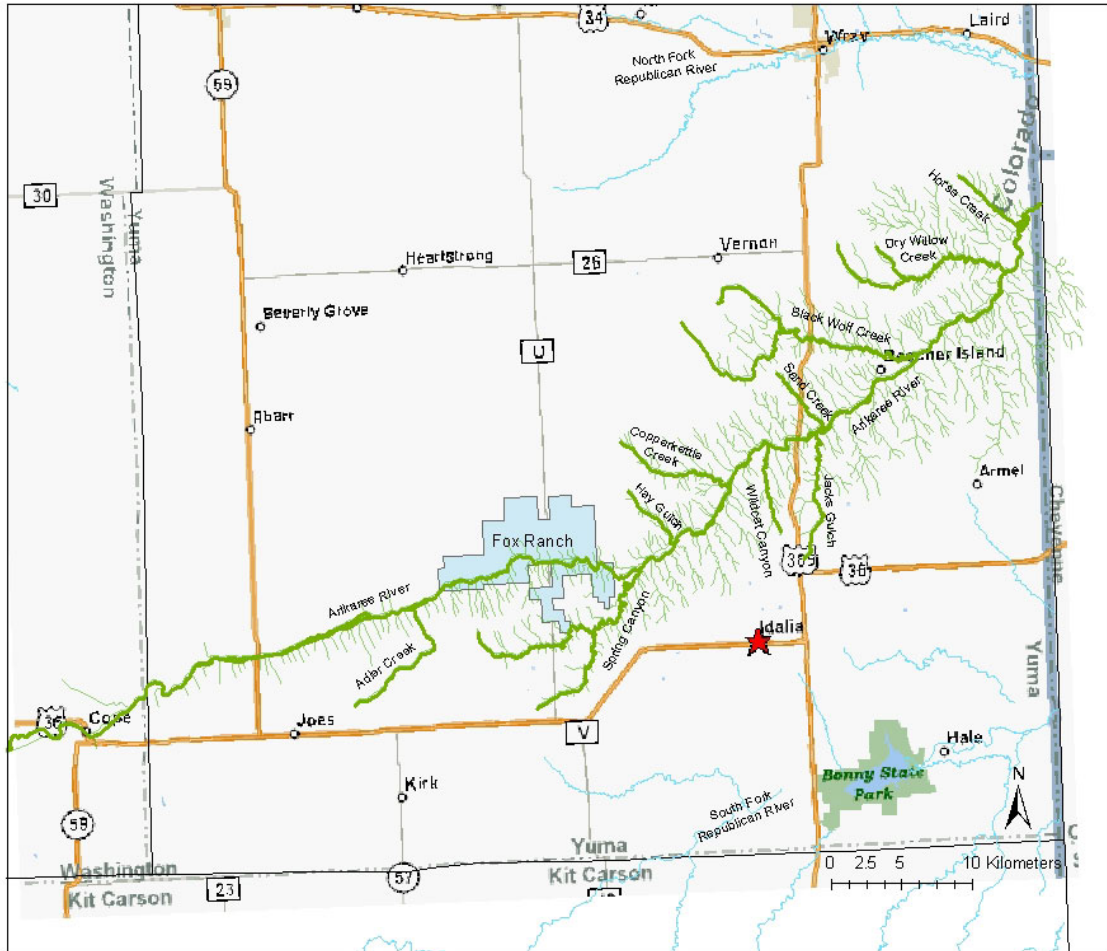


Figure 1-1: Location of the Arikaree River

(CDOT 2006)



**Figure 1-2: Southern Yuma and the Arikaree River with Major Tributaries
(CDOT 2006, Base Map by Mapquest 2006)**

1.2 SITE LOCATION & GEOLOGICAL BACKGROUND

The Arikaree River is groundwater dependent and originates at roughly the edge of the Ogallala formation near Limon, Colorado in Lincoln County (Figure 1-1). The river flows northeast through Southern Yuma County into Kansas and toward the north fork of the Republican River. The ground surface geologic formation at the headwaters of the Arikaree is the Grand Island Formation (Figure 1-3). The sandy material cuts into the

Peoria Loess, which is underlain by the Ogallala Formation (Sharps 1980). Low hydraulic conductivity of the Peoria Loess creates a region of high runoff and consequent low infiltration at the mouth of the Arikaree River. Runoff has left deposits of the alluvial Grand Island formation in the low-lying river channel area created over a long period by erosion.

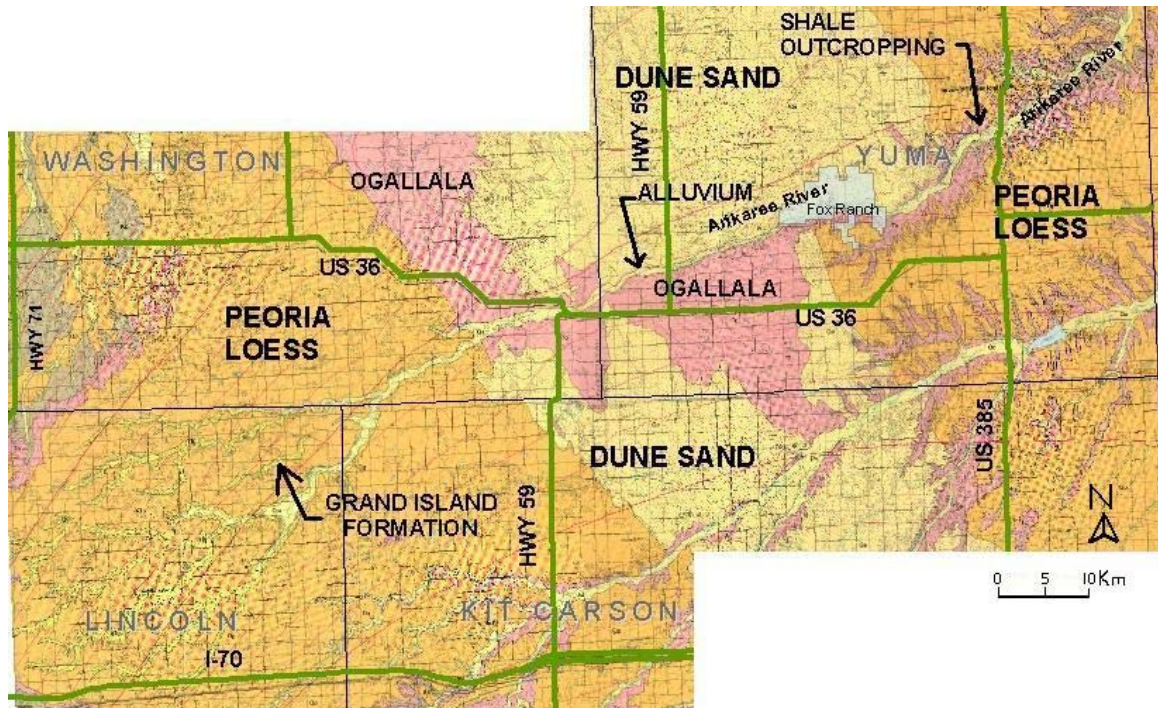


Figure 1-3: Geology of Arikaree River Basin (Sharps 1980)

As the Arikaree River flows northeast through Washington County (Figure 1-2), the Peoria Loess top soil disappears revealing the Ogallala formation below. The Ogallala formation is highly porous and is comprised of various soils from clay to gravel. Reddell (1967) describes the formation as “homogeneous in its heterogeneity” inferring that the soils are consistently mixed throughout the formation. The higher infiltration rate of the Ogallala formation augments groundwater storage. The Ogallala formation is the major

geological formation of the High Plains aquifer and the names are used synonymously. The High Plains aquifer is unconfined in eastern Colorado.

In southern Yuma County, deposits of wind-blown dune sand overlay the Ogallala formation north of the Arikaree River. Yuma County surface geology maps by Sharps (1980) (Figure 1-3) and Weist (1964) (Figure 1-4) are concurring descriptions of the superficial soils.

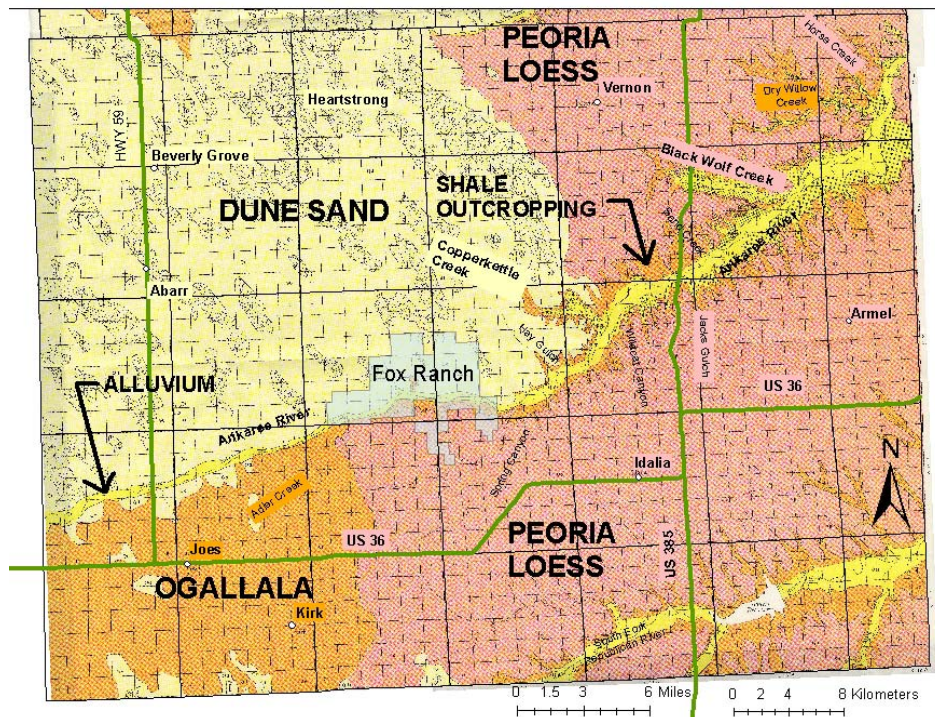


Figure 1-4: Surface Geology of Southern Yuma County (Weist 1964)

The Arikaree River groundwater basin through Southern Yuma County was delineated using data from Weist (1964) as shown in Figure 1-5. Groundwater contours were connected at the point where they are perpendicular to the river to define the basin.

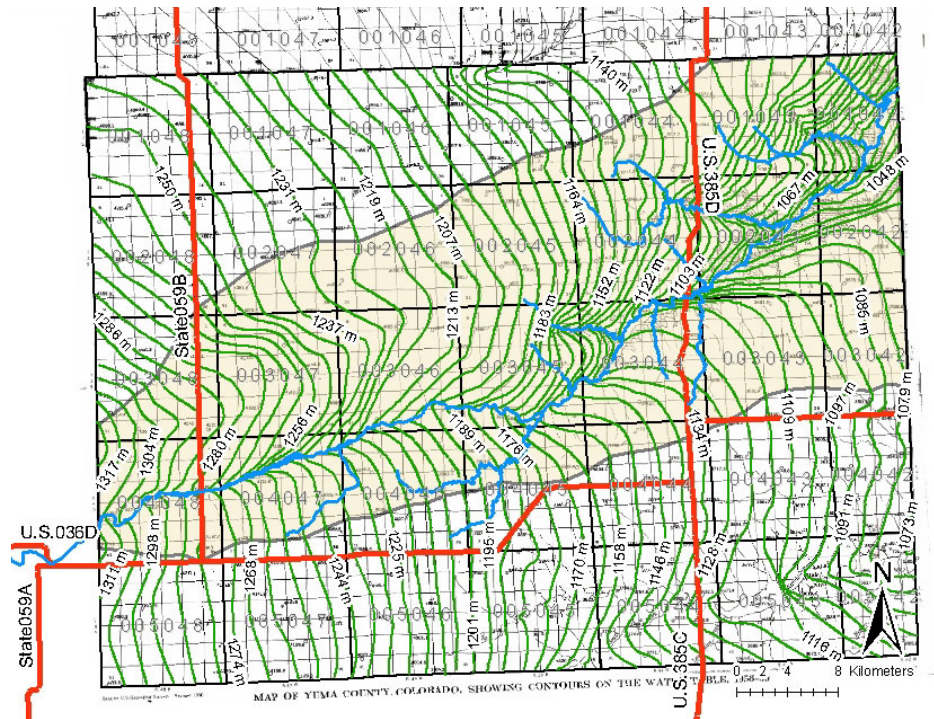


Figure 1-5: 1958 Arikaree River Groundwater Basin & Water Table Contours (Weist 1964)

The elevation of the Pierre Shale Bedrock is higher toward the north edge of the basin as shown in Figure 1-6. Paleo-channels exist on both sides of the river. South of the river, the prominent channel runs west to east. North of the river, the channels proceed to the north from the Arikaree basin toward the north fork of the Republican River. The Pierre Shale bedrock elevation descends to the east at a rate less than that of the ground surface elevation creating intermittent bedrock outcroppings. Outcroppings appear starting around the mouth of Copper Kettle Creek (Figure 1-2) in South Central Yuma County and north of Idalia. At the Kansas border, the U.S. Geological Survey has accepted the Arikaree as the lowest point in Colorado at 1,010 m (3,315 ft) above sea level.

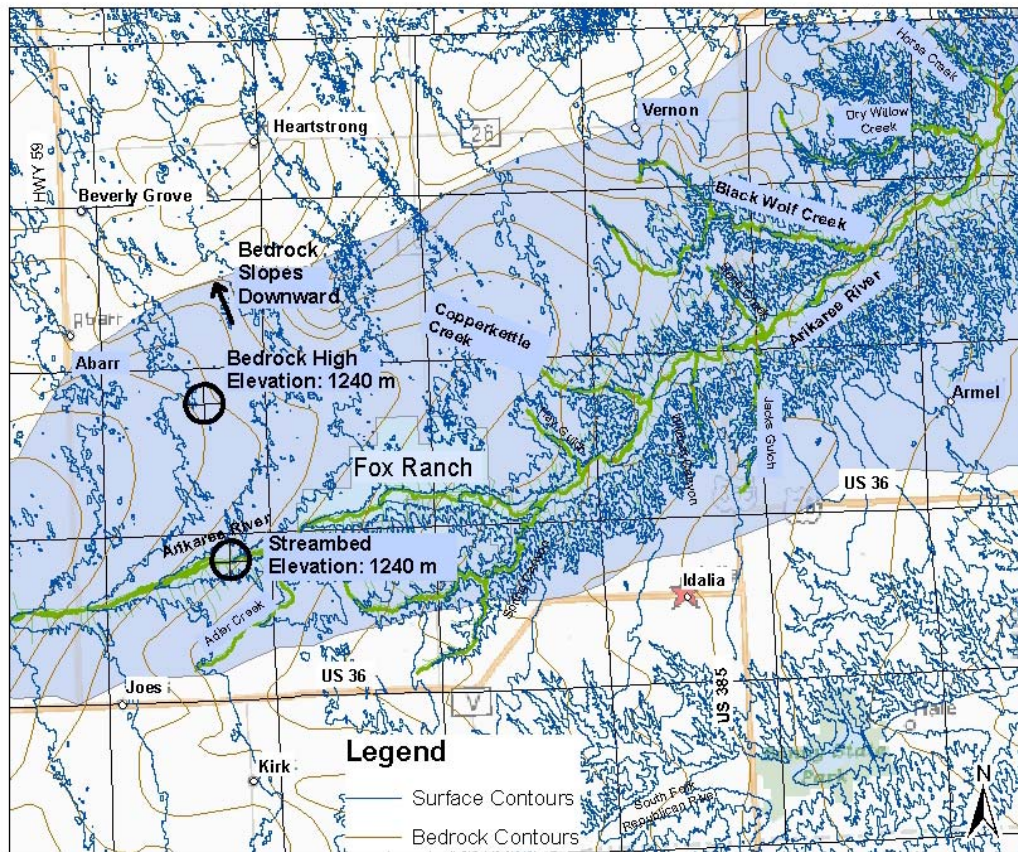


Figure 1-6: Bedrock Contours (Johnson et al. 2002)

The Arikaree River flows through Kansas for roughly three-miles before reaching Nebraska to the north. It continues for ten miles from the Nebraska-Kansas border before reaching the confluence with the north fork of the Republican River. At one time, the flow rate of the Arikaree River was large enough for the river was perennially connected through Yuma County into Nebraska (Wachob 2006). The river is now intermittent and disconnected during summer months.

1.3 RESEARCH OBJECTIVES

The objectives of this study are to improve current understanding of the Arikaree river groundwater system and to develop a defensible conceptualization of the river basin.

The research tasks completed as part of this thesis are:

- 1) Collect and organize data describing the hydrogeological structure of the Arikaree groundwater basin.
- 2) Conceptualize the groundwater basin and flow regime based on collected data.
- 3) Numerically model the groundwater basin in Southern Yuma County associated with the Arikaree River.
- 4) Apply the model to identify wells causing the most stream depletion, compare the results to analytical solutions and determine potential streamflow recovery.
- 5) Develop a regional Southern Yuma County water budget.
- 6) Refine the conceptualization based on the analysis results.

1.4 CONCEPTUALIZATION

One of the main contributions of this thesis was to derive a conceptualization of the Arikaree River water cycle and groundwater system. The final conceptualization is described in depth, in chapter 7 and is supported by the research throughout this text. The final conceptualization has the following major components:

- 1) The Ogallala Aquifer reduces in thickness from west to east because the slope of the bedrock is less than the slope of the ground surface. This creates

outcroppings of bedrock toward the eastern half of Southern Yuma County and modifies the behavior of the river.

- 2) There is an overall water balance deficit, due to irrigation wells, that lowers the watertable and the resulting baseflow to the stream over time.
- 3) The boundary of the groundwater basin is stable and will remain independent in the future, regardless of watertable levels.
- 4) Although all irrigation wells contribute to the decline of the water table over time and ultimately the survival of the river, wells farther than around 3,000-m from the river do not have a seasonal effect on the river stage. Instead, alluvial wells and riparian ET cause intermittent disconnection of the stream and affect the seasonal dynamics of the river.
- 5) The alluvium and groundwater flow through the “alluvial river” is taking the place of channel flow as less water is available for streamflow.
- 6) The Arikaree River through Southern Yuma County must be broken up into 4 distinct regions for conceptualization including: Upstream, Fox Ranch, Transitional and Downstream regions. This is because the river and its behavior due to the surrounding hydrogeology, irrigation and riparian vegetation is very different depending upon the location.
- 7) The channel in the Upstream region is typically dry due to irrigation and lower water table depth.
- 8) The Fox Ranch region is wet, although streamflow is disconnected throughout the summer. This is because of nearby recharge areas and the lack of nearby

irrigation wells. The amount of water available at the surface will continue to decline as water table levels decline.

- 9) Streamflow in the Transitional region continues to decline compared to the Fox Ranch region. The aquifer is disconnected from the river in many locations due to bedrock outcroppings. The alluvium is very dynamic because of reduced base flow.
- 10) The Downstream region is mostly dry except for near the confluences of the river with tributaries. This is because of riparian ET and alluvial wells. The Ogallala aquifer is cut off from the alluvium by bedrock outcroppings. The tributaries intercept east to west groundwater flow. This allows them to stay wet but this water infiltrates into the alluvium at the confluence points.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

Existing information concerning the Arikaree River in Southern Yuma County includes the effects of artificial recharge on groundwater levels, brassy minnow habitat persistence and agricultural studies including irrigation practices. Other pertinent studies include estimated evapotranspiration (ET) rates, recharge rates and stream depletion rates caused by pumping groundwater wells. Data collected from various sources included water table levels, bedrock surface elevations, ground surface elevations, geology, land use, well locations and pump capacities.

2.2 STUDY BACKGROUND

Fardal (2003), Griffin (2004) and Wachob (2006) completed history and background reviews of literature for the Arikaree River near the Fox Ranch property. The reviews detail the development of Southern Yuma County's agricultural economy.

Fardal and Griffin also conducted studies of stream conditions, possible effects of irrigation and agricultural trends for the area surrounding the Fox Ranch. Fardal's study included a preliminary discussion of groundwater pumping and its correspondence to the Arikaree River stream stage. Later, data collected by Griffin improved the understanding

of relationship between stream stage and regional pumping indicating that her conclusion of an inverse relationship between stream stage and regional pumping might be more of an indirect relationship. However, seasonal groundwater use was determined using farmer surveys and power consumption records. The average pump efficiency was estimated for regional groundwater wells to be 61 %.

Griffin's study included stream-depletion factor calculations along with an examination of the correlation of shallow alluvial well levels and nearby stream stage. A large area near the Fox Ranch portion of the Arikaree River was included in the analysis. Effects of pumping from all of the wells in the eight townships highlighted in Figure 2-1 were included in the computation of the total stream depletion from a common point on the river. A portion of the included wells, as indicated on the provided map (Figure 2-1) is not within the 1958 Arikaree River groundwater basin shown shadowed from bottom left to top right on the map provided as.

Griffin (2004) assumed a regional average hydraulic-transmissivity of 2,483- m^2/day (26,736- ft^2/day) in his study. He found, using simplified analytical stream-depletion models, that groundwater irrigation wells could be causing complete seasonal depletion of all Arikaree River streamflow through the Fox Ranch. There was no noticeable change however, found to the timing of the stream-stage decline between two consecutive years, despite a delay in the pumping start date of two weeks during the second year. The pumping start date delay without equal delay in stream-stage decline schedule indicates that there are sources of stream depletion other than irrigation wells.

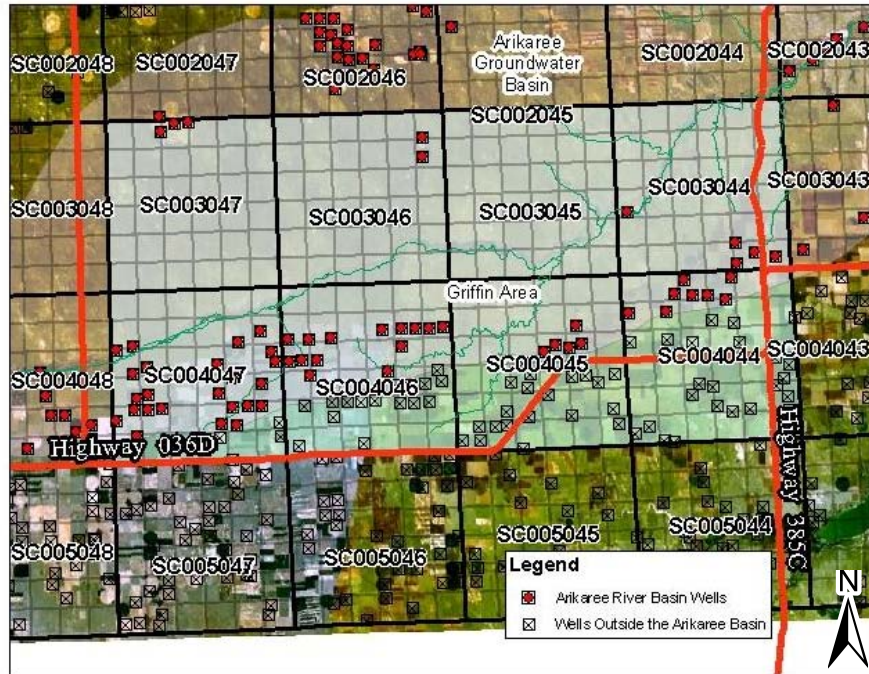


Figure 2-1: Griffin SDF Area (Griffin 2004 data depicted in ArcGIS)

Wachob (2006) documented alluvial water table levels over the 2005 growing season to examine evapotranspiration from riparian areas containing cottonwood stands. Comparisons were made between methods of calculating ET using specific yield (White 1932) and the FAO Penman-Monteith Equation (Allen et al. 1998), used in agricultural calculations. Seasonal riparian ET from cottonwoods was calculated to be approximately 127-cm (50-in) from the alluvium using the White method. The White method evaluates ET using groundwater levels and does not directly account for the initial abstraction or evaporation from open water. Because of this, the ET calculated using the White method analysis is probably not the maximum.

Scheurer (2003) studied brassy minnow persistence at three locations in southeastern Yuma County. The study documented the existence of adult and juvenile

fish associated with spawning for the years 2000 and 2001. The species persisted despite drying of large portions of the river. Scheurer documented stream connectivity and its reestablishment from changing stream conditions. Repopulation of areas where fish had been extirpated was observed after periods of stream connectivity.

Solek (1998) suggested that the Fox Ranch would be the best available land along the Arikaree River to be purchased by The Nature Conservancy for a wildlife preserve. Her conclusions were based on geology and the absence of nearby irrigation wells. Solek cited the vast deposits of dune sand, north of the ranch with thin underlying Ogallala formation as benefits to habitat on the property because the geologic configuration allows high rates of aquifer recharge. Farming is less than ideal in the dune sand, thus discouraging high capacity well installation near the property.

Katz (2001) studied the invasion of plant species into western riparian regions including the Arikaree River valley along with the geomorphology of the alluvium. Flood terracing was found to exist in many stages including from the major flood recorded in 1935 among others. Flooding has influenced plant variety, plant population and ET rates. Large stands of cottonwoods have developed where they did not exist before the 1935 flood.

2.3 REGIONAL GROUNDWATER BASIN

Weist (1964) studied the geology and groundwater resources of Southern Yuma County. Surface geology was mapped and a fence diagram of subsurface geology was created. Contour maps were included showing the elevation of the bedrock surface, water

table surface, ground surface and relationship between each surfaces. Weist approximated the alluvial water table depth between 6 and 15 meters, which varies by location.

Borman et al. (1980) looked at the hydraulic characteristics of the High Plains Aquifer in Colorado. Saturated thicknesses and changes in storage were mapped along with aquifer characteristics including hydraulic conductivity and specific yield. Aquifer properties ranges from Borman were used in the model, detailed in chapter 4.

Surface geology data was compiled by Sharps (1980) for eastern Colorado. The resulting map (Figure 1-3) shows dune sand, Ogallala formation outcropping, Peoria Loess deposit and bedrock outcropping locations throughout Yuma County. The surface geology at the headwaters of the Arikaree River was included.

Reddell (1967) studied natural High Plains Aquifer recharge in Colorado. Recharge in subdivided regions of the aquifer was calculated using a numerical model. The model cell size was six square miles. Reddell suggested that the composite average high plains aquifer recharge for Yuma County is 1.45 in/yr (3.56-cm). Reddell also attempted to quantify regional water budget inputs.

Longenbaugh (1966) studied artificial recharge near the Arikaree River. He concluded that artificial recharge was possible at a study site near Cope, Colorado. Observations wells were used to measure the increases in water table level induced by recharge ponds created using excess surface water.

Dugan et al. (1990) completed a study of The High Plains Aquifer water levels changes. The study included the entire aquifer from South Dakota to Texas. From 1980 and 1988, water table level changes were observed ranging between 3 to 15 meters in portions of the High Plains Aquifer of Colorado. Changes of over 30-m were observed in

other regions during the same time interval. A related study by Luckey (1988) examined the effects of pumping in the aquifer as determined by regional models. Changes in water level were similar for these studies.

Gutentag et al. (1984) showed that groundwater-irrigated agriculture in the High Plains Aquifer of Eastern Colorado increased from between 0 and 10% up to between 25 and 50% during a fourteen-year period from 1964 and 1978. This is a regional estimate from the maps presented in the study. The increase is due to vast well installations during the late 1960's. Expectation of groundwater regulation in the late 1960's and new pump technology were catalysts to development of groundwater wells.

CHAPTER 3 DATA COLLECTION AND OBSERVED GROUNDWATER TRENDS

3.1 STOCK WELLS MEASUREMENTS

Nineteen wind-powered stock wells are located on the Fox Ranch as shown in Figure 3-1. The location of these wells varies substantially in elevation and proximity to the Arikaree River. Differential GPS was used to survey the location and elevation of the stock wells. A site-specific GPS reference point was established for the project and was utilized as the base station for all surveys completed during 2004-2005 including measurements in the survey for Wachob (2006). The base station is a permanent mark etched into a large rock outcropping, located in the horse trap in Figure 3-1. The datum elevation and coordinates for all windmills are provided in Appendix B. Wells 5 and 9, shown to the north of the ranch house and river were not measureable.

The wells were monitored starting in the spring of 2005. All well survey and groundwater measurement points of reference were the center of the well casing cap. Monitoring occurred on various dates throughout the year as access to the wells was obtained. Most wells were visited three times (Table 3-1). The depth to water was measured from the top of the well casing.

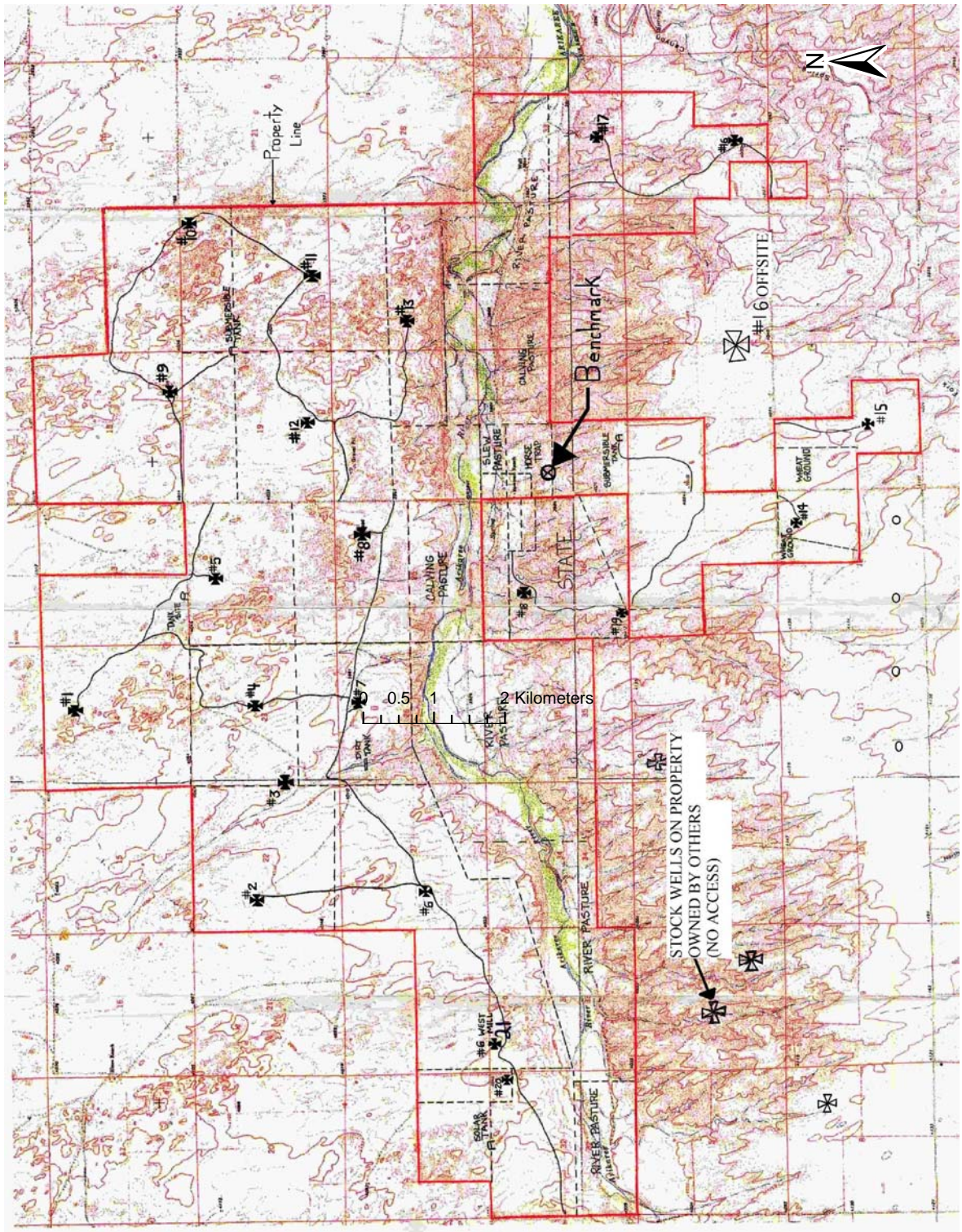


Figure 3-1: Fox Ranch and Stock Wells (Modified Unknown USGS Quad Map)

Figure 3-2 shows the resulting groundwater contour map from the stockwell measurement data (Table 3-1), collected on 8/16/2005 (10/15/2005 for wells 16 & 17). The data set was plotted along with measurements from the shallow alluvial well survey for Wachob (2006), new measurements of wells from the Griffin (2004) study and an ongoing Fish, Wildlife and Conservation Biology study measurements of the stream water-surface elevation at various locations along the river. The water-surface elevation was calculated by adding the stream-stage to riverbed elevations surveyed with differential GPS starting at the river just south of well seven (Figure 3-1) and proceeding east. The riverbed west of well seven was approximated using the data from a DEM (National Elevation Dataset 1999) and GIS. These points are referred to as “hypothetical” in the figure. Appendix B shows the collected data used in the plot.

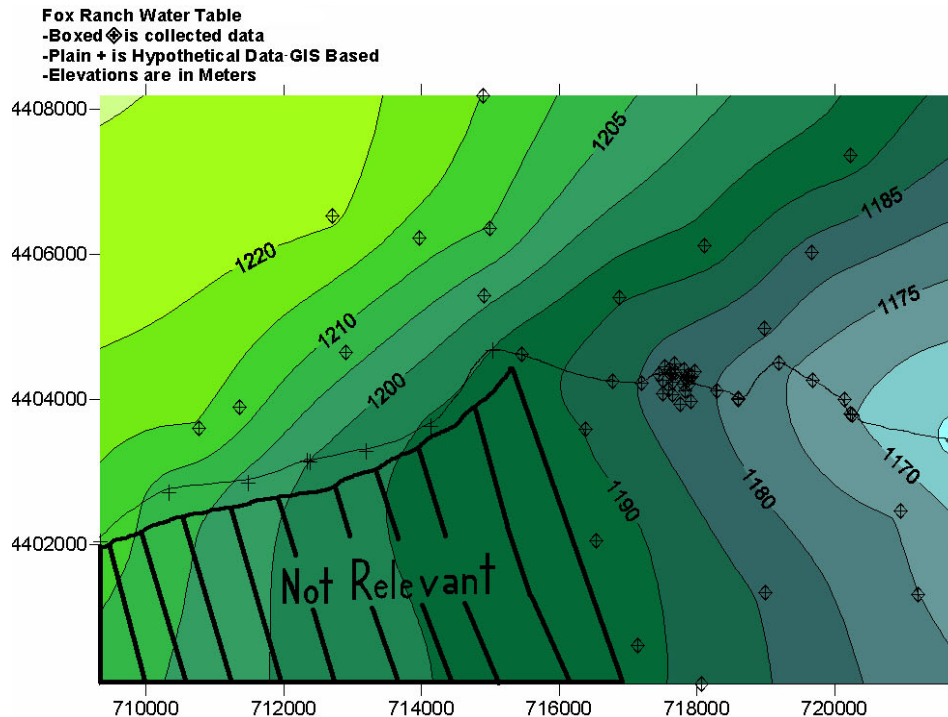


Figure 3-2: Water Table Contours on the Fox Ranch in Southern Yuma County

(Coordinates in UTM NAD 1983 zone 13 N)

Note: Contour lines to the bottom left of the figure, above elevation 1,190 m, are not relevant because no measurable wells were located in that region.

The groundwater gradient was determined using the contour map in Figure 3-2. On the date of these measurements, the gradient is approximately 0.014 to 0.021-m/m toward the river from the north and 0.009 to 0.014-m/m from the south. The contour map shows that the river is gaining through the Fox Ranch.

Table 3-1 shows the measurements taken at each of the wells over the period from 3/15/2005 to 3/16/2006. The maximum change in water level over that time for each well was calculated when multiple observation data were available.

**Table 3-1: Stock Well Depth to Water
(Measured from the top of the well casing)**

Windmill	Depth to Water Table (m)							Max Level Change (m)
	3/15/2005	5/19/2005	6/26/2005	8/16/2005	10/6/2005	10/15/2005	3/16/2006	
1				16.49		16.52		-0.03
2				18.10				0.00
3		6.35	6.08	6.46				-0.38
4				25.63		25.72		-0.09
6				18.47				0.00
7	18.26	18.23	18.47	18.44		18.41		-0.24
8		25.08	25.45	25.33				-0.37
10		27.37	28.31	27.52				-0.94
11		36.30	36.06	36.06				0.24
12		30.55	30.75	30.66				-0.20
13		23.16	23.26	23.16				-0.09
14		49.77	50.11	49.95			50.02	-0.34
15		45.21	45.21				45.38	-0.17
16					44.47	44.44	44.56	-0.12
16 Off Site			53.64	53.73			53.64	-0.09
17					32.89	32.89	32.92	-0.03
18		9.74	9.72	9.72				0.02
19		41.60	41.68	41.79				0.19
20		21.57	21.61	21.67				-0.10
21				24.29				0.00

Because of nearly a one-meter groundwater level reduction followed by close to complete recovery at the August 16th reading, it appears there was an error in the June 26th reading for well 10. Well level reductions of more than 0.3-m occurred in wells 3, 8 and 14. Well 15 is located approximately 2-km east of an irrigation well and Well 14 is located approximately 1.2-km north and 1.6-km northeast of two irrigation wells.

Additional irrigation wells are located approximately 1.6-km west, 0.8-km south and 2.4-km west, 0.8-km south of stock well 14. Wells 14 and 15 are the closest of all measured stock wells to irrigation wells.

No clear downward trend in water levels was observed throughout the year (Figure 3-3). The overall groundwater levels at the end of the growing season were not noticeably lower than in the early season (Table 3-1). The average change in stock well water level was a reduction of 0.21-m. Seasonal changes in the groundwater level at the stock wells appeared affected more by atmospheric conditions and localized river conditions than by irrigation well pumping. This was concluded because water level declines in some stock wells located near the river were within 0.1-m of the decline seen in well 14, located near irrigation wells. Well 7 is an example, of a well far away from the irrigation wells that measured similar declines to well 14 (0.24-m vs. 0.34-m).

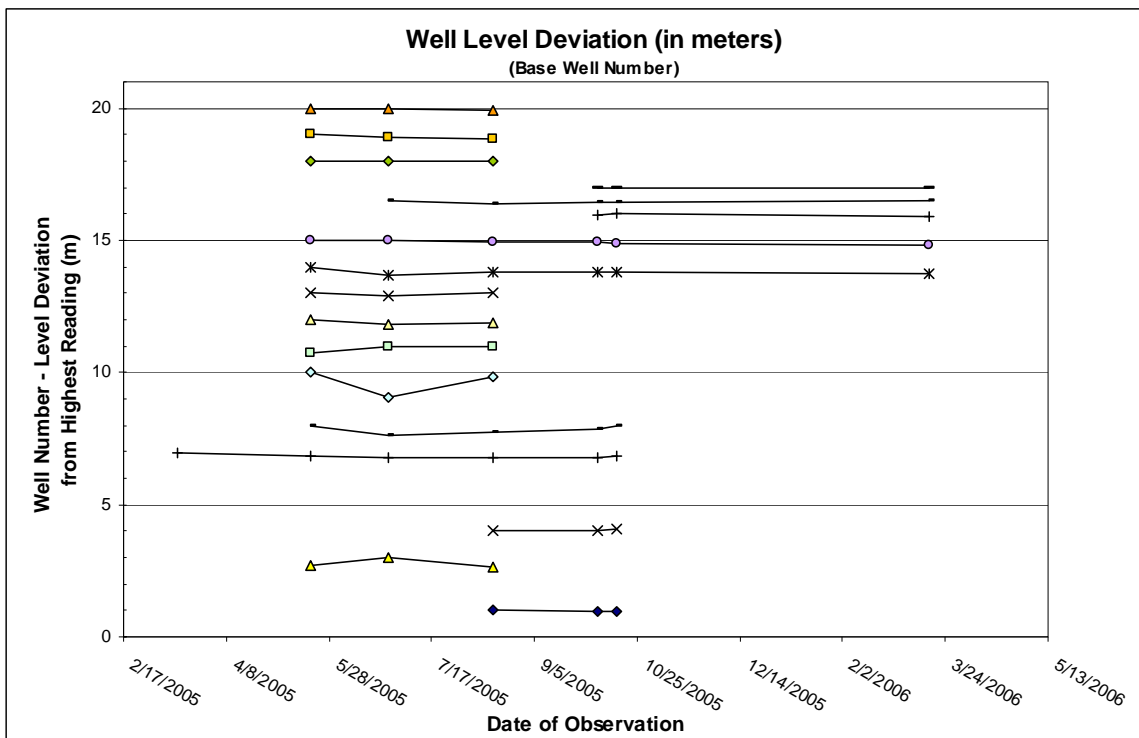


Figure 3-3: Stock Well Level Deviation

Although additional years of data should be collected, it was concluded from the measured data that irrigation pumping was not the primary, but a secondary cause of seasonal water table fluctuations for the Fox Ranch stock wells in Table 3-1. For irrigation pumping on the Fox Ranch to be the primary cause of seasonal water table level decline, it would be expected that the water table elevation be highest on 5/19/2005. It would also be expected that the water table levels decline throughout the growing season to the 10/15/2005 level and that seasonal recovery would increase the water table elevation such that measurements in the beginning of spring on 3/16/2006 would be higher than those measured after irrigation season on 8/16/2005 and 10/15/2005. None of these trends was clear from analysis of this data set.

It was indicated from this data set that irrigation pumping in the aquifer to the north and south of the Fox Ranch was not causing seasonal depletion of the river. If this were the case, stock well water table levels would be expected to recover with similar timing to the observed seasonal streamflow recovery. This data set does not provide enough information about upstream alluvial wells to determine where depletion is coming from.

Wells 14 through 17 (Figure 3-1) are located on the south side of the ranch and are the closest stock wells to the irrigation wells (Figure 3-4). A gradual regional decline for these wells was indicated from the measurements on 3/16/2006. The measurements on that date trended lower than the majority of the previous measurements. Further monitoring should be completed to determine long-term groundwater trends.



Figure 3-4: Southern Yuma County Irrigation Well Locations (USDA 2005; CDWR 2005; CDOT 2006)

CHAPTER 4 ARIKAREE RIVER NUMERICAL GROUNDWATER MODEL

4.1 NUMERICAL MODEL

To achieve a better understanding of the groundwater system contributing baseflow to the Arikaree River, a numerical groundwater model was created representing southern Yuma County. This model was the first attempt for this project and is the foundation for further groundwater modeling and exploration of the factors contributing to the decline of Arikaree River streamflow. This model was used in the conceptualization of the stream basin and was useful in determining where additional research was needed to refine the understanding of the system. Many of the parameters, such as ET and recharge were approximated using previous studies of the river basin and other areas similar to the basin. The most reliable data were used wherever possible.

4.2 NUMERICAL MODELING TECHNIQUES

Typical numerical groundwater modeling strategies implement either a variety of simple models representing various conceptual models of the same system or a single complex and realistic model. Modelers use statistical analysis with the simple model technique, to create a confidence interval of model results. The more complex, realistic models are used for approximating large-scale flow regimes and estimating water-quantity solutions. For this reason, the realistic technique was used for this study. Significant raw data were available for the area because of advances in satellite technology and studies by the USGS, such as Weist (1964). Visual MODFLOW

(Waterloo Hydrogeologic, distributed by Scientific Software Group, Washington D.C.) was the numerical model interface used to create the model. The software contains computer code allowing importation of data in various formats including tabulated data and ESRI shapefiles.

4.3 PROCESSING INFORMATION FOR MODEL INPUT

Geographical information systems (GIS) technology was used extensively for processing raw data into Visual Modflow model data sets. The ArcGIS 9.1 software (ESRI Inc. 2005) was used exclusively for GIS data manipulation and processing. The reader is urged to reference an ESRI ArcGIS manual for file type definitions and explanation of data manipulation techniques.

A water table contour map from Weist (1964) was scanned and converted to a polyline GIS data file. This file and the Johnson et al. (2002), bedrock contours were interpolated into raster data and processed for importation and interpretation by the Visual MODFLOW software. The surface geology map from Weist (Figure 1-4), was digitized and used to identify soil type zones while designating regional evapotranspiration and recharge trends in the model. A USGS digital elevation model (National Elevation Dataset 1999) of the area, containing ground-surface elevation data set was also processed for model importation. Well locations and pump capacity data from the Colorado Division of Water Resources (CDWR 2005) was used in the model.

In order to organize model data effectively, a common spatial referencing system was used. The North American Datum (NAD) 1983 Universal Trans-Mercator (UTM) zone 13N was chosen because it is the current standard for government data in Eastern

Colorado (CDWR 2005). Utilizing ArcGIS, digital-aerial photos and scanned images were aligned or “geo-referenced” to spatial and elevation data sets in NAD 1983 UTM zone 13N. Most historic well and property location data for Yuma County was recorded using the United States Public Land Survey (PLS) system for identifying spatial locations. The PLS coordinates were converted to NAD 1983, UTM zone 13N for alignment to other GIS data.

The complete process used for importing surfaces shown on hardcopy maps into modflow is as follows:

1. Digitize the contour map image by converting it to raster image file
2. Convert the raster file to a digital contour file of polylines
3. Interpolate a Digital Elevation Map (DEM) from a digital contour file
4. Verify the Digital Data
5. Convert a DEM to digital point file
6. Export the point file to a table of values
7. Import the table into modflow to create the model surface.
8. Make appropriate corrections to the imported data set.

The following is a description of the steps involved in the process.

4.3.1 Surface Creation

The ArcGIS toolbox was used to digitize the Weist (1964) water table contour map. The map was scanned to create bit-map image file. The representative image file, based upon a two-dimensional document, was geo-referenced to intersections of PLS

section lines or other common locations and aligned with the spatial reference system. This was a required image distortion process used to match the UTM projection.

The image file was touched up manually to remove any flawed image data resulting from the digitization process. Once the file was cleaned, the image conversion tool was used to convert the image files into poly-line vector shape files. Contours were manually connected where required to create a comprehensive and continuous data set for the entire model area. The now geo-referenced, poly-line contours entities were manually assigned elevation values shown by the Weist (1964) map.

The Weist (1964) contour data set and the Johnson et al. (2002) bedrock surface contour set were converted to raster-value, DEM-type surfaces by interpolating cell elevation values from the contours. The new surface files were created to have a cell sizes of 4.05-ha (10-acres).

4.3.2 Comparison of Surfaces

Arithmetic operations of raster files are possible using the spatial analyst tool in ArcGIS. The tool creates a new raster surfaces that are a data set of cells with associated horizontal location, size and some relevant data. The data are the result of the some specified operation chosen at the creation of the output-surface from the overlapping input-surface cells. A raster file was created showing the proximity of the National Elevation Dataset (1999) ground elevation surface to the Johnson et al. (2002) bedrock elevation surface by subtracting the elevation value of the cells in the bedrock elevation surface from the ground elevation surface. Exposed bedrock locations were defined in the resulting surface at locations where the cells contained negative or zero values. The

locations were verified by comparing the resulting exposed bedrock cells to exposed bedrock regions shown in Figure 1-4.

4.3.3 Importation of Surfaces

ASCII files (basic text files) containing tables of data were used to import surface data. Tables of elevation data and their associated x-y coordinates (interpolation tables) were created from the “parent” DEM files using an ArcGIS data export.

To create the tables, the DEMs were converted to vector point entities centered over the 10-acre raster square. The points were used to extract elevation and coordinate data associated with parent raster cells. The process was used for the ground-elevation surface, bedrock-elevation surface and the 1958 water-table surface (Weist 1964) files. One point was created for every cell in each raster surface. Elevation and UTM coordinate data associated with the points were then exported to ASCII file tables. Visual Modflow used kriging interpolation (Oliver 1990) to create a model surfaces from each table.

The raster surface files and Visual Modflow model were created having equivalent, 4.05-ha (10-acre) cell sizes. Each model cell corresponded to a matching point created from the DEMs so interpolation resulted in very accurate model surfaces. The cell size was chosen because it was the smallest parcel area described in the PLS coordinate system. An image of the uploading screen and resulting cell top and cell bottom surfaces (ground and bedrock surfaces) are shown in Figure 4-1.

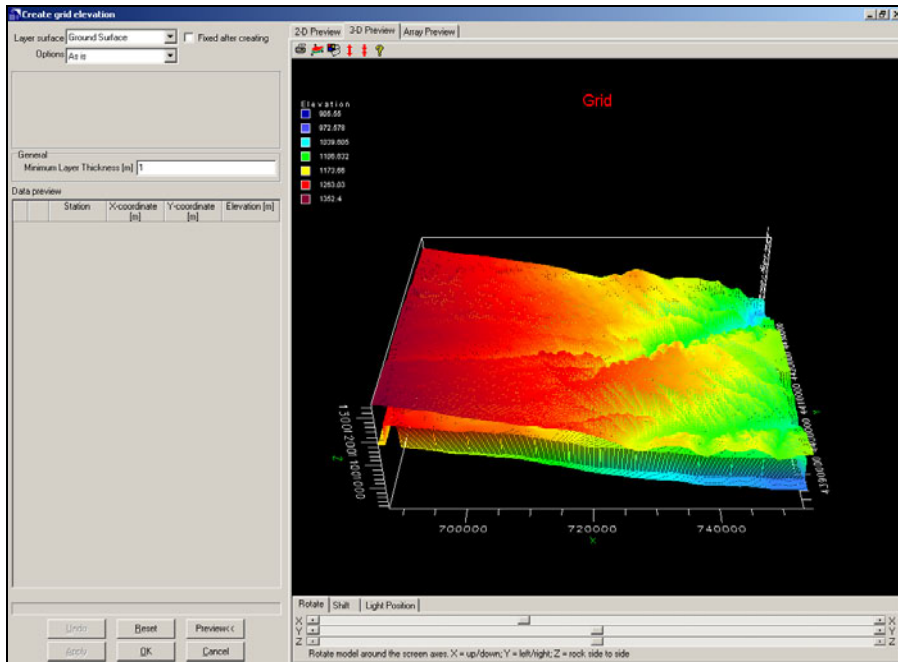


Figure 4-1: Grid Elevation Importation and Resulting Yuma County Surfaces (Visual Modflow v. 4.0 2003)

The initial head surface was uploaded similarly to the ground and bedrock surfaces. However, the initial head interpolation tool does not have the visual output capability used to display the surface as shown in Figure 4-1. Instead, the interpolated initial-head surface was compared visually to the digital image of the Weist (1964) contour map (Figure 4-2). By visual inspection, contours only deviate from the original contours along the boundaries of the image. The initial head surface, shown using the Visual Modflow contouring tools is shown as Figure 4-3.

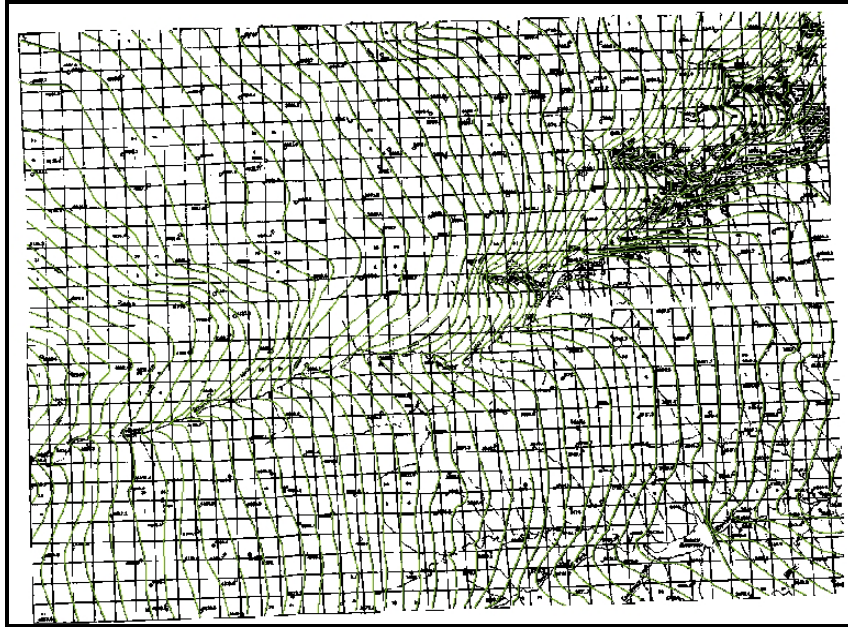


Figure 4-2: Scanned Image of Weist (1964) - 1958 Water Table Contours, Southern Yuma County
(Visual Modflow v. 4.0 2003)

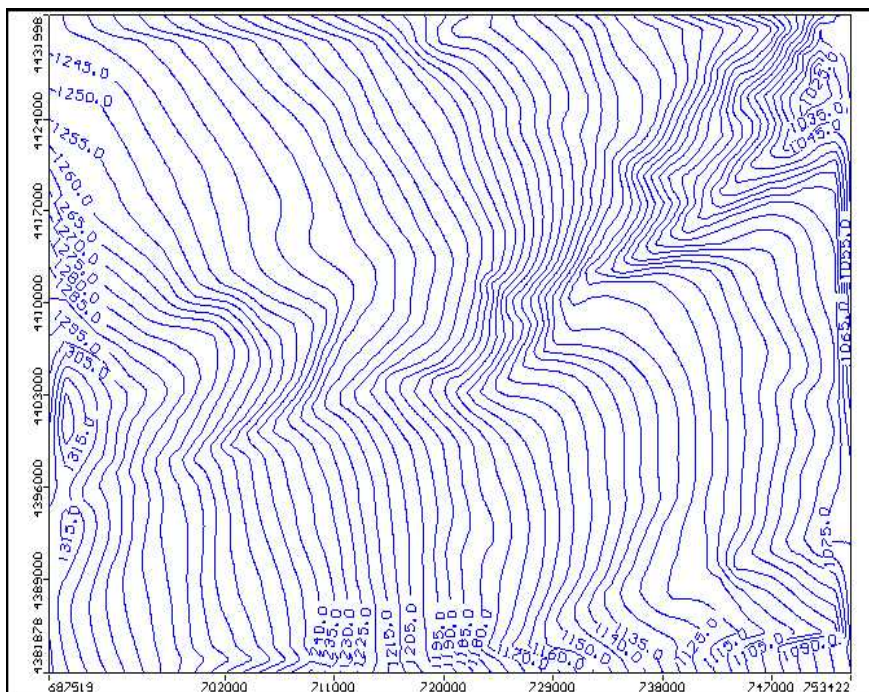


Figure 4-3: Modflow Initial Head Contours After Importation (m)
(Area matches Figure 4-2 - Visual Modflow v. 4.0 2003)

4.3.4 Resolving Surface Importation Errors

Some obvious model-surface errors occurred during importation of the surfaces, mostly around the outer edge of the model. The interpolation algorithm for those areas was constrained to using only elevations from input data on the inner side of the interpolated point. Figure 4-4 shows the original error band around the outer edge of the model.

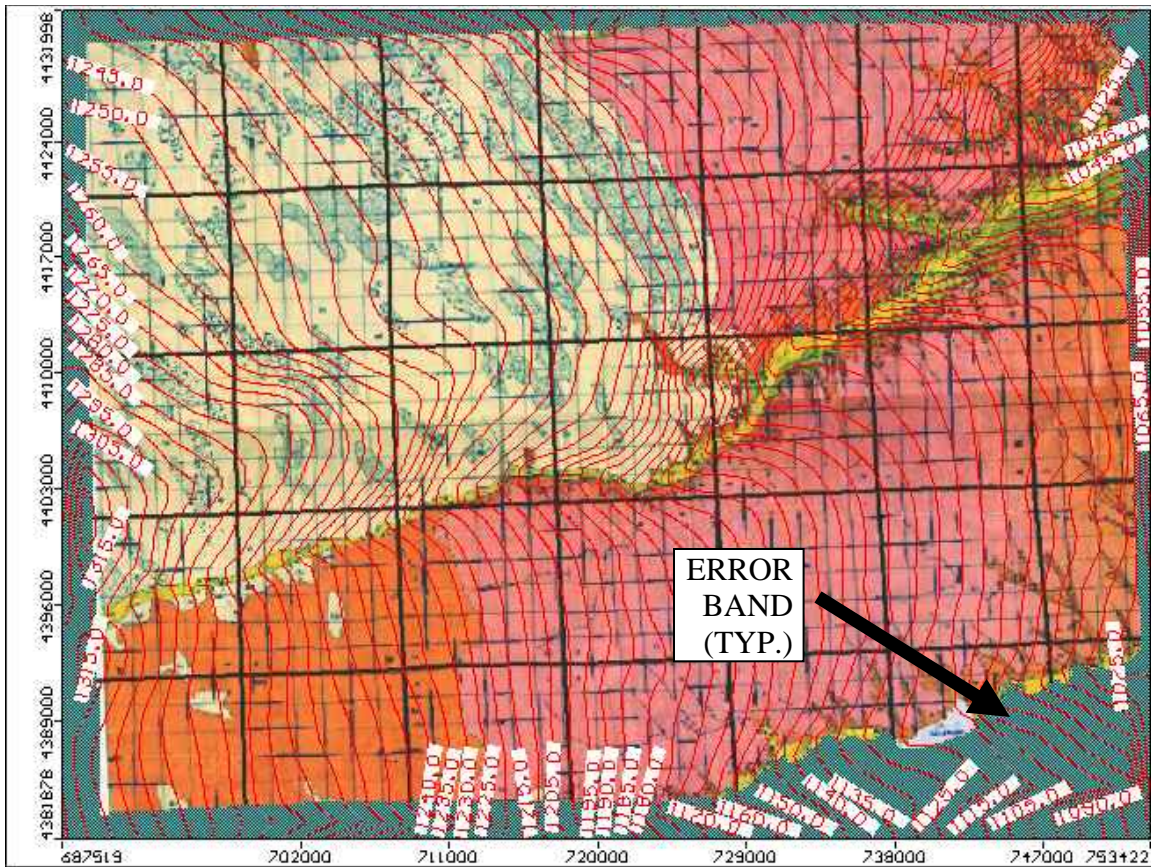


Figure 4-4: Initial Model Domain w/ Initial Head Contours (m) and Interpolation Error Band (Visual Modflow v. 4.0 2003)

Excluding the error band around the outer edge of the model was necessary to avoid erroneous results. Limits of the band were set by inspection of the individual cross sections. Errors could have been avoided by including data points from a larger region

than was encompassed by the model. This was realized after the model was complete but was insignificant to modeling results because the error band was excluded from the model to alleviate the problems.

Localized cell errors occurred in three internal model locations where the interpolated points did not coincide exactly with cell geometry. Local errors were corrected manually by smoothing the surface between the four surrounding cells. Visual Modflow contains an elevation adjustment tool as shown in Figure 4-5. The tool allows the user to edit numerical elevation data manually or adjusting elevation by visually smoothing the cross section line.

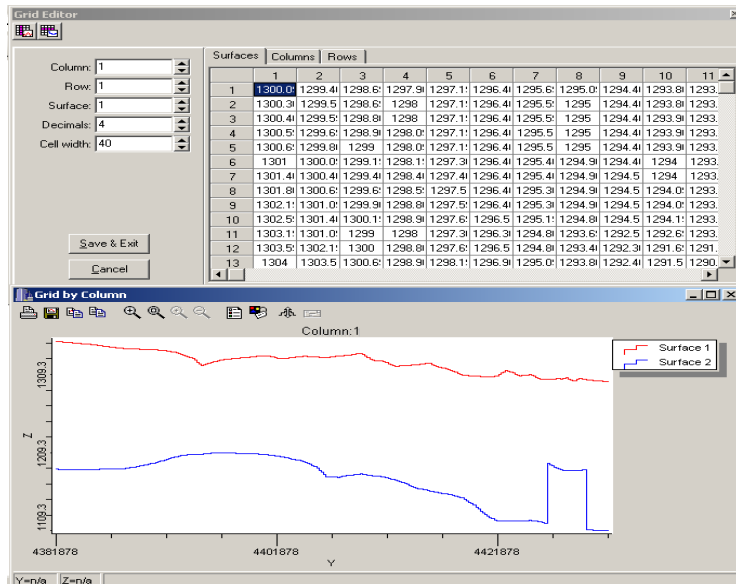


Figure 4-5: Grid Editor for Cell Error Correction (Visual Modflow v. 4.0 2003)

4.3.5 Well Data

The Colorado Division of Water Resources (CDWR 2005) provided well data in data base format. Well coordinates in UTM, rated pump capacities and well identification

numbers were tabulated separately for use in the GIS. Colorado usually requires the owner of a well to provide PLS coordinates indicating the proposed well location upon applying for an installation permit. It was discovered that the owners do not necessarily provide updated well location information after the installation of the well is completed. At times, duplicate well coordinates were provided for multiple wells owned by one party, or the owner provided the coordinates of their dwelling instead of the well installation location.

Well locations were verified using satellite photos (Figure 7-2, USDA 2005). Satellite photos were aligned to the NAD 1983 UTM coordinate system and vector point files created from the well table. Fine resolution (< 3-m) satellite photos served as a method of determining the well location “ground truth”. The location of wells not coincident with an irrigated field but within the groundwater basin and model borders were moved to fields assumed to be irrigated by the wells.

Wells were added manually to the model because each had distinct pumping rates and screening elevations. The screening used for all wells in the model was 100-percent of the well depth, under the assumption that the entire depth of the Ogallala Aquifer is potentially water bearing. Pumping schedules were set based on the Wachob (2005) pumping season length of 123 days, starting on the 135th day of the year (May 15). The Wachob schedule was an average of growing season length from farmer interviews by Fardal (2003). The 95 wells used in the model are shown in Figure 4-6.

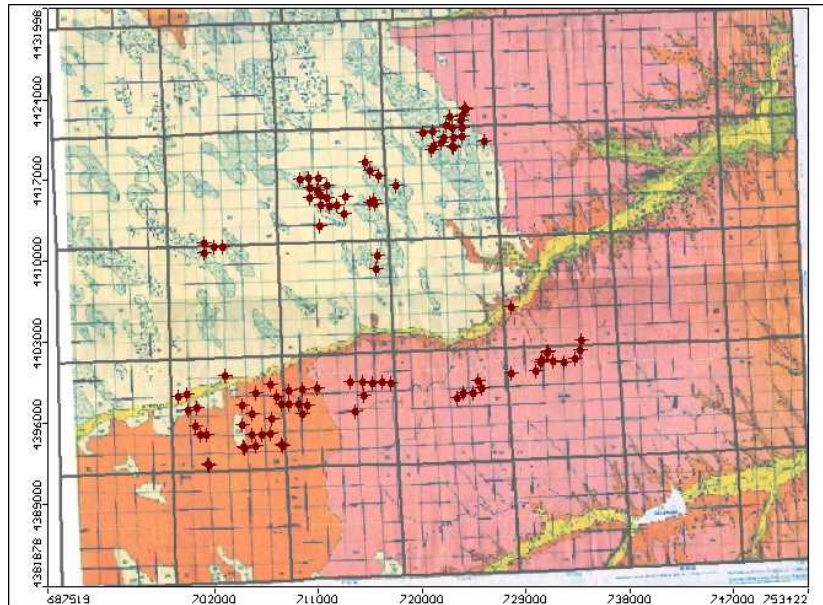


Figure 4-6: Wells Included in Arikaree River Model (Visual Modflow v. 4.0 2003)

4.4 MODEL ASSUMPTIONS, DEVELOPMENT AND PARAMETER VALUES

Important parameters and boundary conditions that affected model results include evapotranspiration rates, recharge rates, pump efficiency, soil hydraulic conductivity, saturated thickness, specific yield and model boundary conditions. The selection of inputs as described in this section improved the initial calibration. These parameters can all be improved with further study of the area. For this first model attempt, it was only possible to find reasonable ranges with supporting literature.

ET rates that have been input into the model are always the maximum possible rate. Calculated ET reduces linearly from the maximum ET rate when the water table is at the ground surface, to zero when the water table is at or below the extinction depth.

4.4.1 Evapotranspiration Assumptions

Riparian evapotranspiration (ET) has recently been a topic of significant debate. There is currently no “correct” technique used to determine riparian ET. Because of the ambiguity of this model input, an attempt was made to use ET data from recent studies in the modeled area, but true riparian ET, both rate and volume, is still unknown. Modeled ET is an educated guess, the parameter was varied, attempting to simulate growing season trends and transpiration.

A study of riparian ET along the Arikaree River at the Fox Ranch has been ongoing starting with the work by Fardal (2003), Griffin (2004) and continued by Wachob (2006). Monitoring of shallow alluvial wells along the river has been part of this study in an attempt to quantify riparian ET, including cottonwood stands. Monitoring was conducted manually on a semi-monthly basis as well as using pressure transducers, recording data at 1-hr intervals. A review of literature concerning riparian ET was included in the study by Wachob (2006).

Lou (1994) found that ET from riparian cottonwoods in New Mexico is around 145-cm per growing season. Pataki (2005) found that riparian ET from *Populus* vegetation is around 114-cm per growing season in the Colorado River Basin of Utah. Robinson (1968) studied a stand of cottonwoods in California and found that ET is approximately 164-cm per year.

Crop ET has been studied for years resulting in the wide use of the FAO Penman-Monteith Equation (Allen et al. 1998) but the equation is not easily applied to riparian vegetation because the method calls for a consistent crop in aerial extent, starting annually from seed with similar age and attributes. Consistency is not characteristic of

natural riparian areas. The riparian area is also very distinct from that of the plains shelf, located a few hundred yards away.

Using the White Method (White 1932) analysis for one growing season worth of observed well data, Wachob (2005) calculated a total growing season ET of 135-cm from cottonwood trees on the Fox Ranch. Specific yield was assumed to be 0.2 for this analysis, which is consistent with the very sandy material found in the alluvium (Fetter 2001). More recently, Squires (2007) and Riley (2009) completed a more in depth study of ET along the riparian areas near the Arikaree in an attempt to improve future models. Their work estimates a lower specific yield of 0.175 and corresponding seasonal riparian ET of about 90-cm.

To model ET using Modflow, a maximum ET rate and an assumed extinction depth are input. The extinction depth parameter is the depth below ground surface that the calculated water table must be for the ET to be assumed negligible. The model assumes a linear reduction in the rate of ET from the maximum input ET to zero as the calculated water table elevation reduces from the ground surface to the extinction depth. Because of this, the ET rate calculated by the model is only the input maximum when the water table reaches the ground surface. The modeled ET is lower than the maximum ET input or zero for the majority of the model because the water table is not normally at or near the ground surface.

The riparian extinction depth used in the model was 5-m to simulate the phreatophytic cottonwoods in the area and the maximum ET rate was 127-cm/year. Extinction depth of phreatophytes such as cottonwood trees can be rather large, upwards of 4.5-m (15-ft) accounting for their root structure (Katz 2001). The surrounding river

basin was assumed to have a 2-m extinction depth because of a mixture of plant types in the area with fewer to no trees.

The extinction depth was set to 0.5-m for the majority of the model with only the riparian and surrounding river basin areas assumed deeper. Doing this reduces the ET rate to zero anywhere that the water table is below 0.5-m from the ground surface. In essence, ET was not used in the model anywhere except in the river basin and riparian areas as shown in Figure 4-7 and Figure 4-8.

The ET parameter was applied to the riparian areas of the model with a maximum rate equal to a cumulative seasonal ET of 127-cm (50-in) distributed only over the 123-day growing season (~1-cm/day). The maximum riparian ET was reduced to a rate equal to 89-cm (35-in) per year (~0.2-cm/day) on day 258 to simulate the transition of the vegetation during autumn and set to zero on day 288 to simulate the winter months. For multi-year runs, the cycle was repeated. Using these inputs, the cumulative maximum possible ET is 133-cm (52.4-in) per season, in situations where the groundwater is at the ground surface and less as the groundwater subsides. This maximum is slightly less than the 135-cm calculated by Wachob (2005).

Areas of high vegetative cover around the river valley were apparent from aerial photos. These are referred to in this study as river basin areas (Figure 4-7). Green spectrums from the photos indicate possible higher moisture levels available for photosynthetic use. These areas were located near the river at lower elevations, and along known and apparent drainage ways.



Figure 4-7: NLT LandSat 7 Visible Spectrum Satellite Photo of Southern Yuma County (NASA World Wind 2006)

River basin ET (Figure 4-7 & Figure 4-8) was applied similarly to the riparian areas of the model but with a smaller maximum rate and extinction depth. The rate was equal to a cumulative seasonal ET of 81-cm (32-in) distributed only over the 123-day growing season (~0.6-cm/day). Maximum river basin ET was reduced to a rate equal to 120-cm (35-in) per year (~0.3-cm/day) on day 258 to simulate the transition of the vegetation during autumn. This was higher than the riparian band assuming that grasses and other riparian vegetation in the river basin area persist after trees in the area shed their leaves. River basin ET was also set to zero on day 288 to simulate the winter months and the cycle was repeated for multi-year runs. Using these inputs the cumulative maximum possible ET in the river basin areas is 91-cm (36-in) in situations where the groundwater is at the ground surface and less as the groundwater subsides.

ET in all other areas was assumed to be equal to a cumulative seasonal ET of 12.8-cm (5-in) distributed over the 123-day growing season only (~0.1-cm/day) with no

reduction for autumn months. This only applies to a handful of cells with high, calculated water table because of the 0.5-m extinction depth set for the remainder of the model.

Figure 4-8 shows the ET zones used in the model where red, white, teal, green and blue were used to designate land usage with the assumed usages being plains/farmland, plains/dune sands, irrigated area, river basin and riparian areas respectively.

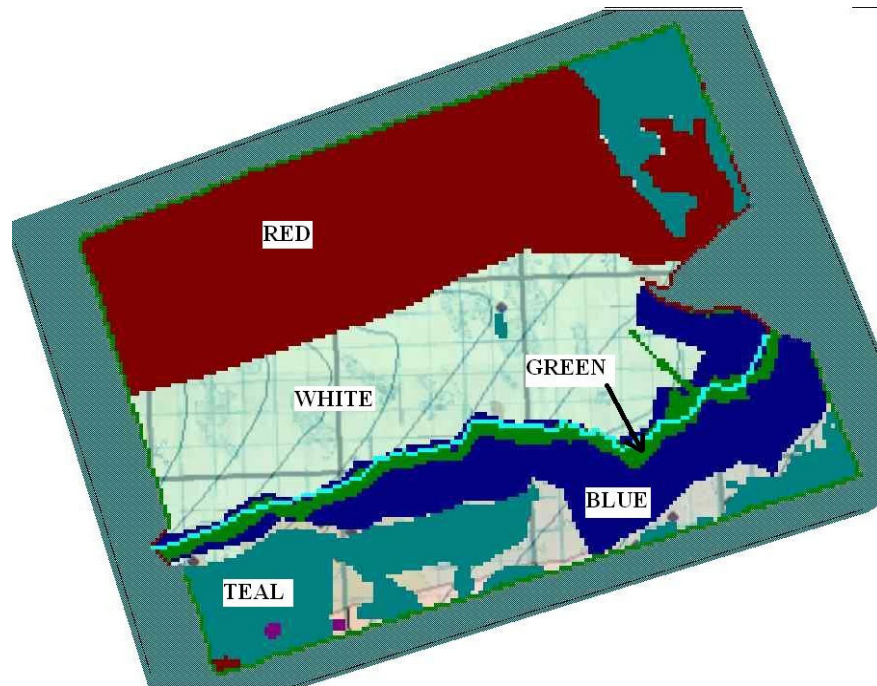


Figure 4-8: Arikaree River Model ET Zones (Visual Modflow v. 4.0 2003)

The cumulative ET distributed over the entire 80,900-ha (200,000-acre) model was calculated to approximately 365-ha-m/yr (2,950-acre-ft/yr). The cumulative ET distributed evenly over the model is therefore 0.45-cm/yr (0.18-in/yr) from groundwater. The total area designated as riparian area is approximately 3,180-ha (7,900-acres) and the river basin area is approximately 11,200-ha (27,700-acres). The cumulative ET, if distributed evenly over the total riparian and river basin area of 14,400-ha (35,600-acres)

roughly is 2.5-cm/yr (1.0-in/yr). If the ET is distributed over the riparian area only, the total ET is 11.5-cm/yr (4.5-in/yr).

The modeled ET is significantly below the literature values of ET for cottonwoods. From these results, it appears the majority of the ET in the model is occurring in the riparian area. Also, the modeled ET may be too low given modeled stream outflow is too high as discussed in later sections and that there is a large discrepancy between the Wachob (2005) riparian ET of 135-cm per growing season and the ET computed by the model. Adjustments to the extinction depths throughout the model and possibly the addition of small values for ET during the winter period may improve the model. These adjustments are hard to justify without improved studies of the parameters.

Even though the calculated ET was far less than the maximum input ET rate, the seasonal riparian ET of 127-cm (50-in) or ~1-cm/growing season day, used for the maximum ET was analyzed to see if it is reasonable for cottonwood trees (*Populus fremonti*), the assumed rate was compared to measured growing-season ET rates. The Northern Colorado region average historical reference ET (13-cm stand of cool weather grass) is 89-cm (35.12-in) for the growing season (April to October) or 0.42-cm/growing season day (Mecham 2004). The total reference ET for the month of June 2006 in Fort Morgan, CO was 27-cm (10.67-in) or 0.90 cm/growing season day for a total of 110.7-cm (43.6-in) per 123-day growing season. The modeled ET rate of ~1-cm/growing season day was considered high but reasonable because of the additional foliage of trees when compared to 13-cm of grass (Lou 1994; Pataki 2005). The model growing season also

started on day 135 (May 15th) and ended on day 258 (September 16th) including July and August, historically the hottest months of the year in Colorado (City Rating.com 2007).

The ET variable was generally not useful for calibration outside of the alluvium and major drainage ways because of the low water table levels with respect to the ground surface. Implications of high ET rates due to riparian vegetation were evident in model results. The model calculated drawdown of more than 0.5-m (chapter 5) along the river due solely to ET.

4.4.2 Recharge Assumptions

Since measurement of groundwater recharge is difficult, the recharge parameter was not well known. Recharge was used partially as a calibration variable within a reasonable range from published data. This variable was ambiguous however, because there were no studies of natural recharge found for the area.

Recharge was assumed to be very high for sandy regions within the model. Ponding on the dunes was limited during a high intensity rainstorm observed by the author on August 16, 2005 (0.8 to 1.2-in/hr, storm depth 0.2-in) (COAgMet 2006) even in local depressions. No ponding remained two minutes after the end of the storm. Average precipitation for Idalia, CO is 45-cm (17.7-in) per year (High Plains Regional Climate Center 2006) of which a high percentage would be expected to infiltrate. Vegetative cover in the dunes is sporadic at best, which also increases infiltration and potential recharge.

Gaye and Edmunds (1996) determined using chloride concentrations that recharge was approximately 30-mm per year in the sands of Northwestern Senegal. This is similar

to the approximation for Yuma County by Reddell (1957) of 36.8-mm per year using a numerical model.

A study by Jackson and Rushton (1987) determined that there is a very large range of possible recharge values for differing ground cover conditions. Recharge values in many cases, were indicated to be much higher than standard approximations. Calibration of a model for their study concluded that recharge input must be around 2.4-cm per year for portions of their study site with clay surface soils. A modeled run for April of 1981 required a much higher recharge rate to calibrate for a sandy soil region. 2.14-million liters per day was used for the 1-km² area, equivalent to a rate of 78.1-cm per year of recharge for that month.

Scanlon et al. (2002) reviewed methods of approximating recharge. Cited studies report ranges of recharge values from 0.01-cm /day to as high as 300-cm/day. Ranges varied by method of recharge computation and site characteristics. Sophocleous and Perry (1985) found a recharge range of 0.25 to 15.4-cm for a five-month span where the primary surface geological formation was dune sand at the study site in south-central Kansas.

Due to the wide range of published recharge rates, the model recharge zones were first delineated using maps of surface geology so they could be varied with calibration. Five basic surface geology zones exist within Southern Yuma County (Figure 1-4, Weist 1964). Dune sand is located northwest of the ranch. The Ogallala formation is exposed at the surface to the southwest of the river. Peoria Loess is the surface material to the east. Alluvial material underlies the Arikaree River channel. Exposed Pierre Shale bedrock is

prevalent to the east of the ranch separating the alluvium and the Ogallala or Peoria Loess top soils.

Well-sorted coarse sands have higher hydraulic conductivities and infiltrative capacity than do other materials (Fetter 2001). Of the five surface formations mentioned above, the sandy alluvial material and dune sand would tend to have the highest infiltrative capacity. Peoria Loess has a lower hydraulic conductivity than the other surface materials. The Ogallala formation is a water bearing and yielding material but cannot be classified as well sorted soil (Reddell 1967). Recharge was assigned to the model based upon mapped surface material locations (Figure 1-3, Figure 1-4).

A high infiltration rate was assumed for the alluvial material. 38-cm (15-in) per year was used for the recharge rate assuming that the majority of the precipitation reaching the ground will find open water or the shallow alluvial water table. The water table through the alluvium is very high and the water table responds very quickly to infiltration events (Wachob 2005). ET also occurs at a high rate and the net recharge is the difference between ET and infiltration. Results from monitoring well observations show rises in the water table level of up to 0.5-m, less than an hour after the start of precipitation (Wachob 2005).

The other modeled areas were assigned recharge based on the surface geology. Recharge input into the model was 12-cm/year for Peoria loess, 15-cm/year for the Ogallala and 20-cm-year for the north dune sands. These are all high and could be improved with more accurate modeled vadose zone calculations and specific yield.

During calibration, recharge values were adjusted if regional water table levels were too high or too low. An additional zone was implemented in the northern dune area

with lower recharge value than southern dune sand (both north of the river) (Figure 4-9). Less recharge and slightly lower sand content was assumed for the soils to the north because of increased farming seen in aerial photos.

No significant changes from initial recharge estimations were required for the Peoria Loess or the Ogallala Formation. Changes made to the rate of recharge from the assumed rate were quite high for dune sand and alluvial material. Final rates were changed from 15-cm (6-in) per year to 33-cm (13-in) per year for the south dune sand, 15-cm (6-in) per year to 20-cm (8-in) per year for the north dune sand and 25-cm (10-in) per year to 38-cm (15-in) per year for the alluvium. Recharge zones assigned in the model are shown in Figure 4-9.



Figure 4-9: Generalized Model Recharge Zones (Visual Modflow v. 4.0 2003)

Stream outflow from the model was expected to be high because of the increased recharge used to maintain high water table elevations. As described later in chapter 5, the model results show that the stream outflow from the model is 356,549-m³/day (145-cfs) too high. Assuming this is due solely to high recharge values, recharge would need to be reduced throughout the model by 16-cm (6.3-in). Obviously, the distribution of the reduction would need to be representative of the proximity of the water table to the ground surface, the ground cover and surface soils. Further study of this parameter is needed to determine that distribution.

Using these inputs, the total recharge calculated by the model was 17,900-ha-m/yr (144,800-acre-ft/yr). Distributed across the 200,000-acre model, this is roughly 22-cm/yr (8.7-in/yr). This is high. Further calibration by recharge and S_{ya} over multiple year runs would help to improve the internal water balance.

4.4.3 Hydraulic Conductivity

Approximate hydraulic conductivity ranges from the USGS (Borman 1983) were used for the Ogallala formation in Southern Yuma County. Borman (1983) suggested that the hydraulic conductivity of the aquifer around the Arikaree River ranges from 15-m/day (50-ft/day) to 61-m/day (200-ft/day). Well driller logs were used in the development of the Borman data. It is clear that this data is very generalized by the rough character of the map. Zones of high hydraulic conductivity are seen within zones of low hydraulic conductivity and vice versa. No obvious deposition method corresponds to this characteristic. Ogallala hydraulic conductivity values between 7.6-m/day (25-ft/day) and 99-m/day (325-ft/day) were used in the model. 152-m/day (500-ft/day) was used for

alluvial hydraulic conductivity, which is very high and could be improved with more research.

Hydraulic conductivity was one of the more important parameters used in model calibration. Water table contour shape was sensitive to hydraulic conductivity. Assignment of cell hydraulic conductivity was an iterative process, attempting to match the shape of the Weist (1964) water table contours with the model-calculated water table contours. Bedrock surface elevation was used to influence trends. High hydraulic conductivity was assigned in bedrock lows, assumed to be paleo-channels.

Hydraulic conductivity was assumed lowest upstream of paleo-channels and was increased incrementally proceeding downstream as dictated by calibration output contours. Hydraulic conductivity was decreased moving away from the river and the paleo-channels. Calibration of the model was simplified by taking into account paleo-channel assumptions. The model was calibrated to the 1958 USGS water table data (Weist 1964) (Figure 1-5). Calibration by recharge was concurrent to calibration by hydraulic conductivity but limited by precipitation and was used to increase or decrease heads regionally. Calibration statistics are provided in section 4.6.

During the calibration, there was found to be no correlation between the surface soils and changes in aquifer hydraulic conductivity. The lack of correspondence between hydraulic conductivity and surface soil type was assumed reasonable because the Ogallala Formation underlies the entire modeled region (excluding bedrock outcroppings).

4.4.4 Specific Yield

Specific yield values between 0.175 and 0.225 were used in the model. Values were taken directly from Borman (1983). Islands of high or low specific yield were apparent in the specific yield map as they were in the map of hydraulic conductivity. This was assumed to be a problem with specific yield data as well, although other studies were not available for comparison. Figure 4-10 shows specific yield zone location used in the model.

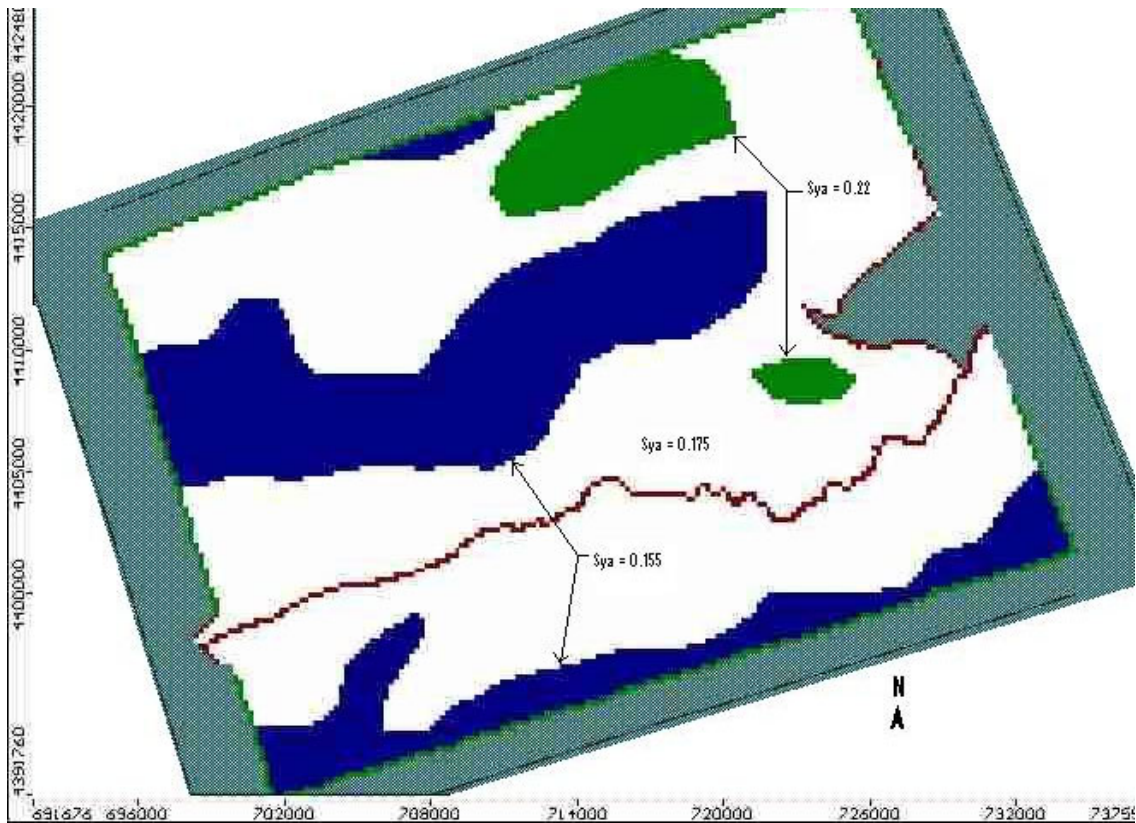


Figure 4-10: Specific Yield Zones (Visual Modflow v. 4.0 2003)

**(Green $S_y = 0.22$, White $S_y = 0.175$, Blue $S_y = 0.155$)
(Adapted from Borman 1983)**

Again, more research is needed to determine the actual specific yield of the soils in the area but published values were used in the model. According to the results of the model, recharge is too high. Because of the high recharge input, specific yield is also probably too high in order to offset recharge. Lower specific yield would reduce the recharge required to calibrate the model and would in-turn, lower stream outflow closer to what was measured in the field.

4.4.5 Model Boundary Conditions

Modeling the Arikaree River basin was first attempted including all of Southern Yuma County. With this configuration, the model was unstable due to some areas of very small saturated thickness. The instabilities occurred when the algorithm could not solve for water level in any particular cell including in areas of bedrock outcropping. These areas were located in the catch basin and downstream of the mouth of Copperkettle Creek (Figure 1-2, Figure 3-4). After examination of the necessary boundary conditions and the location of the cells creating model instabilities, the model was reduced in size as shown in Figure 4-11. Ultimately, the limits of the model were set just outside of the 1958 water table divides of the Arikaree groundwater basin. Upstream and downstream limits were set at Copper Kettle Creek to the east and the western border of range 47, about six miles (9.7-km) west of the Fox Ranch.

Constant head values were assigned to the boundaries calculated by interpolating between initial head values at the section lines. Initial head values from the 1958 data were used (Weist 1964). Constant head boundaries were changed to general heads after initial calibration. General heads were used because water levels in cells specified with a general head boundary can respond to given perturbations such as nearby wells and

recharge. Reference points outside of the model boundaries are required for use of general head boundaries. The points were chosen having a known head, distance from and conductivity to the desired general head boundary.

Annotated lines were drawn as shown in Figure 4-11, on the model interface 1,000-meters away to the north and south and 2,000-meters to the east and west from desired general head boundary location. Input head values were those originally assigned as initial head to the cells at the annotated lines. The harmonic mean of the initially calibrated conductivity from the general head to the target cell was used.

The hydraulic head values were less for reference cells than for boundary cells since the boundaries of the model were set at, or outside of, the water table divide. It was assumed that the boundary was not interfering with cells inside the model when the model maintained initial head values inside the boundary. As such, the water table divide location was maintained.

Cell height was very limited along Copperkettle Creek (Figure 1-2). The model and surface geology maps both show outcropping of bedrock along the creek. Head values were assumed not to change much in the alluvium at the up and downstream edges of the model. Constant head boundaries were therefore used to maintain initial heads in those locations as shown in Figure 4-11. Green cells in the figure signify general head boundaries. The general head boundary condition was used at the north and south boundaries of the model. Red cells in the figure signify constant head boundaries.

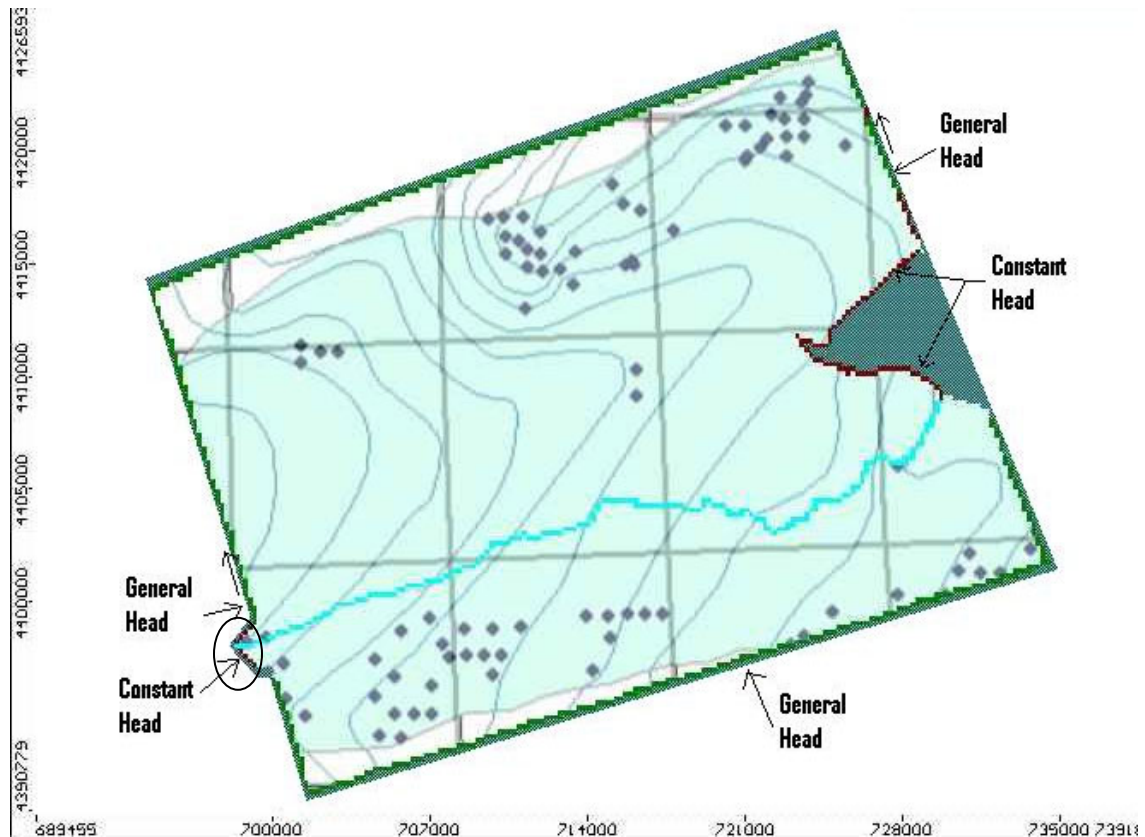


Figure 4-11: Final Model Boundary Conditions w/ Well Locations, Groundwater Basin and Bedrock Contours (Visual Modflow v. 4.0 2003)

4.4.6 Well Pumping Rates

Pump discharge capacities were reduced from rated capacities because of pump age. Most of the wells in the model were installed in the 1950's or 1960's, resulting in an approximate pump age of 40-years. According to a limited number of farmer surveys (Fardal 2003), it was found that pump rates in Southern Yuma County average around 61% of rated capacity. All well pumping rates were reduced to 61% of rated capacity for runs after calibration. Full rated well capacities were used during calibration for wells existing in 1958 according to Weist (1964). All wells used in the model are shown in Figure 4-11 as diamonds.

4.5 STREAM PACKAGE

Initially, constant head cells were used as the stream cell boundary for model calibration. The Weist (1960) water-table contour map and onsite stock well measurements (chapter 3) show that the stream is gaining, justifying the use of a constant head boundary condition as a rough representation of the stream. The stream has a natural maximum stage (head) at flood level, just above where the stream becomes bank full. A minimum head is expected, not far below streambed because the stream is currently gaining according to the groundwater gradient.

After initial calibration, the constant head stream boundary was replaced by a stream package boundary to simulate the dynamics of a flowing stream. The stream package uses the elevations of the top of the designated cells to determine channel slope. The data set used to import the top of cell elevations was not refined enough to show streambed elevation because the stream channel is only a few meters wide. Streambed cells had to be assigned manually. The cells representing the streambed in the model of the Arikaree River were smoothed to ensure stream connectivity. The streambed was defined in the stream boundary cells at a slope obtained using a differential GPS survey of the streambed (Appendix B) along with an aerial photo of the stream. The top-of-cell elevations set at 0.5-m above the streambed to create a 0.5-m deep channel at the measured streambed elevations. The stream package boundary condition was used to create a continuous stream model. Streamflow is transferred from one cell to the next along the stream while simulating gains and losses in flow rate as required by the model due to aquifer conditions. The stream characteristics used as stream package input values

are shown in Table 4-1 and were derived from the October 2005 streamflow measurements.

Table 4-1: Stream Model Characteristics

STREAM PARAMETERS	
Parameter	Value
Manning's Roughness	0.75 (s/m ^{1/3})
Channel Width	1 (m)
Channel Depth	0.5 (m)
Streambed Hydraulic Conductivity	76.2 (m/day)
Headwater Inflow	4,893 (m ³ /day)

4.6 CALIBRATION

Hydraulic conductivity, as previously discussed was the primary calibration parameter for the Arikaree River model. Recharge and ET were secondary calibration parameters. Hydraulic conductivity was used first because calibration was completed by comparing the steady state head results to the 1958 initial heads from Weist (1964). Matching the shape of these contours was only possible using hydraulic conductivity because unreasonable recharge values and zones would have had to be assigned to match the heads. Wells shown in the 1958 data set were pumped during calibration at 100 percent capacity rating. The stream was represented using a constant head boundary during calibration with the stream stage elevation in a given location as the input head value for each cell.

Calibration of the model using the pertinent data from all of Southern Yuma County was completed first to approximate regional groundwater trends. Limits of the Southern Yuma County model were the east and west borders of the county along with the north and south forks of the Republican River within the county as shown in Figure 4-4. Alluvial hydraulic conductivity of 152-m/day was used for the Arikaree and both

forks of the Republican River. Recharge was varied as previously discussed. ET was used to decrease water-table elevation only in areas of local high water tables because the ET model does not extract water when the water table is below the extinction depth.

The model size was later reduced by moving the boundaries to those shown in Figure 4-11. Calibration was then refined for the smaller model. The correlation of the calibrated heads to the 1958 water table was examined by creating observation points throughout the model containing the initial head values from the input data based on the 1958 water table contour map by Weist (1964). 173 points were created, approximately one every square mile as shown in Figure 4-12.

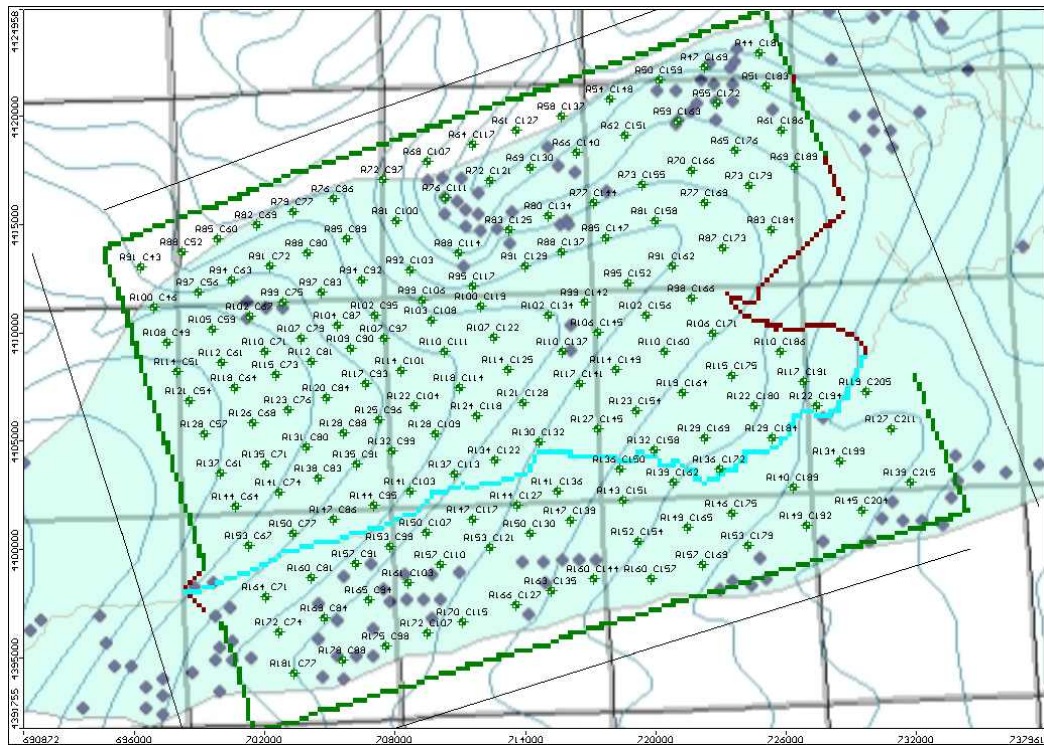


Figure 4-12: Observation Points used for Calibration (Visual Modflow v. 4.0 2003)

Initial head was compared to the model output values for the cells at each of the 173 observation points. At the 95% confidence interval, the standard error of the estimates was 0.242-m with an absolute residual mean of 2.337-m, a maximum residual of 10.07-m and a minimum residual of 0.012-m. The correlation coefficient of the calibration was 0.996. Figure 4-13 is the output head contours overlaid upon the 1958 initial head contours. Figure 4-14 is a graph of the calculated heads versus the observed heads at the calibration points.

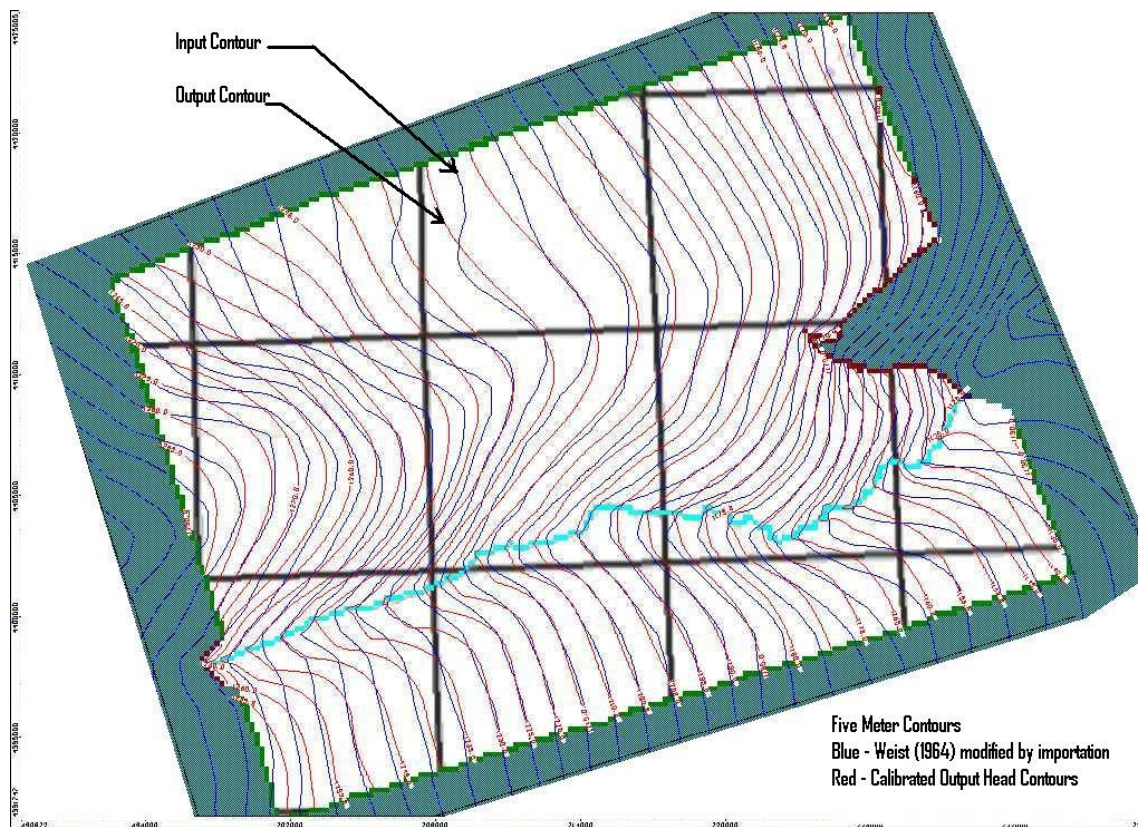


Figure 4-13: Comparison of Calibration Output Head Contours and the Initial Head Contours (Visual Modflow v. 4.0 2003)

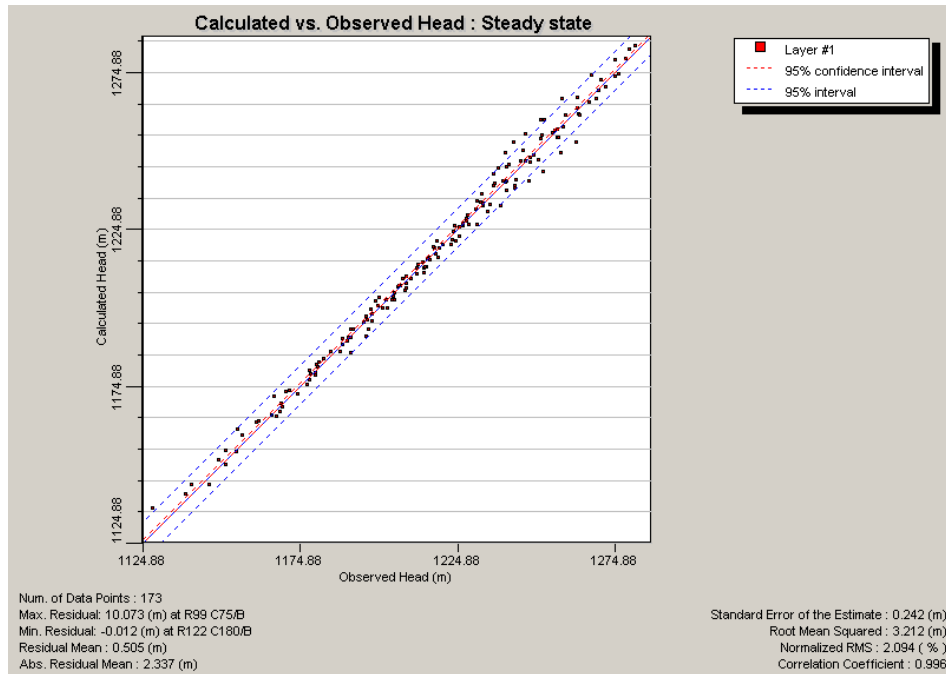


Figure 4-14: Steady-State Model Calibration Correlation Graph (Visual Modflow v. 4.0 2003)

4.7 TRANSIENT STATE MODEL

The last step in modeling the Arikaree River groundwater system was developing a transient model, rather than a steady-state model, and evaluating the calibration.

Evaluation of the seasonal stream-depletion and drawdown from pumping was required to identify which wells around the Fox Ranch would be the best forbearance candidates in terms of quick response time and maximum streamflow recovery.

The recharge was more realistically modeled by omitting pumping from the model during the winter season. The typical Colorado growing season is about 123 days per year (Fardal 2003). By modeling pumping for only the 123 days per year included in the growing season, water-table level recovery was modeled during the non-irrigation season.

Flow in the Arikaree River is typically lowest at the end of the summer, after water has been removed from the area by ET and well pumping. At the end of the growing season, fish habitat is generally lowest because of reduced streamflow. Well analysis was completed using the late-season period.

4.7.1 Development of the Transient Model

Steady state was assumed for initial model calibration. The transient model used the base steady-state data, but time intervals were added to represent the change of seasons. As time intervals were added to the model, the output heads were compared to the 1958 water-table data to check for significant changes in the quality of the calibration relative to steady state. Wells known to exist in 1958 according to Weist (1964) were pumped during the first 135 days (Jan. 1st to May 15th) of the first model year to represent residual effects of previous pumping seasons. This helped to maintain the steady state calibration, before the first growing season.

Water levels for the pre-development (no pumping) transient state model were assumed to recover to the pre-growing season levels each year. The pre-development water levels were assumed to be equal on the same day of each year (e.g. Jan. 1st 1957 compared to Jan. 1st 1958). For this to be true, the assumption was made that there was no yearly water-storage change in the model (the water budget was balanced before development). Ten years of seasonal changes to ET and recharge were added and the initial water table levels were compared to the model output heads at each calibration observation point, for the day representing day 3,785 (May 15th of the eleventh year). At the 95 % confidence interval, the standard error of the estimates was 0.429-m with an

absolute residual mean of 5.537-m, a maximum residual of 17.7-m, and a minimum residual of 0.021-m. The correlation coefficient of the calibration was 0.988. Figure 4-15 is the output head contours for May 15th of the eleventh year overlaid upon the 1958 initial head contours (Weist 1964). Figure 4-16 is a graph of the calculated heads versus the observed heads at the calibration points. After comparing the ten-year model output to the initial heads, all developed wells were pumped to represent the developed model.

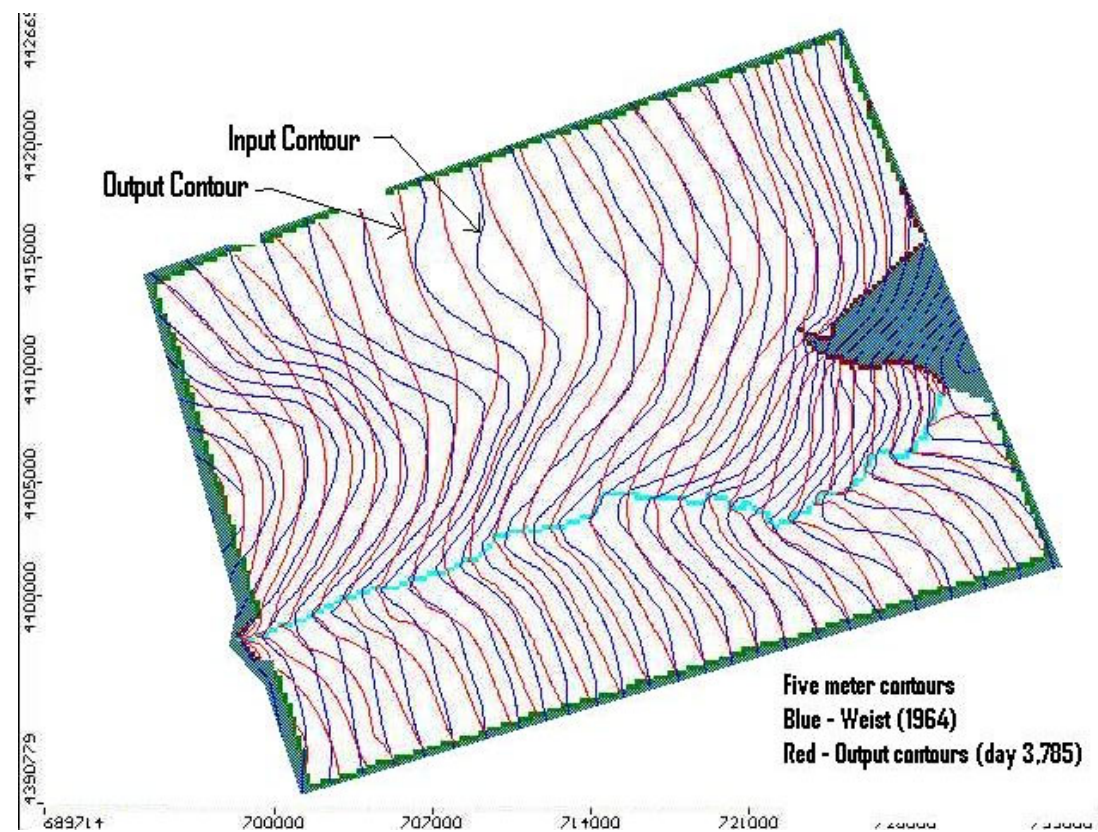


Figure 4-15: 10-year May 15th Pre-development Transient State Model Output Contours vs. Weist (1964) Input data (Visual Modflow v. 4.0 2003)

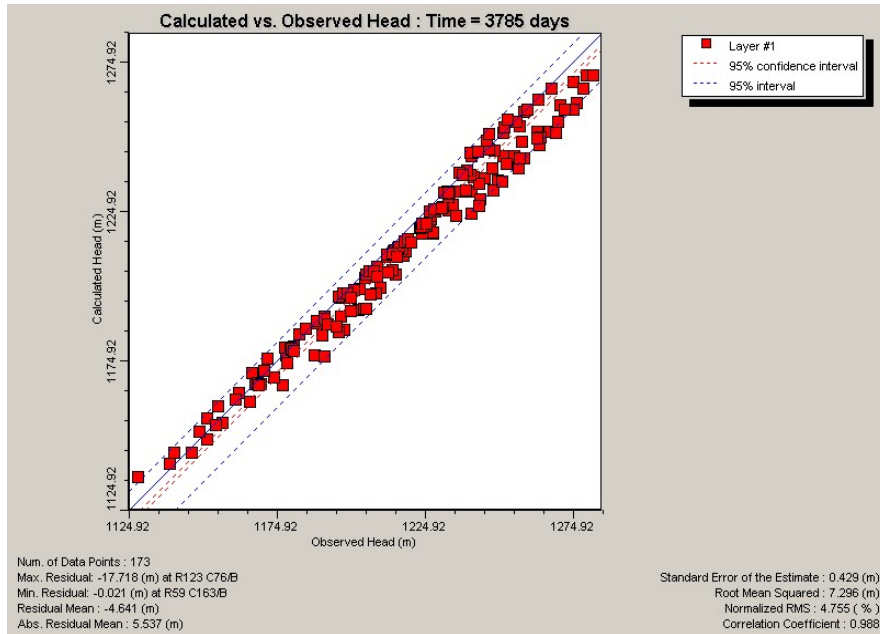


Figure 4-16: Transient State Model Calibration Correlation Graph (Visual Modflow v. 4.0 2003)

For the post-development model, wells were pumped during the growing season from day 135 to day 258 (May 15th to Sept. 15th). Cells containing seven of the 90 wells included in the model (Table 4-2) dried after pumping for multiple seasons. By changing the specific yield to a constant 0.22 throughout the model, from the specific yield shown in Figure 4-10, drying of wells was avoided. This indicated that the ten-year water table projection could be improved using more accurate estimates of specific yield. The model however, was not recalibrated using specific yield to prevent well drying. Instead, well pumping rates for those wells that dried were reduced yearly as the model progressed. Table 4-2 shows the coordinates of the wells with reduced pumping rates, the elevation data for the wells, the rated capacity of each well, the maximum and the minimum pumping rate used for each of the seven wells.

One implication of reducing capacity instead of calibration by S_{ya} was that the water table level at each of these well locations was maintained in close proximity to the

bedrock elevation throughout the transient model runs. Small saturated-thickness (< 6-m) occurred at three of the well locations. The primary cause of well drying is unknown but it is suspected that there is a cumulative effect from incorrect specific yield, uncertainties in the well pumping schedules and pump capacity along with superimposed effects from other wells.

Table 4-2: Wells Requiring Additional Pumping Rate Reductions to Prevent Drying in the Transient Model (See Figure 5-7)

Well	D	J	K	O	V	W	Y
PLS Coordinate	SC00404714AB	SC00404618BA	SC00404713AC	SC00404618AA	SC00304703BC	SC00304704AC	SC00304705DA
UTM Easting (m)	705571.4	708387.6	707415.3	709628.1	702719.5	701976.6	701076.9
UTM Northing (m)	4398855.0	4398889.0	4398319.0	4398922.0	4411269.0	4411253.0	4410782.0
Ground Elevation (m)	1269.8	1250.6	1264.1	1257.4	1280.6	1281.3	1284.0
Initial Water Level (m)	1242.0	1232.9	1237.5	1228.7	1244.7	1246.3	1251.5
Bedrock Elevation (m)	1213.5	1196.1	1198.2	1191.7	1239.3	1242.2	1247.1
Rated Capacity (m ³ /d)	5451	8722	6541	5451	8722	7596	5451
Max Modeled Rate (m ³ /d)	3325	5320	3990	3325	5320	4633	3325
Min. Modeled Rate (m ³ /d)	2317	3134	3543	2862	3407	2998	2862
Int. Sat. Thick. (m)	28.5	36.8	39.3	37.0	5.4	4.0	4.4
Final Reduction %	43%	36%	54%	53%	39%	39%	53%

4.8 NUMERICAL MODEL SUMMARY

A numerical model was created using Visual Modflow v. 4.0 2003, for the Arikaree River groundwater basin in Yuma County. The model was created to be as realistic as possible using input data from published sources. Weist (1964) was the most important and relevant data source used in model because it provided initial head and surface geology data for the model. The format of digital bedrock and ground surfaces developed by the U.S.G.S. was modified and use in the model. Existing wells located within the model boundaries were included based on well data from the Colorado Division or Water Resources (CDWR).

The steady state model was calibrated to match the pre-1958 water table levels using primarily the hydraulic conductivity within a range based on Weist (1964). The

hydraulic conductivity was varied, based on observed trends in bedrock surface and proximity to existing stream channels. The model was developed for transient state analysis of stream depletion caused by wells in close proximity to the Arikaree River near the Fox Ranch, located in south-central Yuma County.

The least-known model inputs were evapotranspiration, recharge and specific yield. Specific yield estimates need to be improved for better multiple-year projections from transient modeling. Evapotranspiration and recharge are active areas of research for this area. Preliminary estimates of these values were used in the model but need to be improved to accurately calculate the water budget for the area.

CHAPTER 5 WELL ANALYSIS

An analysis of stream depletion and drawdown was conducted to determine the effects of irrigation wells located within the model. The analysis compares the results of the numerical model and analytical models. Despite the fact that the model is preliminary and many of the input parameters need to be refined or revised, the well analysis should be valid because the calibration was effective and the analysis is based upon superposition. By superposition, a model will calculate the same results for well analyses regardless of the background conditions, provided the transmissivity and specific yield are appropriate. Superposition is valid for modflow models because the basic differential equation used in the model is linear.

Stream depletion and drawdown, as a result of specific wells pumping, were estimated using the numerical model, the Theis equation and the Glover equation. The drawdowns at the river from ET and irrigation well pumping were calculated using the numerical model and compared to the drawdown calculated using the Theis equation. The numerical model stream depletion was compared to the stream depletion calculated using Glover equation analysis. The numerical model was used to determine which wells have the most impact on streamflow, based on the calculated change in streamflow from

the modeled wells. Results were used to rank wells in order of their importance in hypothetical forbearance considerations.

5.1 DRAWDOWN ANALYSIS

5.1.1 Theis Equation Drawdown

Drawdown from irrigation wells was initially thought to be large along the Arikaree River. An investigation was completed to compare the amount of drawdown from wells versus drawdown from water use by riparian vegetation. The Theis equation (Equation 5-1) was used to calculate drawdown from ET and irrigation wells located closest to the Fox Ranch, 123 days after the start of the growing season. Detailed descriptions of the Theis and related equations are found in McWhorter & Sunada (1977). Equation 5-1 is the drawdown response to pumping of a single isolated well in an infinite, homogeneous, isotropic aquifer:

Equation 5-1

$$s = \frac{Q}{4\pi T} W(u)$$

Where: s = drawdown (L)

Q = well pumping rate (L^3/T)

T = Transmissivity (L^2/T)

W(u) is the exponential integral, referred to as the Theis well function. The Boltzman variable 'u' is:

$$u = \frac{r^2}{4\alpha t}$$

Where: $\alpha = T / S_{ya}$

r = radial distance away from the well (L)

t = time (T)

S_{ya} = Specific Yield

Using 1.09-cm/day, equivalent to 53-in per 123-day growing season (Wachob 2006), for riparian ET and a riparian band of 243-m width, total seasonal riparian ET is 2,660-m³/day per linear kilometer of river. The assumption was made that riparian ET can be represented as a series of pumping wells in the alluvium. Drawdown was calculated for incremental bands, upstream and downstream of a hypothetical point. The bands had lengths in fractions of kilometers starting with 1/64, 1/32, 1/16 and 1/8-km, then increasing by 1/8 km increments to one-kilometer and finally including two and three km bands. Pumping was assumed to occur from the centroid of each band.

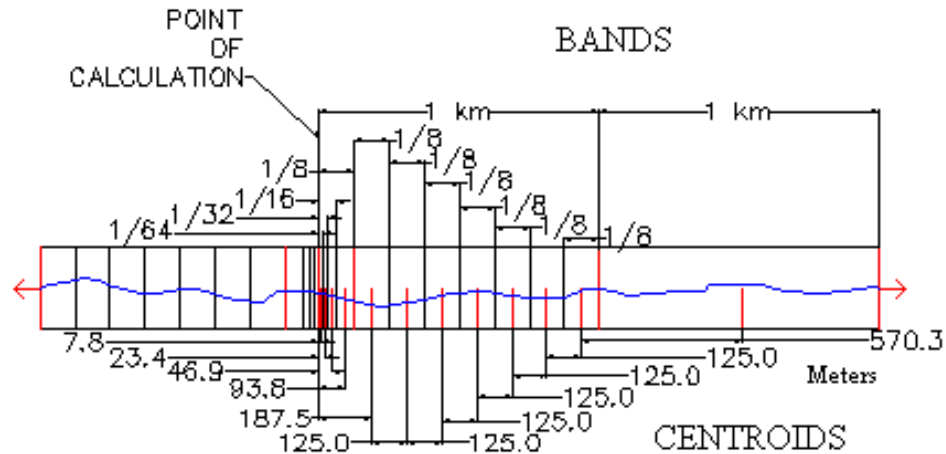


Figure 5-1: Thisis Equation Riparian Bands and Centroid Locations

Transmissivity was assumed to be $1,370\text{-m}^2/\text{day}$ with an alluvial aquifer thickness of 9-meters. The specific yield used by Wachob (2006) of 0.20 was also used for this analysis. At a given location along the river, the drawdown from ET was calculated to be 96-cm after 123 days (Appendix D).

Wells near the Fox Ranch were evaluated using the same method to estimate drawdown. The transmissivity was approximated using the calibrated numerical-model hydraulic conductivity and aquifer depth. Transmissivity of $975\text{-m}^2/\text{day}$ was used for wells located north of the river and $1,025\text{-m}^2/\text{day}$ for wells to the south. Specific yield for the calculations was 0.20 and the unadjusted Colorado Division of Water Resources rated well capacity was used. The nearest irrigation well to the Fox Ranch residence is 4.5-km away according to the GIS data. The total drawdown from the six closest wells after 123 days of pumping was calculated to be negligible ($<0.001\text{-m}$, see Appendix D). Steady-state drawdown from the wells would not be negligible. Using a ten-year pumping period with continuous pumping, the cumulative drawdown for the six wells was calculated to

be 2.1-meters. It is concluded that irrigation wells are too far away to produce drawdown at the ranch within a single growing season.

5.1.2 Numerical Model Drawdown

The seasonal well drawdown calculated by the numerical model was negligible at the river using the stream package boundary condition along the Fox Ranch as shown in Figure 5-2. The model indicates that drawdown occurs at the river adjacent to the well field located to the east of the Fox Ranch (contour intervals starting away from the wells: outer to inner contours are 0.05-m, 0.13-m, 0.25-m, 0.5-m, 0.75-m, 1-m, 2-m and 3-m).



Figure 5-2: Growing Season Well Drawdown w/o ET (Visual Modflow v. 4.0, 2003)

The model calculated extensive seasonal drawdown along the river due to ET. Figure 5-3 shows drawdown contours, the largest of which is 2-meters at the end of the growing season, from ET. By inspection of the model output contours, the total drawdown from ET increases progressing from left (upstream) to right (downstream). This is partly because a constant inflow was specified at the river headwaters with the stream package. Inflow is not decreased as would be required to accurately represent ET upstream of the model. The contour intervals are the same as above for drawdown by irrigation only.



Figure 5-3: Growing Season Drawdown from ET (Visual Modflow v. 4.0 2003)

Figure 5-4 shows the cumulative seasonal drawdown from both irrigation and ET. The cones of depression and drawdowns are larger than in previous figures along the river. The contour intervals are the same as stated for drawdown by irrigation only.



Figure 5-4: Cumulative Seasonal Drawdown, Irrigation and ET at the end of the growing season (day 257) (Visual Modflow v. 4.0 2003)

5.2 STREAM DEPLETION ANALYSIS

Southern Yuma County irrigation wells were analyzed to determine the amount of single-season stream depletion from each well. The numerical model was used, implementing two analysis methods. Results from the numerical model analyses were compared to results obtained using the analytical Glover equation model.

5.2.1 Numerical Model Stream Depletion Analysis

The numerical model was used to calculate stream depletion caused by individual wells. Mass-balance sheets (Figure 5-5) created by Visual Modflow, display the total volume and time-variant rate-of-flow to or from the aquifer due to the various boundary conditions. The model calculates the aquifer mass balance. The terms listed under the heading “in” describe the rate or volume of flow from the boundary into the aquifer. Terms listed under the heading “out” describe the rate or volume of flow from the aquifer into the boundary. The flow into and out of the aquifer due to the stream boundary condition are listed in the mass-balance sheet under the term stream leakage.

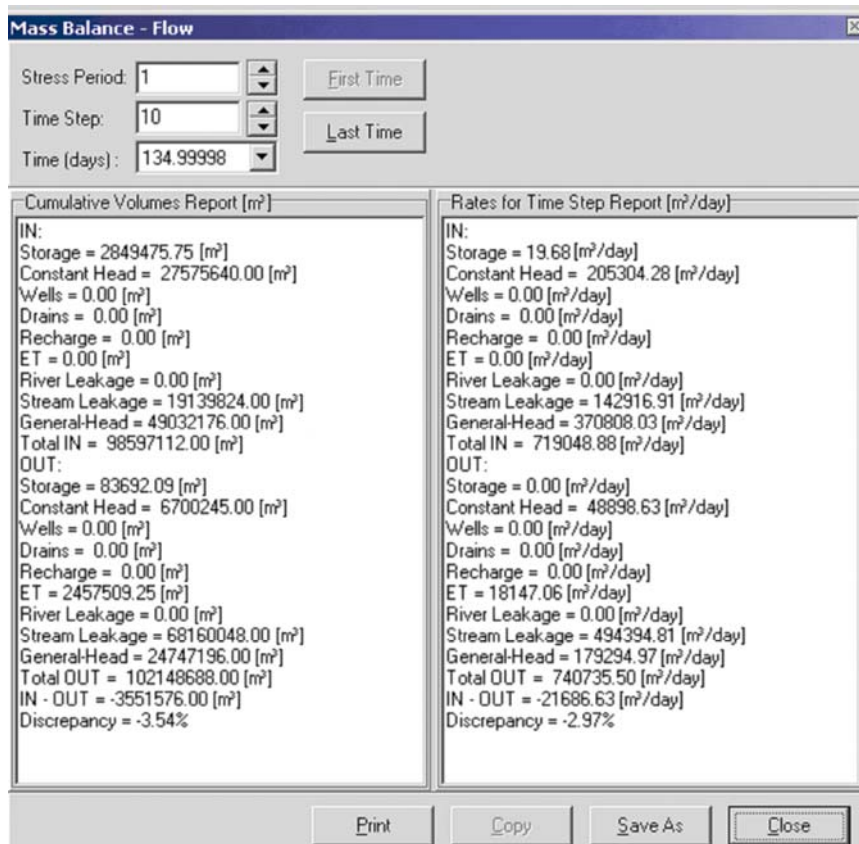


Figure 5-5: Sample Mass Balance Output Sheet (Visual Modflow v. 4.0 2003)

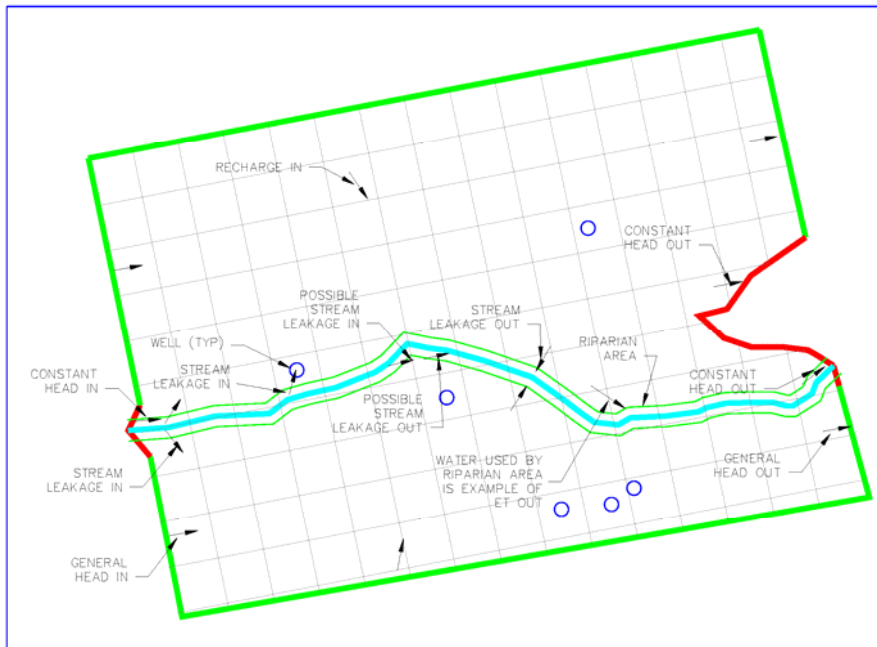


Figure 5-6: Explanation Diagram of Sample Mass Balance Output Sheet (Figure 5-5)

The mass-balance output sheet, shown in Figure 5-5 is for an arbitrary well at the end of stress period 1. As shown, ten time-steps were used in the calculation for stress period 1. Visual Modflow calculates the head value of each cell for each time-step used in the stress period. Stress periods are representative of distinct combinations of constant input variables and can be any length of time. Heads for the first time step of a stress period are calculated using the previous stress period's output heads as initial heads. Each change in model conditions requires an additional stress period. For example, a change in modeled evapotranspiration or boundary cell head would each create a distinct stress period unless occurring on the same model day. Stress period 1 corresponds to the time before the start of the irrigation season (day 1 to 135) in the transient model (see Visual Modflow Documentation for more details). The most important stress period for this

analysis was the stress period ending on day 257, corresponding to the time just before the modeled end of pumping.

Additive and subtractive methods described in sections 5.2.1.1 and 5.2.1.2 were used for stream depletion calculations. The results of these methods of analysis were slightly different. Results from both methods were considered in the well rankings. Appendix F contains the tabulated results for both methods.

5.2.1.1 Additive Method

The additive method was used to determine the amount of single-season drawdown and stream depletion induced by a single well, pumping in the Ogallala aquifer, starting with the calibrated (pre-development) initial heads. A one-year transient model run was used with the input data (ET, recharge, hydraulic conductivity, etc.) described in previous sections and the calibration wells pumping until day 135 (start of seasonal pumping) to maintain calibration. This method was used to isolate well calculation from the cumulative pumping effects in the model.

A mass-balance output sheet similar to that shown in Figure 5-5, was created for a one-year run, the calibration run, representing predevelopment without disturbance from wells, of the model as described in chapter 4. This run was used as the “control” run for comparison to runs with added wells. This was assumed to be the pre-development condition for calculating stream depletion. The sheet contains calculated pre-development mass balance information including the rate of flow into and out of the aquifer from various model entities including the stream.

Single wells were added individually to the model and the transient-state single-season model was re-run for each isolated well. Mass-balance output sheets were created for the model after each run. The change in the net rate of stream influx was calculated by comparing the control run and runs with each well added individually. The difference was assumed to be the single-season change in streamflow caused by each well.

Example Additive Analysis calculation:

Control Run (G):

A. The flux rate into the aquifer from the stream = $129,353.27\text{-m}^3/\text{day}$

B. The flux rate into the stream from the aquifer = $549,772.25\text{-m}^3/\text{day}$

C. The net flux rate: $B - A = 420,418.98\text{-m}^3/\text{day}$

This is the assumed pre-development flux into the stream channel from the aquifer. Hydraulic channel conditions (Section 4.5) were not modified to represent the change due to larger flow rate.

For the pumping of well 'A' located at PLS coordinates SC00304419CD (Appendix G):

D. The flux rate into the aquifer from the stream = $129,543.01\text{-m}^3/\text{day}$

E. The flux rate into the stream from the aquifer = $547,864.25\text{-m}^3/\text{day}$

F. The net flux rate: $E - D = 418,321.24\text{-m}^3/\text{day}$

The net change in flux rate due to well: $C - F = 2,097.74\text{-m}^3/\text{day}$ (384.8-gal/min)

This was assumed to be the rate of stream depletion induced by the well 'A' 123 days after the start of pumping.

5.2.1.2 Subtractive Method

In the subtractive analysis method, wells were removed instead of added to the model. The transient model was run for one season with all wells pumping. This was assumed to represent the developed scenario with all wells being installed simultaneously before the growing season into the pre-development (undisturbed) aquifer. A one-year transient model run was used with the previously described input data (chapter 4) and the calibration wells being pumping until day 135 (start of seasonal pumping) to maintain calibration.

This procedure calculated the rate of seasonal stream depletion caused by all modeled wells. The major difference between the subtractive method analysis and the additive method analysis is that the saturated thickness of the aquifer is reduced in the subtractive method by the pumping from all wells. The reduced saturated thickness in this scenario exacerbates the single-season stream depletion of individual wells located in close proximity to others.

An output sheet was generated for the run with all wells pumping as the control scenario for this analysis. The model was re-run one time with each well removed individually but all others continuing to pump. Output sheets were generated for each run and the change in the rate of flux into the stream for each well was calculated.

Example Subtractive Analysis calculation:

Predevelopment State with all wells pumping:

A. The flux rate into the aquifer from the stream = $127,688.86\text{-m}^3/\text{day}$

B. The flux rate into the stream from the aquifer = $540,778.19\text{-m}^3/\text{day}$

C. The net flux rate: $B - A = 413,089.33\text{-m}^3/\text{day}$

This is the assumed developed flux into the stream channel from the aquifer. Hydraulic channel conditions (Section 4.5) were not modified to represent the change due to larger flow rate.

For the pumping of well 'A' located at pls coordinates SC00304419CD (Appendix G):

D. The flux rate into the aquifer from the stream = $127,536.58\text{-m}^3/\text{day}$

E. The flux rate into the stream from the aquifer = $542,813.69\text{-m}^3/\text{day}$

F. The net flux rate: $E - D = 415,277.11\text{-m}^3/\text{day}$

The net change in flux rate due to well: $F - C = 2,187.8\text{-m}^3/\text{day}$ (401.4-gal/min)

This was assumed the rate of stream depletion induced by well 'A', at the time 123 days after the start of pumping in the disturbed aquifer where saturated thicknesses are smaller because of superimposed cones of depression from other wells pumping.

Well analysis using this method examines the effect of each of the wells on a disturbed water table with many perturbations and a reduced saturated thickness caused by the disturbances. By superposition, effects would be expected to be similar to those of the additive method but changes in saturated thickness in a heterogeneous aquifer, modify the results. (See well map Figure 5-7).

5.2.2 Analytical Glover Equation Analysis

A significant amount of literature is available concerning methods for computing stream depletion. A comprehensive review of literature is available by Miller et al. (2006). The review starts with the mathematical analysis first published by Theis (1941).

The analysis developed by Glover and Balmer (1954) is commonly referred to as the Glover Equation analysis. The method uses a probability integral for computation of stream depletion. Mathematically ideal conditions are assumed for use of the Glover Equation. Methods have been developed for non-ideal conditions such as using image wells to analyze boundary effects. Miller et al. (2006) also studied the use of the semi-analytical stream depletion model for aquifers with definite boundaries.

The development of the SDF term by Jenkins (1968) simplified the analysis allowing broad use of the Glover Equation analysis. Jenkins (1968) not only developed the SDF term but presented non-dimensional relationships between stream-depletion volume and time. The graphical non-dimensional relationships can be used to determine the rate of stream depletion given aquifer characteristics, pumping rate and time. Jenkins is widely cited for stream depletion analysis because of the method's simplicity.

Zlotnik (2005) developed a solution for stream depletion and drawdown in a system with partially penetrating stream. The relationship is transient and requires that the aquifer below the stream be infinite and homogeneous. The solution requires pumping to be from the alluvial aquifer that also underlies the stream.

The numerical model results were compared to the results of the analytical Glover Equation model. The Glover Equation (Glover and Balmer 1954) computes the stream depletion rate (q), as a function of pumping time (t), well discharge rate (Q), and aquifer characteristics shown as Equation 5-2:

Equation 5-2

$$q/Q = \operatorname{erfc}\left(\sqrt{\frac{a^2 S}{4tT}}\right)$$

Where:

q = rate of stream depletion of water to the aquifer (L^3/T)

Q = Well pumping rate (L^3/T)

a = distance to the well from the stream (L)

S = aquifer specific yield (L^3/L^3)

t = time since initiation of pumping (T)

T = transmissivity of the aquifer (L^2/T)

Assumptions of the Glover model include a straight and fully penetrating constant head boundary at the stream, a fully penetrating well, pumping at constant rate (Q), for time t after the start of pumping, in an undisturbed, homogeneous aquifer of constant saturated thickness. Drawdown is considered negligible compared to the saturated thickness so transmissivity is assumed not to vary with time. It was also assumed that water is released instantaneously from storage and residual effects of pumping are assumed negligible (Jenkins 1968).

The rate of stream depletion using the Glover Equation was calculated (Appendix E) for a single growing season of 123 days as was used in the numerical model. Parameters used in the Glover Equation were derived from the calibrated model to ensure input parameter consistency. Recharge was not simulated using the analytical method although it was included in the numerical model.

5.2.2.1 Glover Parameter Estimation

To be conservative when calculating stream depletion from proposed wells, parameters must be used that do not underestimate the actual rate of depletion. This ensures that the well will not use more streamflow than predicted and disrupt habitat. When estimating streamflow recovery after well forbearance, the opposite is true. Overestimation of stream depletion from wells taken out of service would mean that less water would appear as streamflow than was estimated as recovered flow. Parameters used in the following calculations resulted in conservative estimates of stream depletion.

The distance to wells for Glover Equation analysis was taken to be the shortest distance to the river estimated by GIS using geo-referenced satellite photos and well coordinates provided by the CDWR. Use of the distance to the alluvium instead of the stream would produce higher depletion estimates because of the shorter distance and would be reasonable because of the very high hydraulic conductivity of the alluvial sand.

The calibrated numerical model was used to estimate transmissivity using a low estimate of the average calibrated hydraulic conductivity between the stream and the well (excluding the high alluvial hydraulic conductivity). Transmissivity was calculated by multiplying the calibrated hydraulic conductivity by the average of the alluvial and well location saturated thicknesses. Aquifer thicknesses were estimated using the GIS surfaces. Alluvial depths were assumed to be 9-m.

The value of specific yield used in the Glover Equation analysis was based on the specific yield zones used in the numerical model. Values ranged from 0.17 to 0.22 (Figure 1-6).

5.3 STREAM DEPLETION ANALYSIS RESULTS

5.3.1 Numerical Model Stream Depletion Analysis Results

Stream Depletion analysis of the modeled irrigation wells using additive and subtractive methods produced similar but slightly different results. The top 15 wells, in regards to the model calculated single-season change in streamflow for each analysis method, are provided in Table 5-1. The model indicated that these wells produced the largest change in water entering the stream channel by each of the individual methods (day 257 is the end of the irrigation season).

It is worth noting that the rankings are different for the two methods. The impact on streamflow for most of the wells presented is within the “noise” range for the model based upon the percent change in streamflow from each well. This is indicative that the wells have some sort of impact on streamflow in the model, as explained in later sections, but the differences in the rate of stream depletion are too small to be used reliably in ranking of the wells.

Explanation of Table 5-1 Columns:

- 1) Map Designation (see Figure 5-7)
- 2) Well coordinate in Public Land Survey coordinate system or run description.
- 3) Modeled well pumping rate (m^3/day) – 61% CDWR capacity rating.
- 4) Modeled well pumping rate in gallons per minute – 61% CDWR capacity rating.
- 5) Straight-line distance from the well to the stream (m).
- 6) Model calculated rate of stream out-flux into the aquifer at day 257 (m^3/day).
- 7) Model calculated rate of stream in-flux from the aquifer at day 257 (m^3/day).
- 8) Calculated groundwater dependent streamflow (item 5 - 4) (m^3/day).
- 9) Change in the rate of stream out-flux due to the well from control scenario (m^3/day) (well's column 4 – control column 4) in (m^3/day).
- 10) Change in the rate of stream in-flux due to the well from control scenario (m^3/day) (well's column 5 – control column 5) in (m^3/day).
- 11) Change in the calculated groundwater dependent stream (m^3/day) (well's column 6 – control column 6).
- 12) Column 9 in gallons per minute
- 13) General notes about the well and calculation.
 - a. “Alluvial” indicates the well is located within one mile of the river and is assumed to be effectively in the alluvial formation.
 - b. “Low Sat Thick” indicates well is located in an area with initial saturated thickness of less than 6-m.

Table 5-1: Top 15 Wells According to Additive and Subtractive Streamflow Change Results for day 257 (All Shown at End of Pumping)

Map Desc. (1)	Additive Rank	PLS Coordinate (or Run) (2)	Capacity (m ³ /day) (3)	Capacity (gpm) (4)	Distance to Stream (m) (5)	Out of Stream Flux (m ³ /day) (6)	Into Stream Flux (m ³ /day) (7)	Flow (m ³ /day) (8)	Out of Stream Change (m ³ /day) (9)	Into Stream Change (m ³ /day) (10)	Stream Flow Change (m ³ /day) (11)	Stream Flow Change (gpm) (12)	Notes (13)
-	-	All Off	-	-	-	129353	549772	420419	-	-	-	-	Control
A	1	SC00304419CD	2388	438	<200	129543	547864	418321	190	-1908	-2098	-385	Alluvial
B	2	SC00404718AA	2159	396	1180	128868	548338	419470	-485	-1434	-949	-174	
Y	3	SC00304705DA	3325	610	>3000	129452	549085	419633	99	-687	-786	-144	Low Sat Thick
K	4	SC00404713AC	998	183	1290	129450	549083	419633	97	-689	-786	-144	
V	5	SC00304703BC	5320	976	>3000	129446	549081	419635	93	-691	-784	-144	Low Sat Thick
J	6	SC00404618BA	5320	976	2200	129449	549084	419635	96	-689	-784	-144	
Q	7	SC00404608DD	3325	610	3210	129438	549091	419653	84	-682	-766	-141	
L	8	SC00404715DC	3325	610	846	129442	549107	419665	89	-666	-754	-138	
O	9	SC00404618AA	3325	610	2638	129447	549114	419667	94	-658	-752	-138	
P	10	SC00404729AA	4988	915	>3000	129433	549108	419675	80	-664	-744	-136	
X	11	SC00304705AA	3325	610	>3000	129427	549202	419775	74	-570	-644	-118	Low Sat Thick
W	12	SC00304704AC	5320	976	>3000	129394	549180	419786	41	-592	-633	-116	Low Sat Thick
C	13	SC00404718BB	2328	427	183	129058	548853	419794	-295	-920	-625	-115	Alluvial
N	14	SC00404720CD	3325	610	2656	129417	549414	419997	64	-358	-422	-77	
D	15	SC00404714AB	3325	610	2916	129325	549323	419997	-28	-449	-422	-77	

Map Desc. (1)	Subtractive Rank	PLS Coordinate (or Run) (2)	Capacity (m ³ /day) (3)	Capacity (gpm) (4)	Distance to Stream (m) (5)	Out of Stream Flux (m ³ /day) (6)	Into Stream Flux (m ³ /day) (7)	Flow (m ³ /day) (8)	Out of Stream Change (m ³ /day) (9)	Into Stream Change (m ³ /day) (10)	Stream Flow Change (m ³ /day) (11)	Stream Flow Change (gpm) (12)	Notes (13)
-	-	All On	-	-	-	127741	540880	413139	-	-	-	-	Control
A	1	SC00304419CD	2388	438	<200	127537	542814	415277	-205	1933	2138	392	Alluvial
W	2	SC00304704AC	5320	976	>3000	127643	542561	414918	-98	1681	1779	326	Low Sat Thick
B	3	SC00404718AA	2159	396	1180	128224	542634	414411	482	1754	1272	233	
C	4	SC00404718BB	2328	427	183	128089	542078	413989	347	1197	850	156	Alluvial
V	5	SC00304703BC	5320	976	>3000	127840	541230	413389	99	349	250	46	Low Sat Thick
F	6	SC00404719AA	1842	338	<200	127992	541327	413335	251	447	196	36	Alluvial
E	7	SC00404717CD	3325	610	2460	127912	541209	413297	170	328	158	29	
G	8	SC00404712CA	1995	366	1250	127780	540988	413208	38	107	69	13	
Y	9	SC00304705DA	3325	610	>3000	127779	540857	413078	38	-23	61	11	Low Sat Thick
M	10	SC00404511CD	3990	732	3955	127737	540889	413152	-4	9	13	2	
S	11	SC00404405DD	2725	500	5024	127744	540871	413127	2	-10	12	2	
R	12	SC00404404BD	3990	732	4695	127741	540870	413129	0	-10	10	2	
Z1	13	SC00404514DB	4361	800	4890	127735	540866	413131	-6	-14	8	1	
K	14	SC00404713AC	998	183	1290	127737	540869	413132	-4	-12	7	1	
Z2	15	SC00404514CB	5816	1067	4903	127734	540880	413146	-7	-1	7	1	

For the additive analysis, the change in streamflow (columns 9 and 10, Table 5-1) is negative when adding a well. This is because the stream is depleted by adding the well, thereby reducing the rate of streamflow. The change in streamflow for the subtractive analysis is positive because wells are removed from the model to examine the increase in streamflow rate.

Low initial saturated thickness (4-m to 5.5-m) occurred at wells V, W, X and Y as noted in each table (Figure 5-7). These wells are located to the northwest of the Fox Ranch at a distance of approximately 11-km from the river. Although these wells ranked in the top-15 by calculated stream depletion, using at least one of the numerical modeling analysis methods, the results are presumed to be unreliable because a larger internal water-balance percent discrepancy occurred for the analysis of these wells. This is assumed to be an artifact of the Modflow model where drawdown is not negligible with respect to the saturated thickness. Analysis of all other wells produced a water-balance discrepancy of less than 0.1%, while analysis of these wells produced a discrepancy between 0.1% and 0.3%.

The single-season stream depletion calculated by the model for wells D, J, K, L, N, O, P and Q was over 400-m³/day less for the subtractive analysis than for the additive analysis. The causes of this are unknown but are assumed connected with an absence of modeled streamflow in the river near these wells at the end of pumping. These wells are located in the well field to the southwest of the Fox Ranch. The cumulative drawdown for a run with no modeled ET from this well field created a cone of depression as shown in Figure 5-2, that reaches the river after one season of pumping. There are also two alluvial wells upstream of the well field. Over half (2,543 / 4,893-m³/day) of the specified rate of

stream boundary in-flow was calculated to be depleted from the stream by the wells upstream of the well field (B, C, E, F and G).

Wells R and S ranked in the top 15 stream-depletion wells for the subtractive analysis. These wells are existing wells that were used as calibration wells because of their pre-1958 installation date. These wells were ranked but were given an unfair bias in the stream depletion analysis because they had been pumped in the calibration for the winter season prior to the growing season. This would increase the perceived stream depletion by increasing the pumping time. For this reason, the analytical Glover equation was the only reliable method of analysis and ranking for these wells.

These analyses were completed using the entire stretch of the river within the boundaries of the numerical model. The specified headwater inflow for the model was 4,890-m³/day (2-cfs, Section 4.5). Water is allowed to enter or exit the river depending upon the streambed hydraulic conductivity and the difference in head between the stream boundary and the aquifer. Additional water can be moved from the stream boundary to the aquifer by perturbations to the groundwater that change the gradient, such as with ET or irrigation-well pumping.

As shown in Table 5-1, there is a component of stream flux into the stream, but also out of the stream. The total rate of streamflow does not correlate to the actual streamflow seen today. The model was calibrated using 1958 water table levels but utilizes stream boundary conditions and dimensions as observed in 2006. The pre-development streamflow calculated by subtracting the calculated stream out-flux from the calculated stream influx for the additive method “control” run (all wells off) is 420,419-

m³/day (171-cfs). This is much higher than the recorded (USGS gauge date Haigler, NE) pre-development streamflow averaging of 63,870-m³/day (26-cfs).

Much of the discrepancy associated with the streamflow rate is assumed attributed to incorrect stream boundary dimensions and hydraulic conditions. The additional water available in the model is assumed to be attributed to incorrect recharge values. A hydraulic model of the river would be required to improve the conditions of the groundwater model. Calibration by S_{ya} may also improve the calculated stream inflow value since less water may be required to maintain calibration heads in the model.

5.3.2 Glover Equation Results

Glover equation analysis calculations are provided in Appendix E for wells estimated to reduce end-of-season streamflow by at least 10-m³/day using either method in the numerical model for comparison. The results of this analysis are shown in Table 5-2. As explained before, the impact from the majority of these wells is in the “noise” region of the numerical model.

The eight wells producing the largest change in streamflow according to the Glover equation analysis would each produce a single-growing-season change in streamflow rate between 135 and 2,100-m³/day (25 and 385-gpm) through the Fox Ranch (Table 5-2). The range is due to the difference in the calculated stream depletion depending upon the distance to the stream, the aquifer characteristics and the pumping rate. The next 10 most detrimental wells would each produce between 5.5 and 55-m³/day (1 and 10-gpm) change in streamflow at the end of the season. Two additional wells located just outside of the upstream model boundary and close to the river were included in the table and Glover Equation Analysis because of their proximity to the river.

Explanation of Table 5-2 Columns:

- 1) Map Designation (see Figure 5-7)
- 2) Glover Equation analysis rank from day 257 calculated well stream depletion
- 3) Numerical additive analysis rank from day 257 calculated well stream depletion
- 4) Numerical subtractive analysis rank from day 257 calculated well stream depletion
- 5) Well coordinate in Public Land Survey (PLS) coordinate system
- 6) 61% of rated CDWR well capacity (m^3/day)
- 7) 61% of rated CDWR well capacity (gpm)
- 8) Additive analysis calculated change in seasonal streamflow (m^3/day)
- 9) Additive analysis calculated change in seasonal streamflow (gpm)
- 10) Subtractive analysis calculated change in seasonal streamflow (m^3/day)
- 11) Subtractive analysis calculated change in seasonal streamflow (gpm)
- 12) Glover Equation analysis calculated change in seasonal streamflow (m^3/day)
- 13) Glover Equation analysis calculated change in seasonal streamflow (gpm)
- 14) General notes about the well and calculation.
 - a. “Alluvial” indicates the well is located within one mile of the river and is assumed effectively to be in the alluvial formation.
 - b. “High Discrepancy” indicates the numerical model well analysis calculations produced high water balance discrepancies relative to other wells (due to low saturated thickness at the well)
 - c. “Calibration Well” indicates the well was pumped in the calibration of the model, increasing the end of season rate of stream depletion

**Table 5-2: Glover Equation Analysis Results Compared to Numerical Analyses
Pumping Duration: 123 Days (Equal to the End of the Irrigation Season, day 257)**

Map Desc. (1)	Glover Rank (2)	Additive Rank (3)	Subtractive Rank (4)	PLS Well Coordinates (5)	61% Rating (m ² /day) (6)	61% Rating (gpm) (7)	Additive		Subtractive		Glover		Notes (14)
							Streamflow Change (m ³ /day) (8)	Streamflow Change (gpm) (9)	Streamflow Change (m ³ /day) (10)	Streamflow Change (gpm) (11)	Streamflow Change (m ³ /day) (12)	Streamflow Change (gpm) (13)	
A	1	1	1	SC00304419CD	2388	438	2097.7	384.8	2138.0	392.2	2102.4	385.8	Alluvial
B	2	2	3	SC00404718AA	2328	427	948.7	174.0	1271.8	233.3	2049.6	376.1	Alluvial
C	3	13	4	SC00404718BB	1842	338	624.8	114.6	849.8	155.9	1622.4	297.7	Alluvial
D	4	15	18	SC00404714AB	3325	610	421.6	77.3	4.6	0.9	974.3	178.8	
E	5	17	7	SC00404717CD	2159	396	65.8	12.1	158.0	29.0	576.6	105.8	
F	6	16	6	SC00404719AA	1995	366	81.9	15.0	195.8	35.9	533.4	97.9	
G	7	18	8	SC00404712CA	998	183	26.3	4.8	69.1	12.7	278.7	51.1	
I	8	N/A	N/A	SC00404719DD	3990	732	N/A	N/A	N/A	N/A	208.9	38.3	Alluvial - Outside Model
H	9	N/A	N/A	SC00404815CD	1164	213.5	N/A	N/A	N/A	N/A	148.5	27.3	Outside Model
J	10	6	26	SC00404618BA	5320	976	784.0	143.8	1.0	0.2	43.2	7.9	
K	11	4	14	SC00404713AC	3990	732	785.6	144.1	7.3	1.3	26.8	4.9	
L	12	8	25	SC00404715DC	3325	610	754.3	138.4	1.6	0.3	21.8	4.0	
M	13	41	10	SC00404511CD	3990	732	2.8	0.5	12.7	2.3	20.8	3.8	
N	14	14	24	SC00404720CD	3325	610	422.3	77.5	1.7	0.3	16.4	3.0	
O	15	9	19	SC00404618AA	3325	610	752.3	138.0	4.5	0.8	16.3	3.0	
P	16	10	17	SC00404729AA	4988	915	744.0	136.5	4.6	0.9	12.6	2.3	
Q	17	7	73	SC00404608DD	3325	610	766.0	140.5	0.0	0.0	8.9	1.6	
R	18	21	12	SC00404404BD	3990	732	11.4	2.1	9.9	1.8	8.3	1.5	Calibration Well
S	19	29	11	SC00404405DD	2725	500	4.5	0.8	11.9	2.2	5.5	1.0	Calibration Well
T	20	19	88	SC00404725DD	2725	500	17.0	3.1	0.0	0.0	5.1	0.9	Calibration Well
U	21	20	92	SC00404727DD	2725	500	17.0	3.1	0.0	0.0	3.1	0.6	Calibration Well
-	22	22	29	SC00104535BD	5819	1067.5	10.3	1.9	0.0	0.0	3.1	0.6	Calibration Well
-	23	23	41	SC00204510AB	5320	976	10.3	1.9	0.0	0.0	1.4	0.3	Calibration Well
V	24	5	5	SC00304703BC	5320	976	784.0	143.8	250.3	45.9	1.2	0.2	High Discrepancy
W	25	12	2	SC00304704AC	5320	976	633.3	116.2	1779.4	326.4	1.1	0.2	High Discrepancy
X	26	11	67	SC00304705AA	3325	610	643.6	118.1	0.0	0.0	0.7	0.1	High Discrepancy
Y	27	3	9	SC00304705DA	3325	610	786.3	144.2	61.3	11.3	0.6	0.1	High Discrepancy

The results of the Glover Equation Analysis indicate that for a run where the ten most detrimental irrigation wells were not pumping, there would be an end-of-season water budget improvement of up to 8,000-m³/day (3.5-cfs). There would be diminishing seasonal returns for wells as the distance from the well to the river increases pumping rate decreases. The cumulative stream depletion calculated for the next 17 wells in the Glover Equation analysis was only 153.7-m³/day. The locations of the wells presented in Table 5-2 are shown in Figure 5-7.

Wells with Glover Equation analysis rank 2 through 12, 14 through 17, 20 and 21 (B – L, N – Q, T & U) were located in a well field to the southwest of the Fox Ranch as shown in Figure 5-7. Wells in this area are in close proximity to each other. Wells ranked 18 through 21 (R – U) are far from the river and were used in calibration of the model. Glover Equation analysis for these well indicated very low seasonal stream depletion. Wells ranked 22 and 23 are also calibration wells, located far north of the river and do not lie within the borders of the image shown in Figure 5-7. Glover Equation calculations for wells closer to the river produce higher rates of stream depletion and should be considered to rank higher overall than these wells.

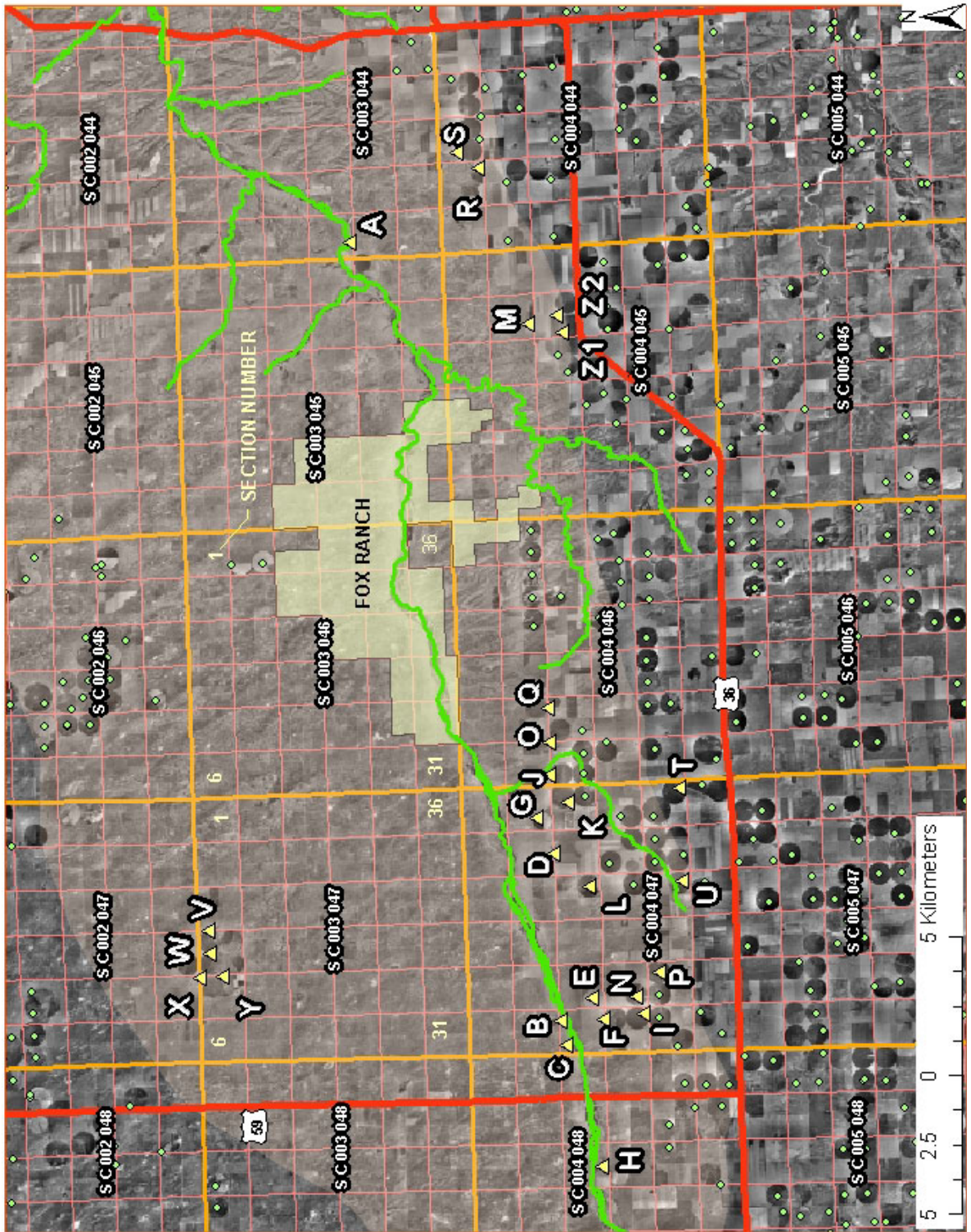


Figure 5-7: Locations of Wells Included in Table 5-2 with Glover Analysis Ranks
 (USDA 2005; CDWR 2005; CDOT 2006)

5.3.3 Well Distance Implications

By this stream depletion analysis, wells located long distances from the river were found to contribute mostly to regional decreases in water table level. Wells more than a limited distance away affect streamflow in a more indirect manner where seasonal stream depletion becomes negligible (calculated end-of-season stream depletion rate is less than 1% of the well pumping rate). Wells must be within 1,200-m (4,000-ft) for wells with capacities less than around 5,000-m³/day to deplete the stream more than a negligible amount (about 10-m³/day).

Around 1,220-m (4,000-ft) to 1,830-m (6,000-ft) is the limit to where, for this area, modeled aquifer condition and a pumping season duration of 123 days, the ratio of stream depletion (q) to well pumping rate (Q) for wells with capacity of 5,450-m³/day (1,000-gpm) drops below 0.01. Very high pumping capacity (around 5,000-m³/day) is required for wells close to this limit to deplete the stream more than 10-m³/day. Analysis of the distance was computed using both the Glover Equation (equation 5-2) and the Arikaree River Numerical Groundwater Model.

5.4 ANALYSIS, OBSERVATIONS & CONCLUSIONS

The calibrated model of the Arikaree River produced some interesting results. Wells close to the river deplete streamflow in a single pumping season while wells further away (>3000-m) generally do not. Because of the short distance at which single-season pumping becomes negligible, wells located upstream of the Fox Ranch along the

alluvium should be considered for forbearance before wells located laterally from the river, at further distances.

It is expected that there exists a maximum distance upstream of the Fox Ranch that forbearance of alluvial wells remains more beneficial to streamflow than forbearance of wells located laterally to the river around the Fox Ranch. An increase in ET is expected from exposed surface water and high water table, causing diminishing returns between the upstream well and the Fox Ranch. Ultimately, to stop the streamflow decline or improve streamflow, the regional water balance deficit would need to be eliminated. Essentially the amount of water entering the region through the aquifer, stream and precipitation must match or be larger than the amount of water being used for irrigation, by evapotranspiration. Many large capacity wells throughout the basin would need to be decommissioned and the aquifer level would have to be allowed to recover.

A reduction in streamflow of $23,480\text{-m}^3/\text{day}$ (9.6-cfs) was calculated by the model between the end-of-season streamflows from year one to year ten. This was calculated using the method described in the well analysis using the mass balance output sheets from runs with all wells pumping seasonally. The total year-one end of season stream influx was $413,090\text{-m}^3/\text{day}$ while the total year ten end of season stream influx was $389,610\text{-m}^3/\text{day}$. This decline is indicative of irrigation-well stream depletion. The water budget is also shown to be unbalanced after well installation as the decline is progressive through the ten-year period. It must be noted, however that the magnitude of the streamflow in the model does not match existing conditions so this streamflow rate reduction would not be the actual change for existing conditions.

The most substantial unknowns in this model are S_{ya} , ET and recharge. ET and recharge would theoretically not change the results of the pumping analysis but the S_{ya} would. Additional work to calibrate by S_{ya} and to improve the model water balance would improve the results substantially. Only after this type of calibration could there be an improvement to the prediction of streamflow from well analysis.

CHAPTER 6 ARIKAREE BASIN WATER BALANCE

The Arikaree River groundwater basin shown in Figure 1-5 is limited in extent. The amount of runoff into the stream and recharge into the aquifer are controlled by the size of the basin. Because of the basin size, the flow of groundwater through the basin is very important to the overall water budget.

The control volume (system) for this water balance is the combined alluvial and high plains (Ogallala) aquifers, along with the stream and other open water in the alluvium. The water budget explanation, as shown in Figure 6-1 details the ten inputs and outputs to the water budget.

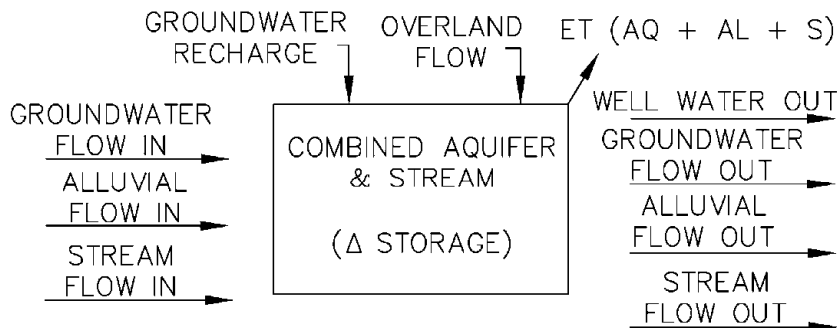


Figure 6-1: Water Budget Explanation

Where:

ET(G) = Evapotranspiration at the ground level from the wetted surface of soils and plants (Evaporation/initial abstraction)

ET(V) = Evapotranspiration from below the ground surface but above the water table, including by plant use (mostly transpiration)

ET(AQ) = Evapotranspiration from the major aquifer, below the water table (mostly negligible except in areas of very high water table)

ET(AL) = Evapotranspiration from the alluvial aquifer including riparian plant use

ET(S) = Evapotranspiration from within the banks of the stream (mostly evaporation)

As shown, the atmospheric inputs to the water-balance control volume are overland flow to the stream, combined aquifer recharge (attributed to precipitation) and evapotranspiration from open water including the stream. The control volume is spatially different for the overland flow contribution from the stream and the recharge area to the aquifer. This is because the drainage basin differs slightly from the groundwater basin. The inputs and outputs are categorized for discussion in this study into atmospheric effects, streamflow, groundwater flow and irrigation effects.

6.1.1 Atmospheric Effects

For the sake of discussion, overland flow, recharge and ET are included in the category of precipitation effects. ET occurring on the plains, both in the vadose zone and at the ground surface must be taken as an abstraction from the total precipitation as shown in Figure 6-1. ET in the riparian areas is assumed to be high because of the dense vegetation and exposed water or very high water table.

The average precipitation upstream of the Fox Ranch property is 42-cm (16.5-in) per year at the USDA Central Great Plains Weather Station in Akron, CO. The groundwater basin area was estimate in GIS to be 149,980-ha (370,600-acres) using water table elevation contours (Figure 1-5). The drainage basin is slightly larger at 159,000-ha (392,000-acres) including some area where the direction of groundwater flow is different from the ground surface gradient. The water-budget groundwater basin, including all contributing area in Southern Yuma County includes more area than the groundwater model from chapter 4. The volume of precipitation in the drainage basin was estimated to be 66,500-ha-m/year (539,000-acre-ft/year). Excluding the river basin and riparian areas 14,400-ha (35,600-acres) as discussed below, the total precipitation in the plains area is 60,600-ha-m/year (491,300-acre-ft/year)

Overland flow from the plains was assumed to be 2.7% of the annual precipitation (1,660-ha-m/year). This was chosen to balances the pre-development water budget based on the other inputs discussed in this section. Because the stream, alluvium, aquifer and ground surface are combined within the control volume, the details of whether this water infiltrates into the alluvium, enters into bank storage, flows directly into the stream or is used in the process of ET is unimportant but the input must be accounted for in the water budget.

Calibration of this study's numerical model required very large values of recharge because of apparent errors in specific yield. It was noted that the recharge would need to be reduced by up to 16-cm (6.3-in) to balance the model water budget and reduce the stream outflow. A reduction of the recharge rate to 15.25-cm (6-in) per year from 20 to 40-cm per year distributed over the model area would be required to eliminate the excess

streamflow without modifications to ET. It was also noted that modeled ET was too low compared to published values since the total ET from the model would only equate to 11.5-cm/year (4.5-in/year) if applied only to the riparian area. This is far below most published values for riparian ET. Since there is so much error in the modeled ET and recharge rates, published values were used in place of modeled values.

Reddell (1967) suggests that there is an average of 3.68-cm (1.45-in) per year of recharge in Yuma County. This was used in the water budget for aquifer recharge in areas outside of the river basin and riparian area as described in chapter 4. Recharge was estimated using a numerical groundwater model with a 15.5-km² (6-sq. mi.) cell size. Figure 1-4 shows that the surface geology through Yuma County can change drastically in an area of 15.5-km². For this reason, Reddell's estimate is appropriate for use in areas much larger than his model cell size but may be unreliable in smaller areas, however there is no better recharge data available. The total area assumed to recharge at 3.68-cm/year (1.45-in/year) is 135,580-ha (335,000-acres) for an upland recharge of 4,990-ha-m/year (40,450-acre-ft/year).

The river basin and riparian areas, totaling 14,400-ha (35,600-acres), were assumed for this water balance to recharge to the aquifer or contribute overland flow (run-off) to the stream at the rate of precipitation since the water table is at or near the ground surface. This has been included in the recharge number since the distribution between recharge and runoff is unknown. The calculated recharge volume from the riparian and river basin using these rates is 6,040-ha-m/year (48,930-acre-ft/yr). The total system recharge is 11,030-ha-m/year (89,420-acre-ft/year).

The sum of overland flow and recharge is equal to the total precipitation reduced by the total ET from the ground surface and vadose zone, including the initial abstraction. Since precipitation is used as a system input for the riparian and river basin areas, ET must be accounted for from the ground surface and vadose zone for these areas. The ground and vadose zone ET rates, however were assumed to be included in the Wachob (2005) riparian growing-season ET rate used in the river basin and riparian areas since reference ET for the area is only 89-cm/year (35.12-in), although it is recognized that the initial abstraction is not fully accounted for in this number.

Wachob (2005) estimated a range of riparian ET rates on the Fox Ranch between 69.2-cm (27-in) and 135-cm (53-in) per year depending upon cottonwood tree coverage, using the White method (White 1932). ET from the 3,180-ha (7,900-acre) riparian area was assumed to be 3,230-ha-m/year (26,170-acre-ft/year) using the average Wachob (2005) ET rate of 101.5-cm (40-in) per growing season. The lower estimate of riparian ET was applied throughout the 11,200-ha (27,700-acre) river basin area assuming an abundance of vegetation and high water table but less open water area. Using the lower estimate, the river basin total ET is 7,750-ha-m/year (62,830-acre-ft/year). The basin total ET from the aquifer and open water is assumed to be 10,980-ha-m/year (89,020-acre-ft/year).

No aquifer or stream ET was assumed on the plains but as discussed, the precipitation that does not runoff or recharge is assumed to be ET from the ground surface or vadose zone. These do not apply in the water balance, according to Figure 6-1 since the runoff and recharge are accounted for on the plains instead of the precipitation.

6.1.2 Streamflow

The two components of streamflow for this water budget are channel inflow and outflow. The average stream outflow from the basin to the USGS stream gauge 06821500 “ARIKAREE RIVER AT HAIGLER, NEBR.” is 1,535-ha-m/yr (12,450-acre-ft/yr). The pre-development average is 2,442-ha-m/yr (19,800-acre-ft/yr) not including data after 1960. Total outflow has continued to fall as pumping continues.

The upstream inflow to the basin is very low and the stream is usually disconnected at the western border of Yuma County. Connectivity upstream was assumed to be re-established only by large precipitation events. For this reason, inflow was assumed to be 10% of the outflow or 153-ha-m/yr (1,245-acre-ft/yr) for the water budget. There are no known stream gauges in this area.

6.1.3 Groundwater

The components of the groundwater flow were alluvial inflow/outflow and Ogallala inflow/outflow. The 1958 USGS water table data (Weist 1964) and Darcy’s Law (Equation 6-1) were used to estimate the groundwater flux through these formations.

Equation 6-1

$$Q = -KA * \left(\frac{dh}{dl} \right)$$

Where: Q = discharge of water through a section of porous media (L³/T)

K = the proportionality constant or hydraulic conductivity (L/T)

A = the cross-sectional area of the media (L²)

^{dh}/_{dl} = the hydraulic gradient (L/L)

The hydraulic gradient in the Ogallala Formation and the alluvial aquifer were determined by measuring the distance between water table contours with known head values. The average upstream hydraulic gradient was estimated to be 0.0059 to the north of the river and 0.0050 to the south. Downstream groundwater flow out of the basin was assumed to be mostly to the south side of the river because the hydraulic gradient is toward the river on the north side. The downstream hydraulic gradient was estimated to be 0.0043. The alluvial hydraulic gradients were estimated to be 0.0056 upstream and 0.0016 downstream.

Saturated-thicknesses were approximated in GIS using the 1958 water table surface (Weist 1964) and the Johnson et al. (2002) bedrock surface (Figure 1-6). The average saturated-thickness in the Ogallala Formation at the upstream end of the basin was estimated to be 16.0-m (52.5-ft) to the north and 18.3-m (60-ft) to the south of the alluvium. The downstream saturated-thickness was estimated to be 12.2-m (40-ft) to the south of the alluvium. The alluvial saturated-thickness was assumed to be 6.1-m (20-ft) along the western border of Yuma County and 3.05-m (10-ft) on the eastern border.

The upstream groundwater basin widths were estimated to be 6.4-km (4.0-miles) to the north and 2.0-km (1.21-miles) to the south of the alluvium. The width of the groundwater basin at the downstream end of the basin, with the hydraulic gradient not directed toward the river was estimated to be 11-km (6.8-miles). The upstream alluvial width was estimated to be 1.3-km (0.8-miles) and the downstream alluvial width was estimated to be 0.7-km (0.4-miles).

The hydraulic conductivities used in this calculation were averaged using the calibrated numerical model. 152-m/day (500-ft/day) was used for the upstream alluvial calculation and 213-m/day (700-ft/day) was used for the downstream alluvial calculation. 35-m/day (115-ft/day) was the average used for all Ogallala Formation groundwater flow calculations.

The Ogallala formation inflow and outflow to the basin were calculated to be 1,005-ha-m/year (8,150-acre-ft/year) and 737-ha-m/year (5,970-acre-ft/year) respectively. The alluvial inflow and outflow to the basin were calculated to be 246-ha-m/year (1,990-acre-ft/year) and 26.5-ha-m/year (210-acre-ft/year) respectively. The total groundwater inflow to the basin was calculated to be 1,251-ha-m/yr (10,140-acre-ft/yr). The total outflow was calculated to be 764-ha-m/yr (6,180-acre-ft/yr). Gradients at the western border of the basin have a more east/west direction than do those at the eastern border. According to the water table map, much of the groundwater flow at the eastern border is directed into the alluvium. It was assumed to convert mostly to stream outflow.

6.1.4 Irrigation

Well pumping and return flow, are included in the irrigation category for this study. Well pumping is a relatively new addition to the water balance, as most high capacity wells were installed in the early 1960's (CDWR, 2005). The total water use of the wells within the boundaries of the Arikaree River basin was calculated to be approximately 8,760-ha-m/yr (71,000-acre-ft/yr) according to the CDWR well records. Rated well capacities were multiplied by 0.61, the ratio of actual to rated capacity

estimated by Fardal (2003). Indications are that most farmers in the area are deficit irrigating (Fardal 2003). Return flows from deficit irrigation were assumed negligible.

6.1.5 Total Water balance

In predevelopment, the water budget components above were balanced as shown in Figure 6-2 by assuming a value for runoff based upon a percentage of the total precipitation. This could be distributed in any number of ways throughout the components of the water budget if not accounted for in runoff. Streamflow in, for example, could be improved by incorporating field measurements, but no information was found to clarify the magnitude of this component. Errors would be expected to occur from the approximations used to determine total recharge depth, seasonal ET, groundwater gradient and saturated thickness.

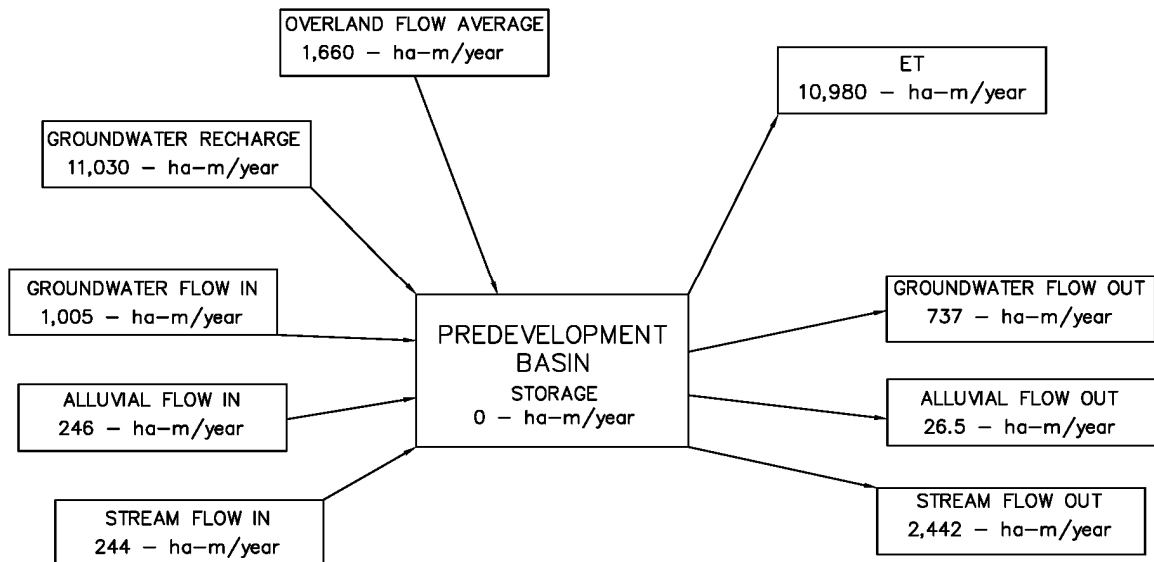


Figure 6-2: Predevelopment Water Balance

By including well pumping for irrigation in the water budget, there is a system deficit of approximately 7,945-ha-m/yr (64,400-acre-ft/yr) as shown in Figure 6-3. Other outflow components would be expected to decrease or water would be released from storage until the water budget returned to a balanced state. An evenly distributed reduction of approximately 60% would be required from other outflow components to balance the water budget. This would reduce the groundwater outflow from 737 to 295-ha-m/yr (5,975 to 2,390-acre-ft/yr), the stream outflow from 1,535 to 615-ha-m/yr (12,450 to 4,980 -acre-ft/yr) and ET from 10,980 to 4,392-ha-m/yr (89,016 to 35,610-acre-ft/yr).

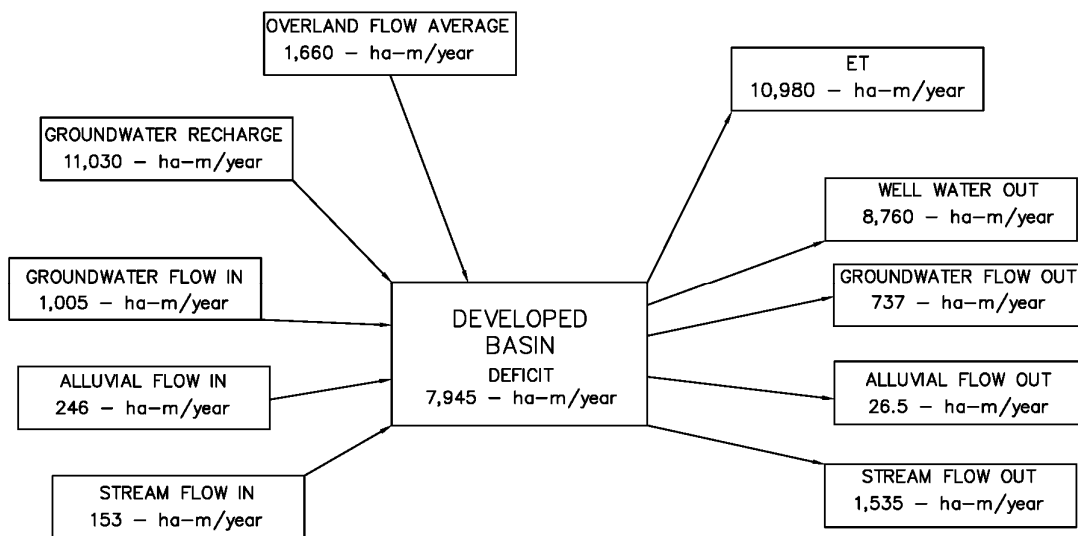


Figure 6-3: Developed Water Balance

Instead of a 60% reduction of all of these inputs, water would also be released from storage resulting in a reduction of the basin water table to account for the water balance

deficit. If the entire deficit were to reduce the water table elevation, assuming an S_{ya} of 0.2, a decline of 26.5-cm (0.89-ft) would be seen over the 149,980-ha (370,600-acre) basin. This is consistent with the 27-cm decline found by Squires (2007). More realistically, however there would be an unequal distribution of basin output reductions.

CHAPTER 7 CONCEPTUALIZATION

7.1 GENERAL ARIKAREE RIVER CONCEPTUALIZATION

The Arikaree River Basin conceptualization includes all information available to the author at the time of the study. Bedrock elevation, well data, geology maps, historic water levels and model results were all considered. The basin aquifer lies within a geologic formation that reduces in thickness as it proceeds east through Yuma County. The separation between the ground and bedrock surfaces decreases, proceeding east. The reduction in thickness is caused by mildly sloping bedrock as compared to the ground surface slope (USGS 1999; Johnson et al. 2002). Characteristics of the river basin that support this surface relationship are the discontinuity of the river upstream (west of the Fox Ranch), the wet reach just before outcropping of bedrock at the Fox Ranch property and the outcropping of bedrock to the east with perennial tributary flow.

Predevelopment data (Weist 1964) shows that the river is induced by a regional groundwater basin where groundwater flow is toward the river from both lateral directions (Figure 1-5). Transient modeling of the Arikaree River (sections 4.7 & 4.8) has shown this to remain true after 10-years of pumping. The model shows that the river does not change from gaining to losing groundwater. Well measurements also support that this has currently not changed (section 3.1). A significant gradient was calculated using the

observed contours (Figure 3-2) of 0.014 to 0.021 directed towards the river from the north and 0.009 to 0.014 from the south.

Transient numerical and analytical stream depletion models show that seasonal stream depletion is negligible from most irrigation wells within the basin. This has been shown to be true for one-year seasonal pumping schedules. Wells located more than approximately 3,000-m away from the river were shown using the model not to directly affect streamflow within a single growing season (appendix F). A complete discussion of the one-year stream depletions is included in chapter 5.

The model calculated using tracer particles, that pumping does not significantly change the location of the groundwater divide (Figure 7-1). Output head of the individual cells along the divide drop less than 1-m after model runs with pumping included. The output contour shape remains similar to the input contour shape. The contours are shown at 4-m intervals so the water table elevation, after seasonal recovery from pumping would have to have changed more than 4-m in the 10-year time interval to show changes.

The stability of the groundwater basin can be attributed in part to a high bedrock ridge that exists to the north of the river. Figure 1-6 shows the bedrock surface and ground surface contours along with an example point where the elevations of the ridge and the adjacent streambed are both approximately 1,240-m. The surfaces used in the numerical model indicate a saturated thickness of less than 5-m along the bedrock ridge north of the river (Weist 1964; Johnson et al. 2002). Physically, if the aquifer thickness declines, the ridge might become dry and the divide would remain, creating a gradient to the south along that ridge.

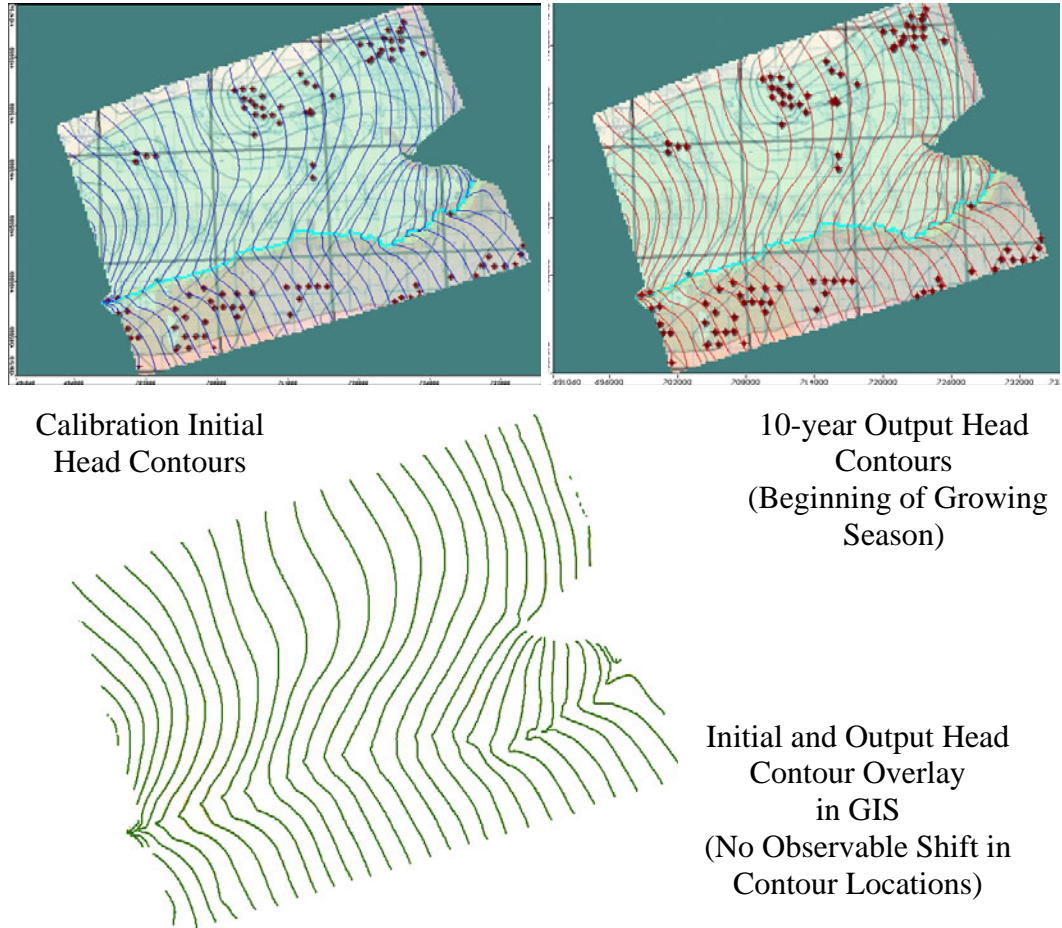


Figure 7-1: Initial and 10-year Water Table Contours (Start of Pumping)

To the south of the river, there is no clear bedrock ridge. The streambed elevations of the Arikaree River and the South Fork of the Republican River are roughly the same near Idalia (around 1,150-m). Because of the similar elevations, while both rivers continue to flow, a groundwater divide would occur between the two rivers. It would be difficult to know whether this is the case if either of the rivers ceases to flow.

Model runs also show that future changes to the system will not compromise the Arikaree River groundwater basin even if streamflow ceases. It would be difficult for the system to become a “pass through” system, where groundwater flows either to the North or South Republican basins without separate drainage from the Arikaree River basin. The

model could not be forced into such a configuration for any reasonable set of input variables.

The deep bedrock surface relative to the ground surface in southwest Yuma County has resulted in larger declines in aquifer water-table levels compared to the water-table level declines near the Fox Ranch. The water table decline has resulted in a river stage below the streambed. No observable flow was present along highway 59 (Figure 1-2) during any of the visits to the river. Alluvial soils are prominent along the river in southwest Yuma County, as indicated by aerial photo showing significant riparian vegetation (Figure 7-2) and supported by surface geology maps (Sharps, 1980).



Figure 7-2: Satellite Photo of the Arikaree River through Southwestern Yuma County (USDA 2005)

Seasonal pumping of alluvial irrigation wells (wells within one mile of the river) depletes the alluvial aquifer directly. In western Yuma County, this is observable using aerial photos as shown in Figure 7-2. The decrease in riparian vegetation downstream of

the well in the figure shows evidence of aquifer depletion. Lower water levels in the alluvium has a local effect of increasing the rate of groundwater influx into the alluvium downstream of the well's typical area of influence. Alluvial water is replaced gradually as the river reaches south-central Yuma County and the Fox Ranch property.

Alluvial wells of southeast Yuma County also act as a drain to the alluvium but a disconnection exists in this region between the Ogallala and alluvial aquifers. The aquifer disconnect is caused by the outcropping of bedrock along the river (Weist 1964) and prevents the hydraulic gradient from further increasing in the Ogallala formation because of alluvial water table decline. The result is that the river and the alluvium are depleted until a connected source such as a tributary or precipitation event returns enough water to the alluvial aquifer for the water-table levels to resurface.

There is an overall water deficit in the basin created by the irrigation wells. This results in declining winter (recovered) water-table levels and seepage to the river. Winter water-table levels are the initial levels at the start of the growing season and therefore affect the early season streamflow before drawdown occurs.

Evapotranspiration is very detrimental to the overall streamflow of the Arikaree River. ET significantly reduces the amount of available water for streamflow. The total modeled riparian ET was 2,297-ha-m (18,622-acre-ft) of water after day 258 (end of growing season). Modeled streamflow continued but a decrease of 7,369-m³/day of stream influx was attributed to ET after day 258 (end of growing season) from runs without pumping. Total water use by cottonwoods, found to be around 135-cm/season (Wachob 2005) is roughly equivalent to the water use of a single irrigation well per mile

of river, pumping at a rate of 2,180 to 3,270-m³/day given a riparian band of 60 to 90-m on both sides of the river (Section 5.1).

Observed diurnal fluctuations in alluvial water table levels are shown in Figure 7-3. Fluctuations indicate that the seasonal decline of streamflow can be attributed in large part, to local deficiencies in the water balance created by ET. Stream stage level tracks the alluvial groundwater levels very closely (Wachob 2005). By inspection of the graph in Figure 7-3, it is seen that large precipitation events, such as those at the beginning of June and July, create a spike in the groundwater level that quickly returns to a base level indicating drainage of bank storage to the stream. The spike is then followed by a diurnal fluctuations, starting from the base level that increase in magnitude up through July and August.

Small events create small rises in groundwater level that do not quickly decline. Instead, diurnal fluctuations follow the rise and the groundwater level continues to decrease at a daily rate consistent with the rate of decline before the storm. The overall rate of decline seems to increase slightly throughout the summer.

In southwestern Yuma County, reductions in streamflow from ET and climactic effects have historically been regulated by larger aquifer baseflow (Wachob 2005). The baseflow would essentially buffer the streamflow ensuring continuity during summer months. Recently water-table levels have been reduced to a point where wintertime level recovery is possible but groundwater flow from the aquifer into the alluvium cannot increase enough to maintain streamflow during periods of high ET.

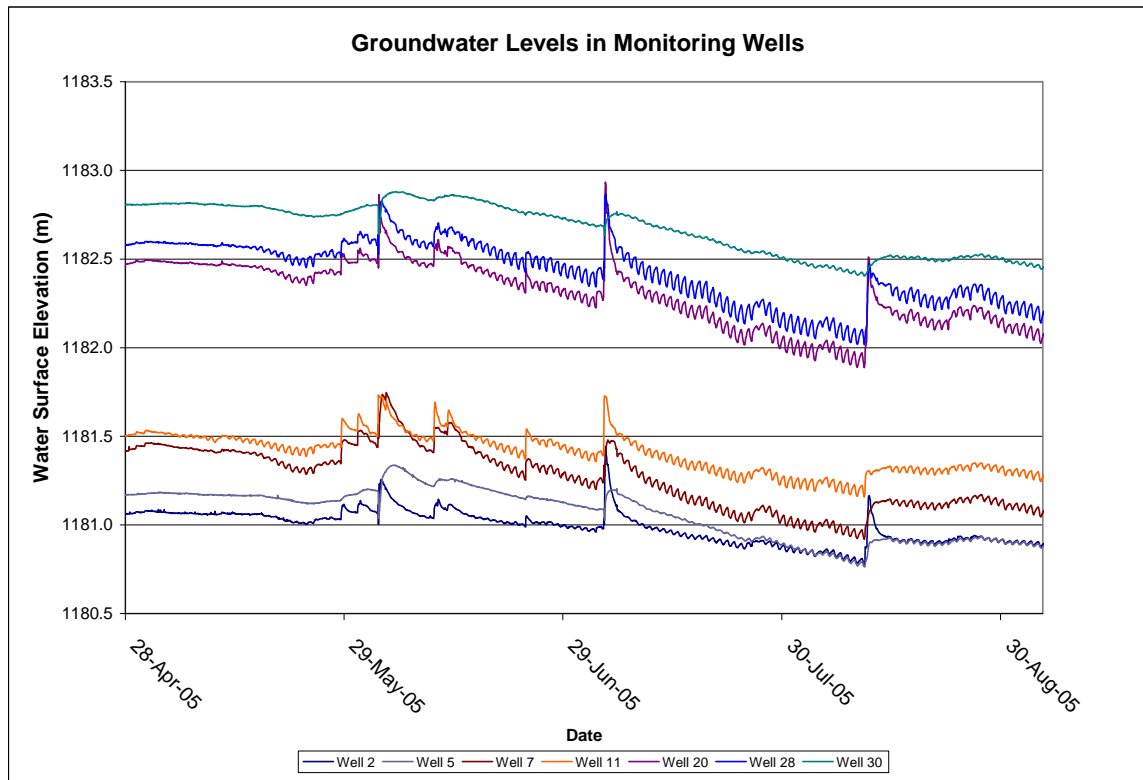


Figure 7-3: Diurnal Alluvial Groundwater Fluctuations on the Fox Ranch (Wachob 2005)

In Southeastern Yuma County, where the aquifer is disconnected from the alluvium, upstream inflow was historically much higher than today. The inflow would have been high enough to accommodate riparian ET without stream depletion. Streamflow out of Yuma County into Kansas and Nebraska was at one time continuous through Haigler, NE (Wachob 2005). Recently total yearly flow volume has been reduced enough to where there is essentially no flow at Haigler. A reduction to only 308,000- m^3/yr (250-acre-ft/yr) of water from an average of 23.3- Mm^3/yr (18,900-acre-ft/year) was seen at the Haigler gage station by 2002 as shown in Figure 7-4. Reduction has been significant despite no noticeable decline in precipitation (Figure 7-5).

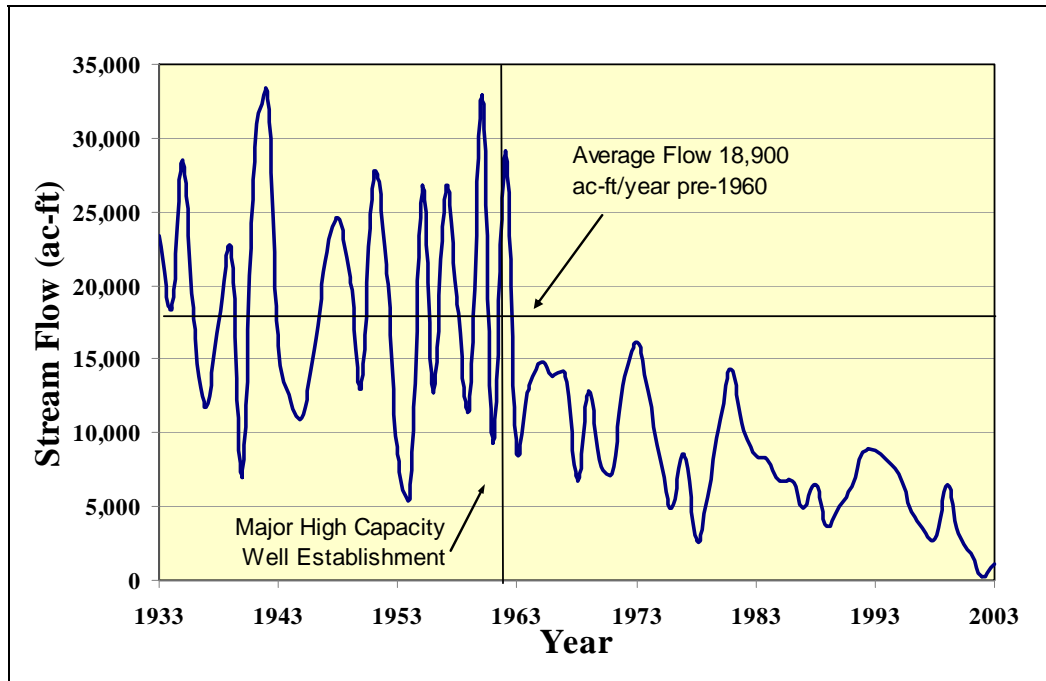


Figure 7-4: Gauge Recorded Streamflow at Haigler, NE (USGS Gauge Data)

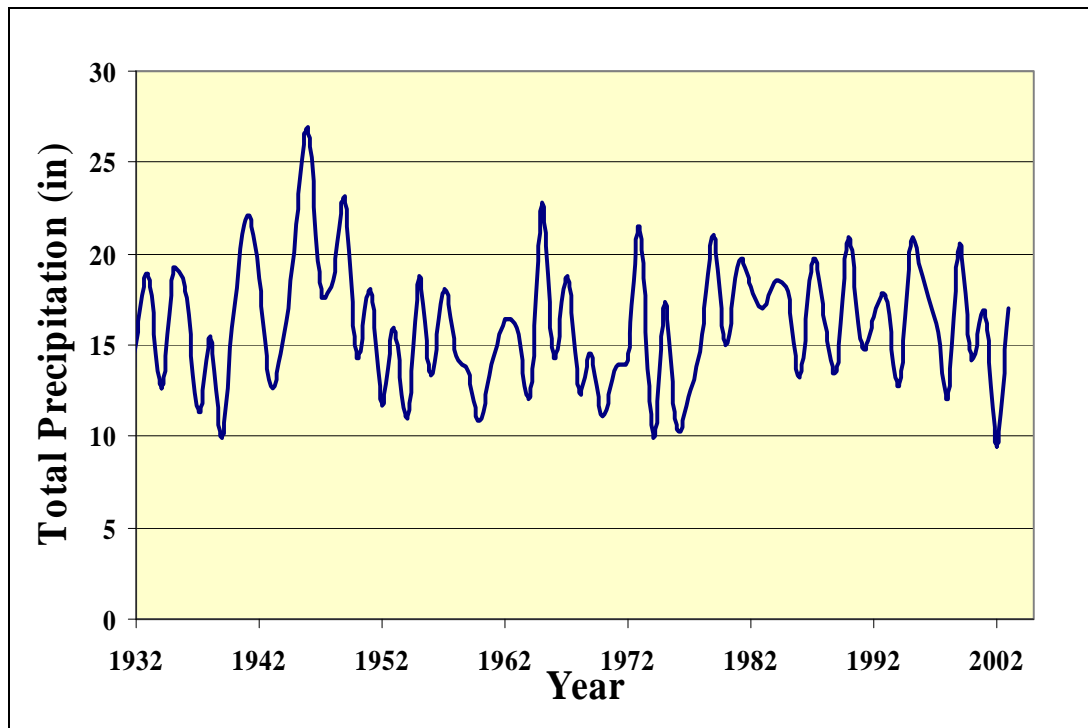


Figure 7-5: Precipitation Data, Akron Colorado Weather Station (Vigil, M. F. (2004))

The Arikaree River through Southern Yuma County can be thought of as being divided by geologic features, groundwater and habitat characteristics into four distinct regions. The regions are as follows: Upstream region, Fox Ranch region, transitional region and downstream region. The four regions are shown in Figure 7-6.

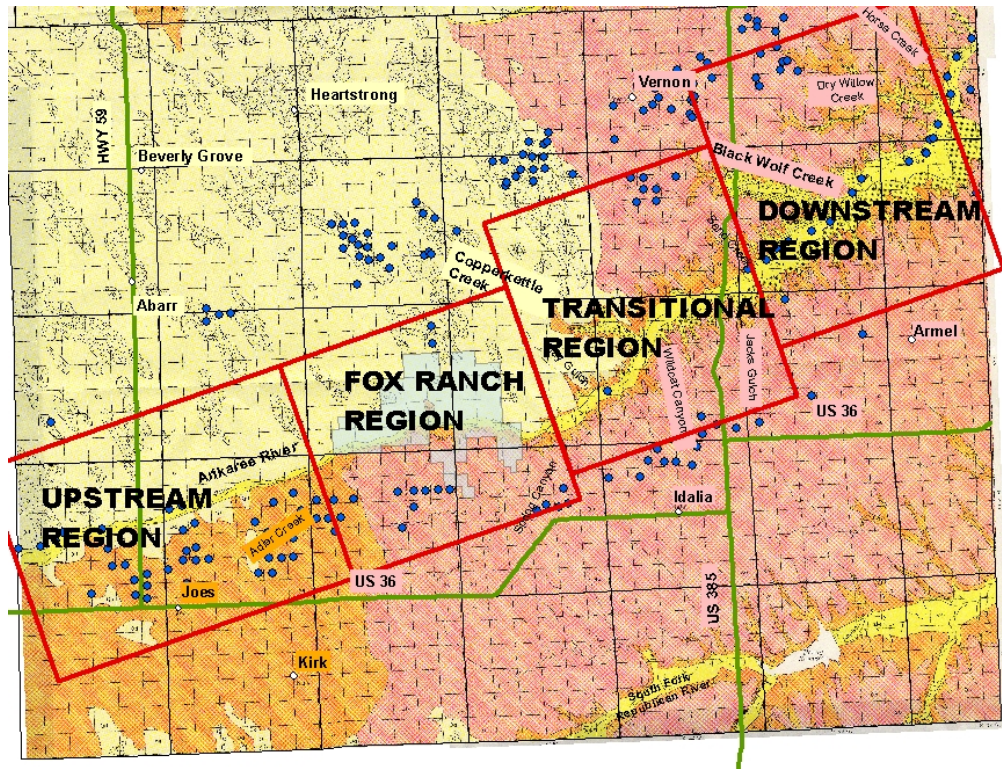


Figure 7-6: Conceptual Regions of the Arikaree River through Southern Yuma County (Background by Weist 1964)

7.2 UPSTREAM CONCEPTUALIZATION

In the upstream region, adjacent to the Yuma and Washington County border, the Arikaree River is ephemeral, flowing only during long precipitation events. The bedrock is deep (~20-m) (USGS 1999, Johnson et al. 2002) in this region and groundwater pumping is prevalent. The groundwater level is low enough so that stream channels are

dry except from precipitation events. Irrigation occurs mostly upstream of highway 59 (Figure 7-6) in Washington County. Proceeding eastward, toward the Fox Ranch, there is less pumping and recharge maintains a higher water table. More riparian vegetation is seen in aerial photos approaching the Fox Ranch.

7.3 FOX RANCH CONCEPTUALIZATION

Located in the center of Southern Yuma County, the Fox Ranch property (Figure 7-7) contains abundant wildlife habitat and is one of the remaining brassy minnow strongholds in Colorado (Scheurer et al. 2003). The property is roughly 12.8-km wide (East/West) and used primarily for grazing cattle, allowing much of the river habitat through the property to remain undisturbed. A significant recharge area, composed mostly of dune sands, is located northwest of the Fox Ranch. Two alluvial irrigation wells are located directly upstream of the western property line. Other irrigation wells exist to the southwest and additional alluvial irrigation wells are located starting 8-km upstream from the ranch.

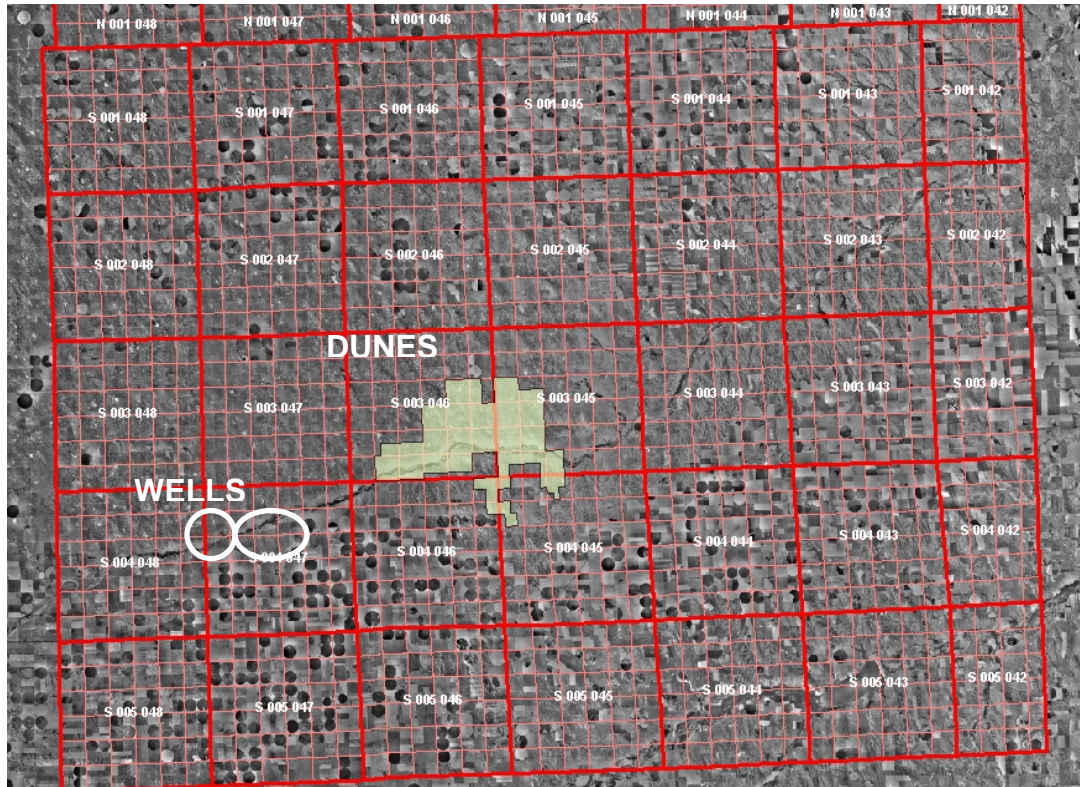


Figure 7-7: Fox Ranch Property Location (Base Aerial Photo by USDA 2002)

The downstream portion of the ranch (east) is usually wet and contains at least intermittent pools throughout the summer even as the river disconnects. Other portions of the river do not stay as wet as the ranch and many reaches dry completely, eliminating fish habitat (Scheurer et al. 2002). The alluvial aquifer and the river itself are assumed to be conceptually the same because of the minimal streamflow. Streamflow was approximately 4,890-m³/day (2-cfs) on October 15, 2005 (~6-days after a major storm event) and 11,000-m³/day (4.5-cfs) was measured March 16, 2006 (typical of early spring flow).

During the winter, streamflow along the Fox Ranch is able to recover from ET and irrigation, allowing the stream to become fully connected. This also occurs year-round after significant precipitation events. During the summer months, the stream and

ET drain water stored in the upper portion of the alluvium during the winter recovery period until the alluvial water table drops below the streambed and streamflow ceases. This also occurs with water stored during precipitation events. After the precipitation events, ET causes the water table to fall below the streambed (Figure 7-3). Figure 7-8 through Figure 7-11 show details of the Fox Ranch conceptualization.

Figure 7-8 is a cross-section of the Fox Ranch, extending out past a nearby irrigation well. Since all wells surrounding the Fox Ranch are farther than 3,000-m from the river, the cone of depression caused by the well pumping does not reach the stream. The water table, however, reduces year to year from the water balance deficit as described in chapter 6, as represented in the figure. A stock well as was monitored for this study is represented in the figure. Figure 7-9 represents the alluvium and shows the effect of ET and the stream draining water in bank storage.

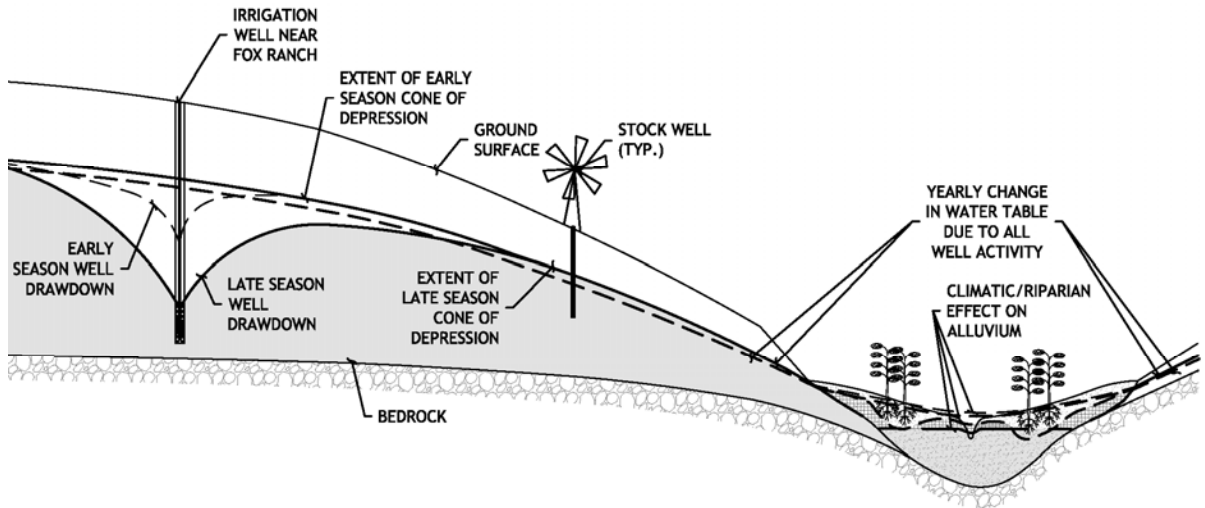


Figure 7-8: N/S Cross-Section of Adjacent Well Effect on Fox Ranch Alluvium

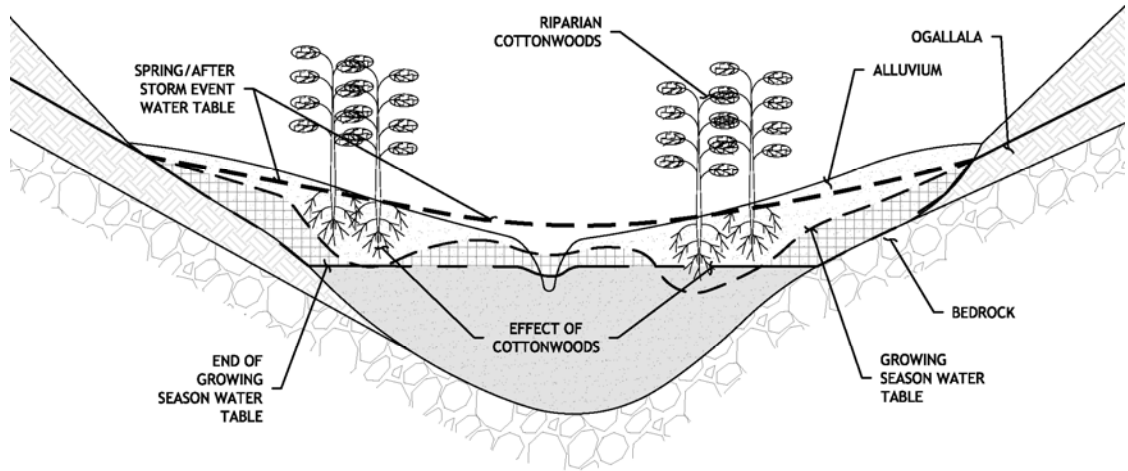


Figure 7-9: N/S Cross Section of Alluvial Deposit Water Table Fluctuations at the Fox Ranch

Figure 7-10 shows a plan view of the Fox Ranch with vector arrow indicating the magnitude of the flow rate through the alluvium, aquifer or water use by the functions of ET. The alluvial vector after the alluvial wells is small. The well field shown impedes base flow from the south.

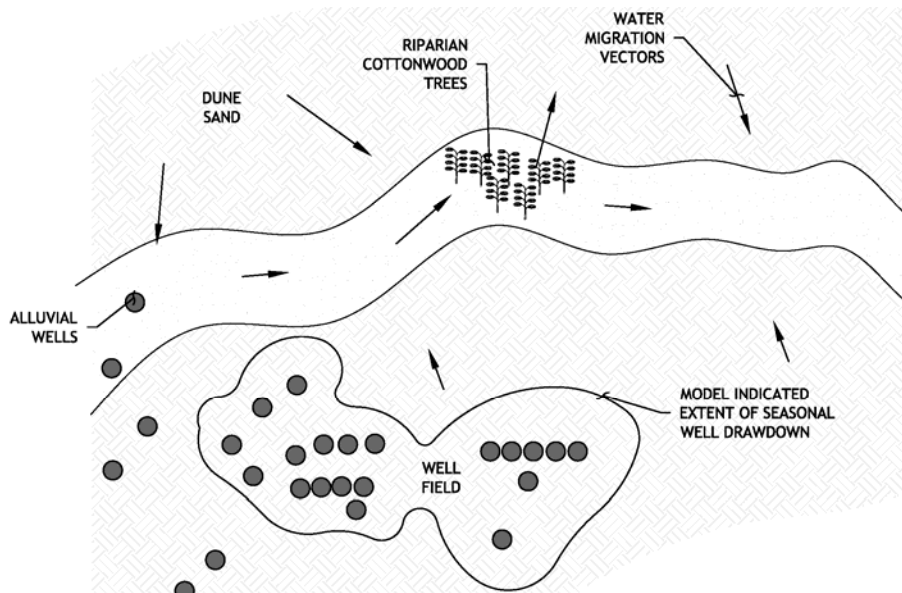


Figure 7-10: Plan View of Fox Ranch Flow Concept

Figure 7-11 shows a profile of the alluvium along the river bed. The alluvial well is shown draining the alluvium. Recharge from the dunes is shown filling the alluvium until streamflow is possible. ET then is shown reducing the alluvial water table. The result is ponding in streambed depressions with disconnection of streamflow.

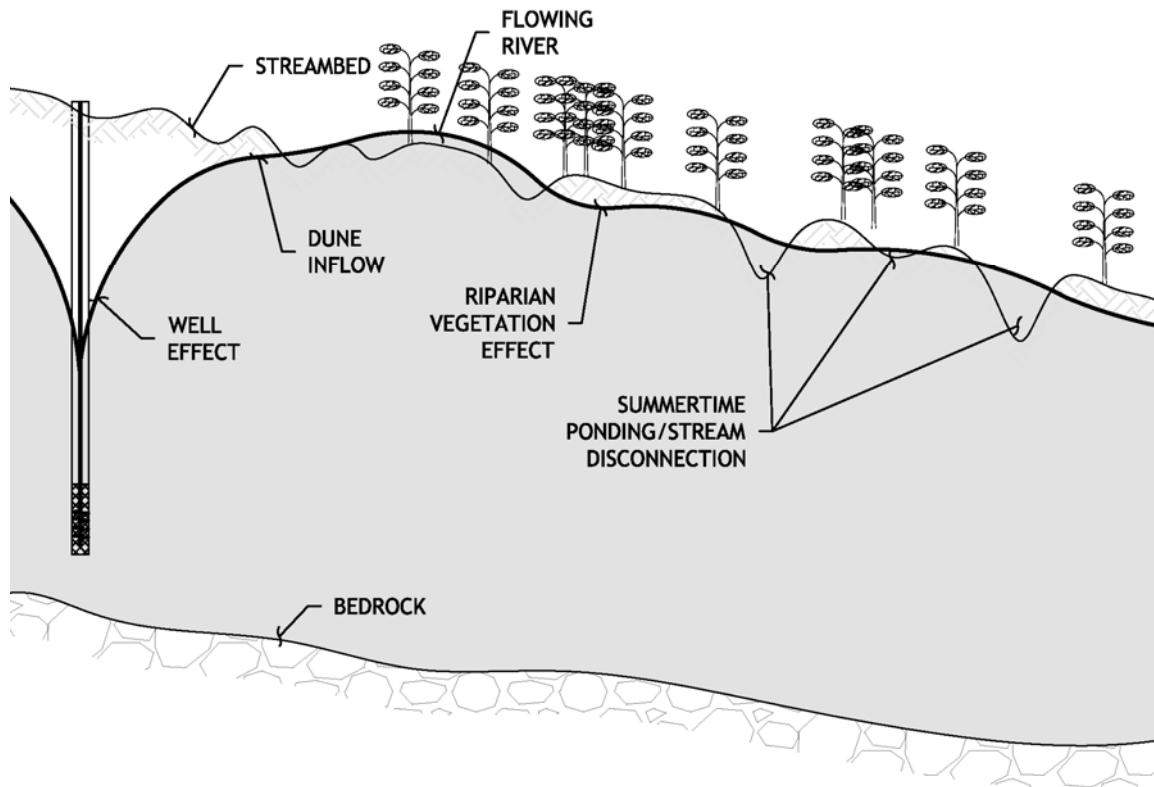


Figure 7-11: W/E Profile along the Streambed of Alluvial Well Effect on Fox Ranch Stream Stage

Figure 7-11 is a profile along the streambed showing the water table as a darker line. The notes draw attention to the effects of the dune recharge area, and riparian ET on the alluvial water table. The lighter line is the streambed. Ponding is shown when the streambed depression is below the water table and the stream is not connected from depression to depression.

The groundwater gradient toward the river is higher from the northwest than from other directions (max 0.021 from the NW vs. 0.014 from the SW) (Figure 3-2). High

recharge rate in the sand dunes contributes to the high hydraulic gradient. The sand dunes to the northwest are the main recharge zone for the Arikaree Basin through the Fox Ranch.

7.4 TRANSITIONAL CONCEPTUALIZATION

The “transitional” region is located starting just west of the confluence of Copper Kettle Creek and the Arikaree River as shown in Figure 7-6. In this region, the alluvium begins to disconnect from the Ogallala aquifer. A lower groundwater influx exists because of this disconnection. Base streamflow begins to decline because the stream base-flow is highly dependent upon upstream alluvial inflow. Alluvial flow is depleted seasonally by at least one well (i.e. well A, Table 5-2) located just downstream of the Fox Ranch. Seeps from the Ogallala Aquifer, passing over the bedrock into the alluvium become the dominant water source of the alluvial aquifer in this area. The conceptualization is shown in Figure 7-12.

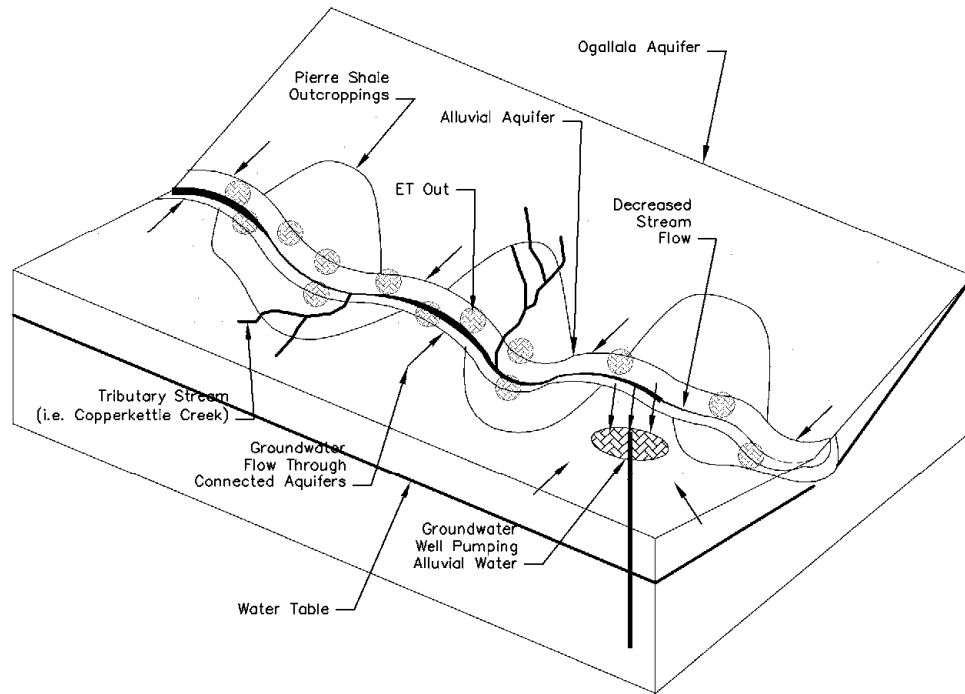


Figure 7-12: Transitional Region

7.5 DOWNSTREAM CONCEPTUALIZATION

Upstream of the Blackwolf Creek and the Arikaree River confluence is the start of the reach designated as “downstream” (Figure 7-6). Alluvial deposits in the main stretch of the river disconnect from the Ogallala Aquifer in the direction of groundwater influx. Intermittent connection of the alluvial soils and the Ogallala Aquifer exists southeast of the river but water-bearing material is very shallow. For the majority of the growing season, the alluvial water table is below the streambed. Ogallala Aquifer does not have enough connection with the alluvium or capacity to maintain the alluvial water table. Streamflow has all but disappeared during the summer months as shown in Figure 7-13.

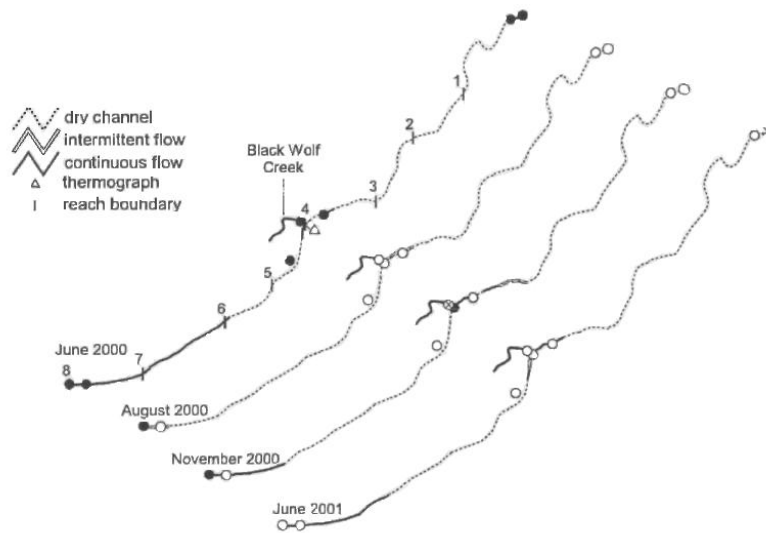


Figure 7-13: Connectivity diagrams of the downstream stretch (from Scheurer et al. 2003)

Bedrock has been worn away along the river creating a depression under the streambed. Weist (1964) shows that the alluvium has been deposited directly on the surface of the bedrock. The geological relationship was confirmed by overlaying the ground surface and the bedrock surface using GIS. Water moves downstream through the alluvial aquifer, below the riverbed. Alluvial deposits are a sink for surface water because of their low elevation and groundwater level.

Many alluvial irrigation wells are active on the southeast side of the Arikaree River, both up and downstream of Blackwolf Creek. Wells are located mostly on the southeast side of the river where there is a slight connection of the alluvial and the Ogallala aquifers. Pumping of these wells contributes significantly to the low water levels in the alluvium along with ET from riparian vegetation.

The groundwater gradient from the northwest side of the river remains directed toward the river. The ground surface elevation declines at a greater slope, proceeding eastward, than does the bedrock surface elevation. Bedrock is exposed as the two

surfaces intersect and the water bearing material of the Ogallala disappears. Springs and seeps are created and tributaries such as Blackwolf Creek capture the exposed water. The groundwater is forced to the surface, seeping into channels and becoming overland flow as shown in Figure 7-14.

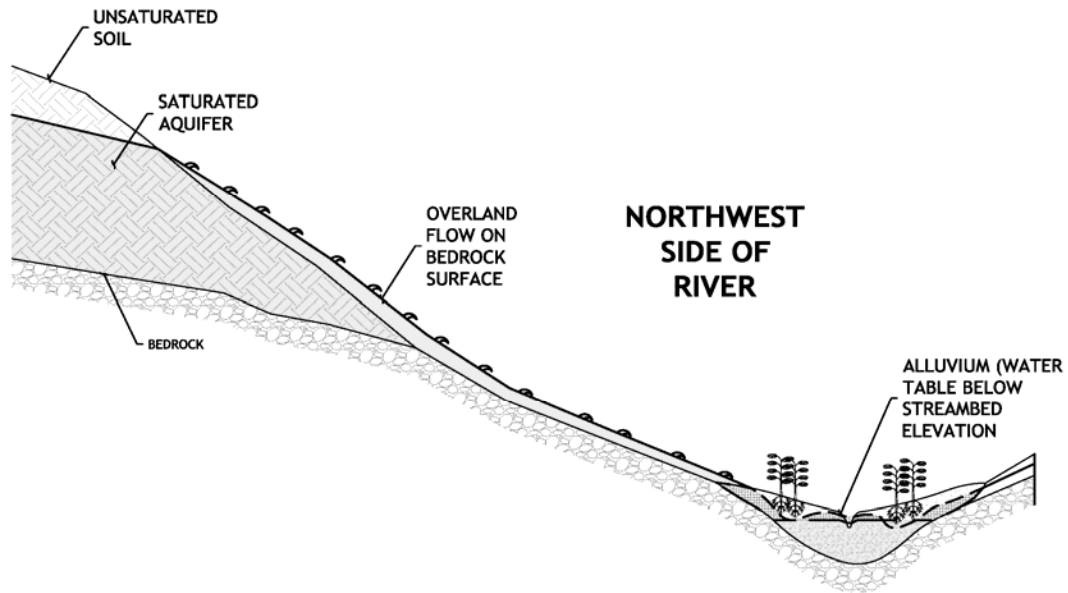


Figure 7-14: Diagram of the Downstream Arikaree River Conceptualization

The depths of the alluvium below tributary streams are generally very shallow with bedrock directly below. Much of the water collected by the tributaries appears as streamflow. Blackwolf Creek and other tributaries to the north of the river are typically wet (Scheurer et al. 2002) from captured groundwater. The tributaries are expected to remain wet until the aquifer is depleted and evapotranspiration is higher than the rate at which groundwater is converted to streamflow. Tributary flow to the Arikaree infiltrates into the alluvial sand as it reaches the river because the groundwater level is below the streambed.

CHAPTER 8 SUMMARY AND CONCLUSIONS

8.1 SUMMARY

The objectives of this study were to improve current understanding of the Arikaree River groundwater system and to develop a defensible conceptualization of the river basin. The research presented was an investigation of the effects of groundwater pumping in the Ogallala Aquifer on the Arikaree River in Southern Yuma County Colorado. The calculated change in the Arikaree River streamflow due to pumping of modeled wells was used to evaluate the effects of pumping on the river. A detailed numerical groundwater model was created to examine the effects that irrigation well pumping and declining aquifer levels have on the Arikaree River. The study was focused specifically on the reach of the river through the Fox Ranch property but included evaluation of the regional effects in Southern Yuma County.

The effect of well pumping on streamflow was evaluated using both the numerical model and analytical methods to determine which would be most beneficial forbearance targets in efforts to recover lost habitat. The results of the numerical and analytical models are similar and were considered in the selection of target wells.

A water balance was created for the Arikaree River basin through Southern Yuma County. The numerical model and previous studies were used to create the water budget and determine balance criteria. A total deficit of over 7,400-ha-m/yr (60,000-acre-ft/yr)

was approximated from irrigation well pumping. Effects of the deficit are evident in the change in streamflow and water levels over time. Over time, deficits in the water balance are expected to be distributed between reductions of streamflow, ET, groundwater outflow and water table declines throughout the basin.

A conceptualization of the river was developed to explain the groundwater trends and seasonal habitat characteristics along the river. The conceptualization was created using supporting studies, research of the groundwater levels, geology through Southern Yuma County and the numerical groundwater model.

8.2 CONCLUSIONS

The Arikaree River is located in a stable groundwater basin. Conceptualization of the river, however, must be divided into four regions where the river behaves differently because of the geology, hydrogeology, surrounding agriculture and ecology. The effects of evapotranspiration and groundwater pumping along the river are very detrimental to achieving the goal of sustaining streamflow. ET is the major cause of seasonal water-table fluctuations and seasonal streamflow declines. The year-to-year streamflow decline is affected most by irrigation pumping and the water budget deficit reducing baseflow to the alluvium. The decline in water table levels, found to be caused by groundwater pumping through investigation of the water budget, must be stopped or reversed in order to sustain or improve stream baseflow.

The Arikaree River through southern Yuma County, was divided into Upstream, Fox Ranch, Transitional and Downstream Regions. The Upstream Region is ephemeral and the water table receded too far too sustain streamflow. The Fox Ranch Region is wet,

mostly because the alluvial water table is not yet low enough to drop below the bottom of the ponds and pools scoured out of the alluvium. This may change as time passes. This region benefits from a nearby recharge area and lack irrigation wells in close proximity to the river. Streamflow through the Transitional Region is intermittent as is the connection of the alluvium to the aquifer. Other than increasing streamflow into the region by some means of reversing the water-budget deficit upstream, there is no obvious way to improve streamflow through the region. There are few wells that could be decommissioned in the region and there appears to be no practical way of reducing riparian ET. The Downstream Region passes through an area where the alluvium is disconnected from the regional aquifer. Tributaries to the area cut off groundwater flow from east-to-west through the regional aquifer. Water is released from aquifer storage to the tributaries where it is conveyed via streamflow to the Arikaree River alluvium. As tributary waters enter the Arikaree River alluvium, pools appear before water eventually dissipates into the alluvial sands.

One season of stockwell observation along the Fox Ranch has provided some clues as to the dynamics of the groundwater basin. The alluvial groundwater flow must be considered in conjunction with the stream because a high percentage of the water, relative to most rivers is conveyed through the alluvium. The stockwells are located within two to three miles of the river within the aquifer. In this area, single-season declines in water-table levels were not observed, suggesting that irrigation wells pumping lateral to the river, do not have a single-season impact on streamflow around the Fox Ranch. Numerical modeling and plotting of the groundwater contours suggest that the stream will continue gain from the aquifer even if streamflow ceases and the water table

continues to decline. Riparian ET and alluvial well pumping upstream of the Fox Ranch however, contribute to the seasonal decline of streamflow.

Well observations, drawdown calculations and the numerical model suggest that wells located more than 3,000-m from the river generally have a negligible single-season impact on the river. These wells have an impact on the regional water table, water balance and ultimately the change in base-flow from year-to-year. This could be conceptualized as the superposition of the drawdowns from all wells in the basin over many seasons. Because of this, alluvial wells located upstream of the region where there is a desire to increase the streamflow, should be looked at for decommissioning or forbearance prior to wells located laterally from the river and at some distance. Afterward, the highest capacity wells should be targeted in an attempt to improve the basin water balance.

8.3 WELL DETAILS

Ten wells were determined to be forbearance targets. It was calculated that these wells cause at least 5-gpm flow rate reduction in the streamflow. This was calculated using the numerical model and by the Glover equation. A list of the top 17 wells was compiled (Table 5-2) using the results of the numerical model analyses and Glover equation analysis. Ten additional wells are included in Table 5-2 with notes indicating these wells are calibration wells or create a high discrepancy with the internal model water balance. These wells are listed but are not recommended forbearance wells.

8.4 RECOMMENDATIONS FOR FUTURE RESEARCH

An updated study of water levels in wells throughout the county would improve the regional numerical model by providing more recent data for calibration. A study of bedrock elevations, especially near the alluvium would be beneficial for quantifying total stream and alluvial outflow. A better understanding of pumping schedules and rates would allow a more sophisticated analysis to be completed showing actual depletions by wells. A regional hydraulic conductivity and specific yield study would help to validate the model inputs. Continued studies of ET, and recharge would significantly improve the water balance and the calibration of numerical models.

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Appendix A

Public Land Survey Coordinate System Notes

Public Land Survey Coordinate System Notes:

Townships are divided into 36-square mile divisions. Each township is 6-miles in width and breadth. The north-south borders of townships are called township lines while the east-west borders are referred to as range lines.

Labels and location descriptions in the form SC00304736AB refer to the township, range, section and sub-section designations of the physical location.

The first letter indicates the principal meridian used to find the specific location. S indicates the sixth principal meridian, which is used for eastern Colorado.

The second letter indicates the direction of the location from the intersection of the baseline and the principal meridian. In eastern Colorado, C is to the south of the baseline coinciding with the 30th mile north of the border between Yuma and Kit Carson Counties.

The first set of three digits in the description indicates the location's township. The 003 indicates the location is in the third township south of the baseline, in a section between 12 and 18 miles from the baseline.

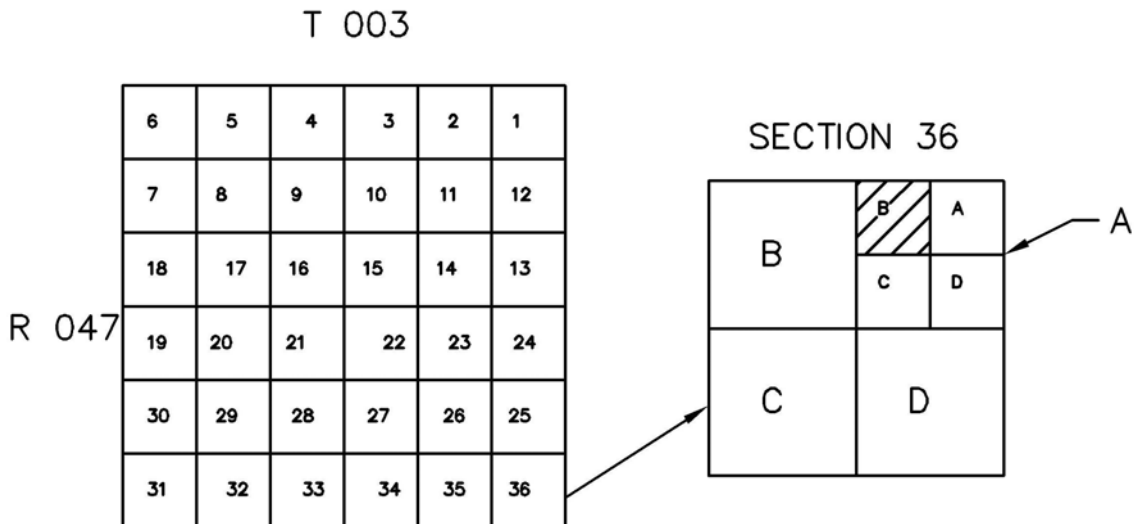
The second set of three digits in the description indicates the location's range. The 047 indicates the location is in the 47th range west of the 6th principal meridian in a section between 282 and 288 miles west of the baseline.

The last two digits in the description indicate the section number of the location within the township. Sections are numbered 1 to 36 from the northeast corner of the township and progress to section 36 alternating back and forth proceeding south, ending with section 36 at the southwest corner of the township.

The third letter indicates the location's quarter section. Labels are assigned to quarter sections from A to D starting in the northeast and proceeding counterclockwise.

The fourth letter indicates the location's quarter of its quarter section. Labels are assigned to quarters of quarter sections from A to D starting in the northeast and proceeding counterclockwise.

The written description of a point at the PLS coordinate SC00304736AB would be the northwest quarter of the northeast quarter of section 36, township 3 south, range 47 west of the 6th principal meridian.



Appendix B

Fox Ranch Windmill and Well Survey Data

Static Differential GPS Survey Data for the Fox Ranch Property in Southern Yuma County

GPS Instrument - Ashtech Locus - Ashtech 471 El Camino Real, Santa Clara, CA 95050
 Surveyors - Ryan Banning & Erik Wachob

Notes: Data Surveyed On or Before October 27, 2005
 Coordinate System UTM NAD 1983 Zone 13 N
 "Datum" is: Top of the Casing for wells, Ground Surface for Existing Grade Survey
 Depth Measured from Top of Well Casing
 Windmill Locations are Shown in Figure 3-1

GPS Site Designation	Location Name	Easting (m)	Northing (m)	Datum Elev. (m)	Depth (m)	Depth (ft)	Water Surface Elevation (m)	Datum Elev. (ft)
	Base Station (Ranch Rock)	7177141.15	4403674.923	1196.524	-	-	-	3925.80
14	Windmill 01	714900.073	4408185.063	1231.343	16.490	54.10	1214.85	4039.83
12	Windmill 02	712710.188	4406522.734	1238.982	18.105	59.40	1220.87	4064.89
10	Windmill 03	713971.807	4406228.529	1219.144	6.462	21.20	1212.68	3999.80
13	Windmill 04	715001.081	4406360.434	1235.494	25.634	84.10	1209.86	4053.45
20	Windmill 06	712901.896	4404640.746	1225.658	18.471	60.60	1207.18	4021.18
9	Windmill 07	714914.273	4405434.049	1219.928	18.441	60.50	1201.48	4002.38
8	Windmill 08	716872.398	4405405.513	1215.851	25.329	83.10	1190.52	3989.00
15	Windmill 10	720226.538	4407368.989	1219.813	27.524	90.30	1192.29	4002.00
16	Windmill 11	719664.425	4406019.176	1219.091	36.058	118.30	1183.03	3999.63
17	Windmill 12	718108.064	4406121.697	1223.721	30.663	100.60	1193.05	4014.82
18	Windmill 13	718981.166	4404978.414	1204.336	23.165	76.00	1181.17	3951.22
6	Windmill 14	717143.893	4400604.758	1241.088	49.957	163.90	1191.13	4071.80
4	Windmill 15	718074.660	4400076.588	1233.982	45.218	148.35	1188.76	4048.49
7	Windmill 16 (Offsite)	718993.614	4401335.229	1238.127	53.737	176.30	1184.38	4062.08
24	Windmill 16	721215.151	4401311.278	1219.472	44.440	145.80	1175.03	4000.88
23	Windmill 17	720966.404	4402465.37	1207.456	32.888	107.90	1174.57	3961.46
3	Windmill 18	716379.342	4403588.726	1199.702	9.723	31.90	1189.98	3936.02
5	Windmill 19	716533.111	4402053.958	1235.561	41.789	137.10	1193.77	4053.67
11	Windmill 20	710765.631	4403602.102	1236.355	21.672	71.10	1214.68	4056.27
21	Windmill 21	711364.77	4403886.159	1236.772	24.293	79.70	1212.48	4057.64
	Observation well 1 (Wachob)	717845.732	4404284.245	1182.573	1.321	4.33	1181.25	3879.82
	Observation well 2 (Wachob)	717934.977	4404309.498	1182.55	1.651	5.42	1180.90	3879.74
	Observation well 3 (Wachob)	717877.781	4404326.226	1183.533	2.438	8.00	1181.09	3882.97
	Observation well 4 (Wachob)	717810.408	4404405.426	1183.742	2.032	6.67	1181.71	3883.66
	Observation well 5 (Wachob)	717971.709	4404383.733	1183.131	2.235	7.33	1180.90	3881.65
	Observation well 6 (Wachob)	717863.873	4404264.132	1182.347	1.168	3.83	1181.18	3879.08
	Observation well 7 (Wachob)	717888.504	4404206.632	1183.097	2.007	6.58	1181.09	3881.54
	Observation well 8 (Wachob)	717797.073	4404214.261	1183.396	1.880	6.17	1181.52	3882.52
	Observation well 9 (Wachob)	717833.762	4404118.945	1182.893	1.486	4.88	1181.41	3880.87
	Observation well 10 (Wachob)	717767.551	4403933.159	1183.44	1.118	3.67	1182.32	3882.67
	Observation well 11 (Wachob)	717920.080	4403972.893	1182.719	1.422	4.67	1181.30	3880.30
	Observation well 20 (Wachob)	717630.109	4404339.429	1184.521	2.362	7.75	1182.16	3886.21
	Observation well 21 (Wachob)	717514.810	4404261.647	1184.581	2.032	6.67	1182.55	3886.41
	Observation well 22 (Wachob)	717650.040	4404236.105	1183.775	1.753	5.75	1182.02	3883.76
	Observation well 23 (Wachob)	717595.753	4404135.426	1184.189	1.357	4.45	1182.83	3885.12
	Observation well 24 (Wachob)	717507.226	4404076.171	1184.471	1.638	5.38	1182.83	3886.05
	Observation well 25 (Wachob)	717649.818	4404062.487	1183.682	1.397	4.58	1182.28	3883.46
	Observation well 27 (Wachob)	717689.209	4404375.095	1182.877	2.108	6.92	1180.77	3880.82
	Observation well 28 (Wachob)	717612.918	4404407.108	1183.032	1.905	6.25	1181.13	3881.33
	Observation well 29 (Wachob)	717534.625	4404441.497	1185.456	2.794	9.17	1182.66	3889.28
	Observation well 30 (Wachob)	717675.207	4404490.640	1185.749	3.251	10.67	1182.50	3890.24
	Stage Gauge 7 (Griffin)	717625.558	4404361.716	1181.936	-0.191	-0.63	1182.13	3877.73
101	USGS Gauge (Fox Ranch)	721718.676	4403431.788	1163.018	-0.457	-1.50	1163.48	3815.66
33	U Road River Bottom West	717205.554	4404217.104	1184.82	0.152	0.50	1184.67	3887.19
26	Stage Gauge 5 (Griffin)	720261.095	4403791.915	1169.716	0.434	1.42	1170.15	3837.64
27	Obs. Well E (Griffin)	720228.723	4403799.043	1170.762	0.576	1.89	1170.19	3841.07
28	Riv Btm by Gauge E (Griffin)	720233.058	4403802.297	1170.172	0.025	0.08	1170.15	3839.14
29	Misc. Pond	719683.818	4404264.344	1172.528	-1.006	-3.30	1173.53	3846.87
32	River Bottom	719197.998	4404503.675	1175.662	-0.165	-0.54	1175.83	3857.15
34	River Bottom	720140.655	4403992.93	1170.379	-0.823	-2.70	1171.20	3839.81
35	(Faulke) Well 1	718603.359	4404000.358	1180.271	1.554	5.10	1178.72	3872.27
36	(Faulke) Well 1 River Bottom	718606.737	4404008.165	1178.223	-0.335	-1.10	1178.56	3865.55
37	River Bottom	718292.824	4404114.086	1179.57	-0.427	-1.40	1180.00	3869.97
38	River Bottom	717452.335	4404340.892	1183.572	-0.244	-0.80	1183.82	3883.10
39	Beaver Pond Bottom	716779.701	4404255.248	1185.623	-1.189	-3.90	1186.81	3889.83
40	River Bottom	715454.267	4404616.636	1191.509	-0.411	-1.35	1191.92	3909.14

Appendix C
Public Gauge Data

Akron Weather Data

Cummulative Precipitation for the USDA Weather Station in
Akron, Colorado

Source:

USDA-ARS Central Great Plains Weather Station

Vigil M. F. (2004)

<u>Year</u>	<u>Precip. (in)</u>	<u>Precip. (cm)</u>	<u>Year</u>	<u>Precip. (in)</u>	<u>Precip. (cm)</u>
1908	16.85	42.80	1956	13.3	33.9
1909	22.46	57.05	1957	18.0	45.8
1910	17.36	44.09	1958	14.4	36.6
1911	14.51	36.86	1959	13.6	34.5
1912	20.73	52.65	1960	10.9	27.7
1913	16.55	42.04	1961	14.3	36.4
1914	15.58	39.57	1962	16.4	41.8
1915	25	63.50	1963	16.0	40.5
1916	13.74	34.90	1964	12.3	31.2
1917	17.5	44.45	1965	22.8	58.0
1918	22.28	56.59	1966	14.3	36.3
1919	15.52	39.42	1967	18.8	47.7
1920	21.35	54.23	1968	12.5	31.6
1921	13.44	34.14	1969	14.5	36.8
1922	16.66	42.32	1970	11.1	28.1
1923	18.16	46.13	1971	13.8	35.0
1924	14.08	35.76	1972	14.2	36.1
1925	11.82	30.02	1973	21.5	54.7
1926	20.16	51.21	1974	9.9	25.2
1927	20.4	51.82	1975	17.3	44.0
1928	15.37	39.04	1976	10.4	26.4
1929	19.61	49.81	1977	12.5	31.9
1930	19.03	48.34	1978	15.6	39.5
1931	10.74	27.28	1979	21.1	53.5
1932	15.14	38.46	1980	15.0	38.0
1933	18.9	48.01	1981	19.6	49.7
1934	12.61	32.03	1982	18.2	46.2
1935	19.09	48.49	1983	17.0	43.1
1936	18.21	46.25	1984	18.6	47.2
1937	11.35	28.83	1985	17.9	45.5
1938	15.5	39.37	1986	13.2	33.6
1939	9.93	25.22	1987	19.7	50.1
1940	16.78	42.62	1988	16.2	41.2
1941	22.09	56.11	1989	13.6	34.4
1942	18.67	47.42	1990	20.9	53.0
1943	12.72	32.31	1991	14.9	37.8
1944	15.74	39.98	1992	16.5	42.0
1945	21.61	54.89	1993	17.7	45.0
1946	26.79	68.05	1994	12.8	32.4
1947	17.72	45.01	1995	20.7	52.6
1948	18.51	47.02	1996	18.8	47.7
1949	23.04	58.52	1997	16.2	41.0
1950	14.41	36.60	1998	12.2	30.9
1951	18.08	45.92	1999	20.6	52.2
1952	11.69	29.69	2000	14.3	36.3
1953	15.95	40.51	2001	16.8	42.6
1954	11.01	27.97	2002	9.5	24.1
1955	18.76	47.65	2003	17.0	43.2
			<hr/>	<hr/>	<hr/>
			AVE	16.5	41.8

**Stream Gauge Data for the Arikaree River
USGS Gauge Station at Haigler, Nebraska**

Source:

U.S. Geological Survey National Water Information System

http://waterdata.usgs.gov/nwis/help?codes_help#dv_cd

USGS 06821500 ARIKAREE RIVER AT HAIGLER, NEBR.

<u>Year</u>	<u>Flow (ac-ft)</u>	<u>Flow (m³/day)</u>	<u>Year</u>	<u>Flow (ac-ft)</u>	<u>Flow (m³/day)</u>
1933	23,425	79,161	1969	12,891	43,563
1934	18,503	62,529	1970	7,649	25,849
1935	28,469	96,207	1971	7,279	24,600
1936	16,348	55,246	1972	13,849	46,801
1937	11,800	39,878	1973	16,155	54,595
1938	17,441	58,939	1974	12,907	43,620
1939	22,397	75,688	1975	8,066	27,258
1940	7,087	23,951	1976	4,934	16,675
1941	29,386	99,307	1977	8,576	28,981
1942	33,209	112,227	1978	2,742	9,266
1943	15,868	53,624	1979	5,666	19,148
1944	12,061	40,760	1980	10,875	36,751
1945	11,001	37,178	1981	14,349	48,490
1946	15,658	52,914	1982	10,120	34,199
1947	22,258	75,219	1983	8,450	28,555
1948	24,630	83,235	1984	8,198	27,705
1949	20,510	69,312	1985	6,783	22,924
1950	13,080	44,203	1986	6,712	22,683
1951	27,554	93,117	1987	4,840	16,356
1952	21,466	72,543	1988	6,527	22,057
1953	8,559	28,923	1989	3,689	12,467
1954	5,760	19,465	1990	5,059	17,097
1955	26,666	90,116	1991	6,388	21,587
1956	12,764	43,136	1992	8,683	29,342
1957	26,727	90,321	1993	8,818	29,800
1958	19,172	64,789	1994	8,252	27,886
1959	11,854	40,059	1995	7,174	24,245
1960	32,877	111,105	1996	4,678	15,808
1961	9,330	31,531	1997	3,609	12,197
1962	29,161	98,547	1998	2,848	9,626
1963	8,974	30,325	1999	6,496	21,952
1964	13,246	44,764	2000	3,223	10,890
1965	14,807	50,039	2001	1,813	6,128
1966	13,856	46,823	2002	206	696
1967	14,093	47,625	2003	1,073	3,625
1968	6,670	22,540	Average	12,623	42,659

Appendix D

**123-Day Drawdown Comparison
and
Calculations
(ET vs. Irrigation Wells)**

Drawdown from Riparian ET Along the Arikaree River

By Theis Equation (See Equation 5-1)

Tree ET Rate	780	gpm/mile	4255	m ³ /day-1.6 km
K	500	ft/day	152	m/day
b	30	ft	9	m

1/8 mile section

Q	97.5	gpm	532	m ³ /day
T	15000	ft ² /day	1393	m ² /day
Sya	0.2			
Alpha	75000	ft ² /day	6967	m ² /day
t	123	days		

Total Drawdown = sum of drawdown x2
 Total Drawdown 3.16 ft
0.96 m

Miles from Point	Distance (ft)	ET (gpm)	EI (ft ³ /day)	Sat Thick(ft)	K (ft/day)	T (ft ² /day)	Sy	U	Drawdown (ft)	W(u)
1/64	41.25	12.2	2346	30	500	15000	0.2	4.6E-05	0.117	9.407
1/32	123.75	12.2	2346	30	500	15000	0.2	4.2E-04	0.090	7.210
1/16	247.5	24.4	4693	30	500	15000	0.2	1.7E-03	0.145	5.825
1/8	495	48.8	9385	30	500	15000	0.2	6.6E-03	0.221	4.444
1/4	990	97.5	18770	30	500	15000	0.2	2.7E-02	0.306	3.077
3/8	1650	97.5	18770	30	500	15000	0.2	7.4E-02	0.209	2.102
1/2	2310	97.5	18770	30	500	15000	0.2	1.4E-01	0.149	1.496
5/8	2970	97.5	18770	30	500	15000	0.2	2.4E-01	0.107	1.079
3/4	3630	97.5	18770	30	500	15000	0.2	3.6E-01	0.078	0.780
7/8	4290	97.5	18770	30	500	15000	0.2	5.0E-01	0.056	0.561
1	4950	97.5	18770	30	500	15000	0.2	6.6E-01	0.040	0.400
2	7920	780.0	150160	30	500	15000	0.2	1.7E+00	0.059	0.075
3	13200	780.0	150160	30	500	15000	0.2	4.7E+00	0.001	0.002

Drawdown from Irrigation Wells Near the Fox Ranch Property

By This Equation (See Equation 5-1)

Wells	Distance (miles)		Distance (m)	CDWR Yield		Sat Thick (m)	K (m/day)	T (m ² /day)	S _{ya}	U	Drawdown (m)	W(u)
				gpm	m ³ /day							
1	3.25	North	5368	600	3271	21	46	975	0.2	12.01	4.31E-06	1.61E-05
2	3.75	North	6154	620	3380	21	46	975	0.2	15.78	4.32E-06	1.57E-05
3	2.75	South	4444	1200	6542	34	30	1022	0.2	7.86	3.05E-05	5.99E-05
4	2.75	South	4587	1200	6542	34	30	1022	0.2	8.37	2.07E-05	4.06E-05
5	2.75	South	4861	1200	6542	34	30	1022	0.2	9.40	1.21E-05	2.37E-05
6	2.75	South	5246	1200	6542	34	30	1022	0.2	10.95	8.74E-06	1.71E-05
Total Drawdown (m)											0.00008	

Appendix E

Glover Equation Analysis

Computation Sheet for Glover Equation Analysis

-Table shows the Glover equation analysis using Jenkins (1968) sdf tables

Glover Rank (1)	Additive Rank (2)	Subtractive Rank (3)	Well PLS Coordinate (4)	Flow Change (m ³ /day) (5)	Flow Change (m ³ /day) (6)	61% Rating (m ³ /day) (7)	Ogallala Sat Thick (m) (8)	Alluvial Sat Thick (m) (9)	Ave. Sat. Thickness (m) (10)	K Approx (m/day) (11)	S (12)	Well Distance (m) (13)	t/(sdf) (14)	q/Q (15)	q (m ³ /day) (16)
1	1	1	SC00304419CD	2097.7	2138.0	2388	9.0	9	9.0	152	0.22	183	22.93	0.88	2103
2	2	3	SC00404718AA	948.7	1271.8	2328	9.0	9	9.0	152	0.22	183	22.93	0.88	2050
3	13	4	SC00404718BB	624.8	849.8	1842	9.0	9	9.0	152	0.22	183	22.93	0.88	1623
4	15	18	SC00404714AB	421.6	4.6	3325	10.0	9	9.5	61	0.20	846	0.50	0.29	974
5	17	7	SC00404717CD	65.8	158.0	2159	24.0	9	16.5	61	0.20	1180	0.44	0.27	577
6	16	6	SC00404719AA	81.9	195.8	1995	28.0	9	18.5	61	0.20	1250	0.44	0.27	533
7	18	8	SC00404712CA	26.3	69.1	998	21.0	9	15.0	76	0.20	1290	0.42	0.28	279
8	0	0	SC00404719DD	N/A	N/A	3990	9.0	9	9.0	152	0.22	2412	0.13	0.05	209
9	0	0	SC00404815CD	N/A	N/A	1164	23.0	9	16.0	53	0.19	1600	0.22	0.13	149
10	6	26	SC00404618BA	784.0	1.0	5320	35.0	9	22.0	23	0.18	2200	0.07	0.01	43
11	4	14	SC00404713AC	785.6	7.3	3990	38.0	9	23.5	23	0.18	2500	0.06	0.01	27
12	8	25	SC00404715DC	754.3	1.6	3325	33.0	9	21.0	23	0.17	2460	0.06	0.01	22
13	41	10	SC00404511CD	2.8	12.7	3990	34.0	9	21.5	61	0.21	4100	0.05	0.01	21
14	14	24	SC00404720CD	422.3	1.7	3325	46.4	9	27.7	15	0.17	2656	0.04	0.00	16
15	9	19	SC00404618AA	752.3	4.5	3325	36.0	9	22.5	18	0.17	2638	0.04	0.00	16
16	10	17	SC00404729AA	744.0	4.6	4988	48.8	9	28.9	15	0.17	3800	0.02	0.00	13
17	7	73	SC00404608DD	766.0	0	3325	35.0	9	22.0	15	0.17	3210	0.02	0.00	9
18	21	12	SC00404404BD	11.36	9.95	3990	27.0	9	18.0	53	0.20	5700	0.02	0.00	8
19	29	11	SC00404405DD	4.49	11.86	2725	29.1	9	19.0	46	0.20	5500	0.02	0.00	6
20	19	88	SC00404725DD	17.0	0	2725	49.8	9	29.4	23	0.18	5300	0.02	0.00	5
21	20	92	SC00404727DD	17.0	0	2725	51.2	9	30.1	15	0.17	5750	0.01	0.00	3
22	22	29	SC00104535BD	10.3	0	5819	48.0	9	28.5	46	0.20	13166	0.00	0.00	3
23	23	41	SC00204510AB	10.3	0	5320	24.7	9	16.8	30	0.19	11950	0.00	0.00	1
24	5	5	SC00304703BC	784.0	250.3	5320	5.4	9	7.2	53	0.20	10881	0.00	0.00	1
25	12	2	SC00304704AC	633.3	1779.4	5320	4.1	9	6.5	53	0.20	10881	0.00	0.00	1
26	11	67	SC00304705AA	643.6	0	3325	4.4	9	6.7	53	0.20	10881	0.00	0.00	1
27	3	9	SC00304705DA	786.3	61.3	3325	4.4	9	6.7	46	0.20	10881	0.00	0.00	1

See page 137 for an explanation of variables

Glover Equation Analysis Computation Sheet Explanation

- (1) Glover Analysis well rank by day 257 rate of stream depletion
- (2) Numerical additive analysis rank by day 257 rate of stream depletion
- (3) Numerical subtractive analysis rank by day 257 rate of stream depletion
- (4) Well coordinate in public land survey coordinate system (PLS)
- (5) Numerical model additive analysis day 257 streamflow change due to well addition
- (6) Numerical model subtractive analysis day 257 streamflow change due to well addition
- (7) 61% of CDWR rated well capacity
- (8) Ogallala aquifer saturated thickness at the well from GIS
- (9) Assumed alluvial saturated thickness (9-m all wells)
- (10) Average saturated thickness between well and stream
- (11) Approximate hydraulic conductivity between well and stream from the calibrated numerical model
- (12) Approximate average specific yield between well and stream from numerical model
- (13) Linear distance from the well to the stream
- (14) Pumping time divided by Jenkins (1968) sdf

$$sdf = \frac{a^2 S}{T}$$

Where:

a^2 = linear distance from the well to stream - (13)²

S = specific yield of the aquifer (average used) - (12)

T = transmissivity of the aquifer (average used) - (10)*(9)

- (15) Stream depletion rate q (m³/day) divided by the well pumping rate Q (m³/day) from Jenkins (1968)
- (16) Stream depletion rate q (m³/day) for well (15)*(7)

Appendix F

Numerical Model Wells Ranks Grouped by Analysis Method

Numerical Model Additive Ranks

-Table shows the comparison of the numerical model results between scenarios with no wells pumping and with individual wells added.
 -Influx and Outflux are based on the zone budge outputs from the model.
 -Influx is movement of water from the stream to the aquifer and outflux is movement of water from the aquifer to the stream.

Additive Rank (1)	PLS Coordinate (or Run) (2)	Capacity (m ³ /day) (3)	Distance to Stream (m) (4)	Stream Outflux (m ³ /day) (5)	Stream Influx (m ³ /day) (6)	Stream Flow (m ³ /day) (7)	Outflux Delta (m ³ /day) (8)	Influx Delta (m ³ /day) (9)	Flow Change (m ³ /day) (10)
-	All Off Steady	-	-	129,353	549,772	420,419	-	-	-
1	SC00304419CD	2,388	<200	129,543	547,864	418,321	190	-1,908	-2,098
2	SC00404718AA	2,159	1180	128,868	548,338	419,470	-485	-1,434	-949
3	SC00304705DA	3,325	>3000	129,452	549,085	419,633	99	-687	-786
4	SC00404713AC	998	1290	129,450	549,083	419,633	97	-689	-786
5	SC00304703BC	5,320	>3000	129,446	549,081	419,635	93	-691	-784
6	SC00404618BA	5,320	2200	129,449	549,084	419,635	96	-689	-784
7	SC00404608DD	3,325	3100	129,438	549,091	419,653	84	-682	-766
8	SC00404715DC	3,325	846	129,442	549,107	419,665	89	-666	-754
9	SC00404618AA	3,325	2638	129,447	549,114	419,667	94	-658	-752
10	SC00404729AA	4,988	>3000	129,433	549,108	419,675	80	-664	-744
11	SC00304705AA	3,325	>3000	129,427	549,202	419,775	74	-570	-644
12	SC00304704AC	5,320	>3000	129,394	549,180	419,786	41	-592	-633
13	SC00404718BB	2,328	183	129,058	548,853	419,794	-295	-920	-625
14	SC00404720CD	3,325	2656	129,417	549,414	419,997	64	-358	-422
15	SC00404714AB	3,325	2916	129,325	549,323	419,997	-28	-449	-422
16	SC00404719AA	1,842	<200	129,243	549,580	420,337	-110	-192	-82
17	SC00404717CD	3,325	2460	129,219	549,572	420,353	-134	-200	-66
18	SC00404712CA	1,995	1250	129,364	549,757	420,393	11	-16	-26
19	SC00404725DD	2,725	>3000	129,352	549,754	420,402	-1	-18	-17
20	SC00404727DD	2,725	>3000	129,352	549,754	420,402	-1	-18	-17
21	SC00404404BD	3,990	4695	129,352	549,760	420,408	-1	-13	-11
22	SC00104535BD	5,819	>3000	129,364	549,772	420,409	10	0	-10
23	SC00204510AB	5,320	>3000	129,364	549,772	420,409	10	0	-10
24	SC00404515DB	5,653	4462	129,353	549,762	420,409	0	-10	-10
25	SC00404514CB	5,816	4903	129,355	549,765	420,410	2	-7	-9
26	SC00404514DB	4,361	4890	129,355	549,765	420,410	2	-7	-9
27	SC00404515CB	3,325	4747	129,356	549,767	420,411	3	-6	-8
28	SC00404407CB	5,653	4715	129,359	549,772	420,414	5	0	-5
29	SC00404405DD	2,725	5024	129,350	549,764	420,414	-4	-8	-4
30	SC00404610DC	3,325	>3000	129,353	549,776	420,423	0	4	-4
31	SC00404611CD	3,990	>3000	129,353	549,776	420,423	0	4	-4
32	SC00404611DD	3,990	>3000	129,353	549,776	420,423	0	4	-4
33	SC00404617CC	3,990	>3000	129,353	549,776	420,423	0	4	-4
34	SC00404618CD	3,325	3212	129,353	549,776	420,423	0	4	-4
35	SC00404618DC	3,990	>3000	129,353	549,776	420,423	0	4	-4
36	SC00404619AD	3,325	>3000	129,353	549,776	420,423	0	4	-4
37	SC00404722DC	3,325	>3000	129,353	549,776	420,423	0	4	-4
38	SC00404723CA	3,325	>3000	129,353	549,776	420,423	0	4	-4
39	SC00404729BD	2,725	>3000	129,353	549,776	420,423	0	4	-4
40	SC00404713DD	3,990	2500	129,349	549,772	420,422	-4	-1	-3
41	SC00404511CD	3,990	3955	129,349	549,765	420,416	-5	-7	-3
42	SC00304612CD	1,995	4917	129,352	549,768	420,416	-1	-4	-3
43	SC00404612CD	3,990	4349	129,352	549,768	420,416	-1	-4	-3
44	SC00404612DC	3,990	>3000	129,352	549,768	420,416	-1	-4	-3
45	SC00104534DB	4,988	>3000	129,353	549,772	420,419	0	0	0
46	SC00104535CA	4,988	>3000	129,353	549,772	420,419	0	0	0
47	SC00104535CB	3,325	>3000	129,353	549,772	420,419	0	0	0
48	SC00204502BA	3,990	>3000	129,353	549,772	420,419	0	0	0
49	SC00204502CA	3,990	>3000	129,353	549,772	420,419	0	0	0
50	SC00204503AA	2,993	>3000	129,353	549,772	420,419	0	0	0
51	SC00204503BA	3,990	>3000	129,353	549,772	420,419	0	0	0
52	SC00204503CA	5,320	>3000	129,353	549,772	420,419	0	0	0
53	SC00204503DA	3,990	>3000	129,353	549,772	420,419	0	0	0
54	SC00204504AC	3,990	>3000	129,353	549,772	420,419	0	0	0
55	SC00204509AB	3,690	>3000	129,353	549,772	420,419	0	0	0
56	SC00204509AC	6,650	>3000	129,353	549,772	420,419	0	0	0
57	SC00204510BB	5,453	>3000	129,353	549,772	420,419	0	0	0
58	SC00204512BA	2,660	>3000	129,353	549,772	420,419	0	0	0
59	SC00204519BA	2,993	>3000	129,353	549,772	420,419	0	0	0
60	SC00204611DD	3,821	>3000	129,353	549,772	420,419	0	0	0

Numerical Model Additive Ranks

-Table shows the comparison of the numerical model results between scenarios with no wells pumping and with individual wells added.

-Influx and Outflux are based on the zone budge outputs from the model.

-Influx is movement of water from the stream to the aquifer and outflux is movement of water from the aquifer to the stream.

Additive Rank (1)	PLS Coordinate (or Run) (2)	Capacity (m ³ /day) (3)	Distance to Stream (m) (4)	Stream Outflux (m ³ /day) (5)	Stream Influx (m ³ /day) (6)	Stream Flow (m ³ /day) (7)	Outflux Delta (m ³ /day) (8)	Influx Delta (m ³ /day) (9)	Flow Change (m ³ /day) (10)
61	SC00204613BC	3,990	>3000	129,353	549,772	420,419	0	0	0
62	SC00204613DB	3,325	>3000	129,353	549,772	420,419	0	0	0
63	SC00204616CD	4,508	>3000	129,353	549,772	420,419	0	0	0
64	SC00204617CD	3,985	>3000	129,353	549,772	420,419	0	0	0
65	SC00204617DC	3,440	>3000	129,353	549,772	420,419	0	0	0
66	SC00204620AC	2,660	>3000	129,353	549,772	420,419	0	0	0
67	SC00204620DC	3,990	>3000	129,353	549,772	420,419	0	0	0
68	SC00204621AA	3,990	>3000	129,353	549,772	420,419	0	0	0
69	SC00204621BC	3,990	>3000	129,353	549,772	420,419	0	0	0
70	SC00204621CA	3,440	>3000	129,353	549,772	420,419	0	0	0
71	SC00204622DB	3,990	>3000	129,353	549,772	420,419	0	0	0
72	SC00204624CD	3,151	>3000	129,353	549,772	420,419	0	0	0
73	SC00204625BA	2,829	>3000	129,353	549,772	420,419	0	0	0
74	SC00204625BB	3,440	>3000	129,353	549,772	420,419	0	0	0
75	SC00204627BA	3,990	>3000	129,353	549,772	420,419	0	0	0
76	SC00204627DB	4,154	>3000	129,353	549,772	420,419	0	0	0
77	SC00204628AD	4,437	>3000	129,353	549,772	420,419	0	0	0
78	SC00204628BA	3,440	>3000	129,353	549,772	420,419	0	0	0
79	SC00204633CD	3,440	>3000	129,353	549,772	420,419	0	0	0
80	SC00304435CC	3,990	>3000	129,353	549,772	420,419	0	0	0
81	SC00304612BA	2,060	>3000	129,353	549,772	420,419	0	0	0
82	SC00404403AD	3,156	>3000	129,353	549,772	420,419	0	0	0
83	SC00404403CC	4,486	>3000	129,353	549,772	420,419	0	0	0
84	SC00404404DC	3,325	>3000	129,353	549,772	420,419	0	0	0
85	SC00404408DB	4,988	5819	129,353	549,772	420,419	0	0	0
86	SC00404410AB	4,154	>3000	129,353	549,772	420,419	0	0	0
87	SC00404614BC	3,658	>3000	129,353	549,772	420,419	0	0	0
88	SC00404622AC	3,325	>3000	129,353	549,772	420,419	0	0	0
89	SC00404724CA	3,325	>3000	129,353	549,772	420,419	0	0	0
90	SC00404725BD	3,990	>3000	129,353	549,772	420,419	0	0	0
91	SC00404726AD	3,990	>3000	129,353	549,772	420,419	0	0	0
92	SC00404726BC	3,325	>3000	129,353	549,772	420,419	0	0	0
93	SC00404726CD	3,325	>3000	129,353	549,772	420,419	0	0	0
94	SC00204621DD	3,440	>3000	129,353	549,772	420,419	0	0	0
95	SC00204504BC	3,990	>3000	129,353	549,772	420,419	0	0	0

- (1) Individual well stream depletion ranking for the additive analysis method using the numerical model for model day 257
- (2) Public land survey system coordinate for the well added to the model (All Off is the control run for pre-development conditions)
- (3) Well pumping rate used in the numerical model (61%) of CDWR capacity rating
- (4) Straight line distance of the well from the stream
- (5) Model calculated rate of stream out-flux into the aquifer at day 257
- (6) Model calculated rate of stream in-flux from the aquifer at day 257
- (7) Calculated groundwater dependent stream flow at day 257 (item 6-5)
- (8) Calculated change in stream out-flux into the aquifer due to the well from control (Well column 5 minus All Off column 5)
- (9) Calculated change in stream in-flux from the aquifer due to the well from control (Well column 6 minus All Off column 6)
- (10) Calculated change in groundwater dependent stream flow due to well (Well column 7 minus All Off column 7) – rates are negative because well addition has a depleting effect on stream flow

Numerical Model Subtractive Ranks

-Table shows the comparison of the numerical model results between scenarios with all wells pumping and with individual wells removed
 -Influx and Outflux are based on the zone budge outputs from the model.
 -Influx is movement of water from the stream to the aquifer and outflux is movement of water from the aquifer to the stream.

Subtractive Rank (1)	PLS Coordinate (or Run) (2)	Capacity (m ³ /day) (3)	Distance to Stream (m) (4)	Stream Outflux (m ³ /day) (5)	Stream Influx (m ³ /day) (6)	Stream Flow (m ³ /day) (7)	Outflux Change (m ³ /day) (8)	Influx Change (m ³ /day) (9)	Flow Change (m ³ /day) (10)
-	All On	-	-	127,741	540,880	413,139	-	-	-
-	Initial	-	-	129,225	561,808	432,583	-	-	-
1	SC00304419CD	2,388	<200	127,537	542,814	415,277	-205	1,933	2,138
2	SC00304704AC	5,320	N/A	127,643	542,561	414,918	-98	1,681	1,779
3	SC00404718AA	2,159	1180	128,224	542,634	414,411	482	1,754	1,272
4	SC00404718BB	2,328	183	128,089	542,078	413,989	347	1,197	850
5	SC00304703BC	5,320	N/A	127,840	541,230	413,389	99	349	250
6	SC00404719AA	1,842	<200	127,992	541,327	413,335	251	447	196
7	SC00404717CD	3,325	2460	127,912	541,209	413,297	170	328	158
8	SC00404712CA	1,995	1250	127,780	540,988	413,208	38	107	69
9	SC00304705DA	3,325	N/A	127,779	540,857	413,078	38	-23	61
10	SC00404511CD	3,990	3955	127,737	540,889	413,152	-4	9	13
11	SC00404405DD	2,725	5024	127,744	540,871	413,127	2	-10	12
12	SC00404404BD	3,990	4695	127,741	540,870	413,129	0	-10	10
13	SC00404514DB	4,361	4890	127,735	540,866	413,131	-6	-14	8
14	SC00404713AC	998	1290	127,737	540,869	413,132	-4	-12	7
15	SC00404514CB	5,816	4903	127,734	540,880	413,146	-7	-1	7
16	SC00404407CB	5,653	4715	127,738	540,871	413,133	-4	-10	6
17	SC00404729AA	4,988	>3000	127,746	540,880	413,134	5	0	5
18	SC00404714AB	3,325	2916	127,788	540,932	413,144	47	52	5
19	SC00404618AA	3,325	2638	127,739	540,873	413,135	-3	-7	4
20	SC00404612DC	3,990	>3000	127,740	540,883	413,143	-1	3	4
21	SC00404515CB	3,325	4747	127,736	540,871	413,135	-6	-9	4
22	SC00404515DB	5,653	4462	127,737	540,879	413,142	-5	-2	3
23	SC00404713DD	3,990	2500	127,742	540,879	413,137	1	2	2
24	SC00404720CD	3,325	2656	127,742	540,882	413,141	0	-2	2
25	SC00404715DC	3,325	846	127,737	540,874	413,137	-5	-6	2
26	SC00404618BA	5,320	2200	127,750	540,888	413,138	9	8	1
27	SC00304612CD	1,995	4917	127,740	540,879	413,138	-1	-2	1
28	SC00104534DB	4,988	>3000	127,741	540,880	413,139	0	0	0
29	SC00104535BD	5,819	>3000	127,741	540,880	413,139	0	0	0
30	SC00104535CA	4,988	>3000	127,741	540,880	413,139	0	0	0
31	SC00104535CB	3,325	>3000	127,741	540,880	413,139	0	0	0
32	SC00204502BA	3,990	>3000	127,741	540,880	413,139	0	0	0
33	SC00204502CA	3,990	>3000	127,741	540,880	413,139	0	0	0
34	SC00204503AA	2,993	>3000	127,741	540,880	413,139	0	0	0
35	SC00204503BA	3,990	>3000	127,741	540,880	413,139	0	0	0
36	SC00204503CA	5,320	>3000	127,741	540,880	413,139	0	0	0
37	SC00204503DA	3,990	>3000	127,741	540,880	413,139	0	0	0
38	SC00204504AC	3,990	>3000	127,741	540,880	413,139	0	0	0
39	SC00204509AB	3,690	>3000	127,741	540,880	413,139	0	0	0
40	SC00204509AC	6,650	>3000	127,741	540,880	413,139	0	0	0
41	SC00204510AB	5,320	>3000	127,741	540,880	413,139	0	0	0
42	SC00204510BB	5,453	>3000	127,741	540,880	413,139	0	0	0
43	SC00204512BA	2,660	>3000	127,741	540,880	413,139	0	0	0
44	SC00204519BA	2,993	>3000	127,741	540,880	413,139	0	0	0
45	SC00204611DD	3,821	>3000	127,741	540,880	413,139	0	0	0
46	SC00204613BC	3,990	>3000	127,741	540,880	413,139	0	0	0
47	SC00204613DB	3,325	>3000	127,741	540,880	413,139	0	0	0
48	SC00204616CD	4,508	>3000	127,741	540,880	413,139	0	0	0
49	SC00204617CD	3,985	>3000	127,741	540,880	413,139	0	0	0
50	SC00204617DC	3,440	>3000	127,741	540,880	413,139	0	0	0
51	SC00204620AC	2,660	>3000	127,741	540,880	413,139	0	0	0
52	SC00204620DC	3,990	>3000	127,741	540,880	413,139	0	0	0
53	SC00204621AA	3,990	>3000	127,741	540,880	413,139	0	0	0
54	SC00204621BC	3,990	>3000	127,741	540,880	413,139	0	0	0
55	SC00204621CA	3,440	>3000	127,741	540,880	413,139	0	0	0
56	SC00204622DB	3,990	>3000	127,741	540,880	413,139	0	0	0
57	SC00204624CD	3,151	>3000	127,741	540,880	413,139	0	0	0
58	SC00204625BA	2,829	>3000	127,741	540,880	413,139	0	0	0
59	SC00204625BB	3,440	>3000	127,741	540,880	413,139	0	0	0
60	SC00204627BA	3,990	>3000	127,741	540,880	413,139	0	0	0

Numerical Model Subtractive Ranks

-Table shows the comparison of the numerical model results between scenarios with all wells pumping and with individual wells removed
 -Influx and Outflux are based on the zone budge outputs from the model.
 -Influx is movement of water from the stream to the aquifer and outflux is movement of water from the aquifer to the stream.

Subtractive Rank (1)	PLS Coordinate (or Run) (2)	Capacity (m ³ /day) (3)	Distance to Stream (m) (4)	Stream Outflux (m ³ /day) (5)	Stream Influx (m ³ /day) (6)	Stream Flow (m ³ /day) (7)	Outflux Change (m ³ /day) (8)	Influx Change (m ³ /day) (9)	Flow Change (m ³ /day) (10)
61	SC00204627DB	4,154	>3000	127,741	540,880	413,139	0	0	0
62	SC00204628AD	4,437	>3000	127,741	540,880	413,139	0	0	0
63	SC00204628BA	3,440	>3000	127,741	540,880	413,139	0	0	0
64	SC00204633CD	3,440	>3000	127,741	540,880	413,139	0	0	0
65	SC00304435CC	3,990	>3000	127,741	540,880	413,139	0	0	0
66	SC00304612BA	2,060	>3000	127,741	540,880	413,139	0	0	0
67	SC00304705AA	3,325	>3000	127,741	540,880	413,139	0	0	0
68	SC00404403AD	3,156	>3000	127,741	540,880	413,139	0	0	0
69	SC00404403CC	4,486	>3000	127,741	540,880	413,139	0	0	0
70	SC00404404DC	3,325	>3000	127,741	540,880	413,139	0	0	0
71	SC00404408DB	4,988	5819	127,741	540,880	413,139	0	0	0
72	SC00404410AB	4,154	>3000	127,741	540,880	413,139	0	0	0
73	SC00404608DD	3,325	3210	127,741	540,880	413,139	0	0	0
74	SC00404610DC	3,325	>3000	127,741	540,880	413,139	0	0	0
75	SC00404611CD	3,990	>3000	127,741	540,880	413,139	0	0	0
76	SC00404611DD	3,990	>3000	127,741	540,880	413,139	0	0	0
77	SC00404612CD	3,990	4349	127,741	540,880	413,139	0	0	0
78	SC00404614BC	3,658	>3000	127,741	540,880	413,139	0	0	0
79	SC00404617CC	3,990	>3000	127,741	540,880	413,139	0	0	0
80	SC00404618CD	3,325	3212	127,741	540,880	413,139	0	0	0
81	SC00404618DC	3,990	>3000	127,741	540,880	413,139	0	0	0
82	SC00404619AD	3,325	>3000	127,741	540,880	413,139	0	0	0
83	SC00404622AC	3,325	>3000	127,741	540,880	413,139	0	0	0
84	SC00404722DC	3,325	>3000	127,741	540,880	413,139	0	0	0
85	SC00404723CA	3,325	>3000	127,741	540,880	413,139	0	0	0
86	SC00404724CA	3,325	>3000	127,741	540,880	413,139	0	0	0
87	SC00404725BD	3,990	>3000	127,741	540,880	413,139	0	0	0
88	SC00404725DD	2,725	>3000	127,741	540,880	413,139	0	0	0
89	SC00404726AD	3,990	>3000	127,741	540,880	413,139	0	0	0
90	SC00404726BC	3,325	>3000	127,741	540,880	413,139	0	0	0
91	SC00404726CD	3,325	>3000	127,741	540,880	413,139	0	0	0
92	SC00404727DD	2,725	>3000	127,741	540,880	413,139	0	0	0
93	SC00404729BD	2,725	>3000	127,741	540,880	413,139	0	0	0
94	SC00204621DD	3,440	>3000	127,741	540,880	413,139	0	0	0
95	SC00204504BC	3,990	>3000	127,741	540,880	413,139	0	0	0

- (1) Individual well stream depletion ranking for the subtractive analysis method using the numerical model for model day 257
- (2) Public land survey system coordinate for the well added to the model (All On is the control run for pre-development conditions, Initial is output data for day 135)
- (3) Well pumping rate used in the numerical model (61%) of CDWR capacity rating
- (4) Straight line distance of the well from the stream
- (5) Model calculated rate of stream out-flux into the aquifer at day 257
- (6) Model calculated rate of stream in-flux from the aquifer at day 257
- (7) Calculated groundwater dependent stream flow at day 257 (item 6-5)
- (8) Calculated change in stream out-flux into the aquifer due to the well from control (Well column 5 minus All Off column 5)
- (9) Calculated change in stream in-flux from the aquifer due to the well from control (Well column 6 minus All Off column 6)
- (10) Calculated change in groundwater dependent stream flow due to well (Well column 7 minus All Off column 7) rates are positive because removing the well reduced the rate of stream depletion

Appendix G

Top 15 Additive & Subtractive Analysis Output Sheet Printouts See Table 5-1 for Details

WELL PRINTOUT SHEETS NOTE

Printout sheets contain raw mass balance output data produced by Visual Modflow v. 4.0, 2003 for model runs during well analysis (see Chapter 5). Labeled per Figure 5-6.

Additive Analysis – All Wells Off

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 834899.75 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33382738.00 [m³]
General-Head = 27710020.00 [m³]
Total IN = 223335776.00 [m³]
OUT:
Storage = 2791624.00 [m³]
Constant Head = 13443163.00 [m³]
Wells = 3463910.75 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874134.50 [m³]

Rates for Time Step Report [%s]

IN:
Storage = 3534.00 [m³/day]
Constant Head = 136245.53 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129353.27 [m³/day]
General-Head = 104344.32 [m³/day]
Total IN = 862524.13 [m³/day]
OUT:
Storage = 17774.17 [m³/day]
Constant Head = 51756.55 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20325.36 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549772.25 [m³/day]
General-Head = 224429.72 [m³/day]

Additive Analysis – SC00304419CD
(Analysis Well A)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 877912.44 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33404272.00 [m³]
General-Head = 27710020.00 [m³]
Total IN = 223400320.00 [m³]
OUT:
Storage = 2790472.75 [m³]
Constant Head = 13442316.00 [m³]
Wells = 3757523.75 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2873051.25 [m³]

Rates for Time Step Report [%s]

IN:
Storage = 3731.16 [m³/day]
Constant Head = 136245.53 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129543.01 [m³/day]
General-Head = 104344.34 [m³/day]
Total IN = 862911.06 [m³/day]
OUT:
Storage = 17749.41 [m³/day]
Constant Head = 51747.97 [m³/day]
Wells = 2387.10 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20313.24 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 547864.25 [m³/day]
General-Head = 224429.42 [m³/day]

Additive Analysis – SC00404718AA
(Analysis Well B)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 924530.06 [m³]
Constant Head = 35199636.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33332090.00 [m³]
General-Head = 27710976.00 [m³]
Total IN = 223388816.00 [m³]
OUT:
Storage = 2791493.25 [m³]
Constant Head = 13442854.00 [m³]
Wells = 3750156.75 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2873518.00 [m³]

Rates for Time Step Report [%s]

IN:
Storage = 3941.48 [m³/day]
Constant Head = 136370.56 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 128867.91 [m³/day]
General-Head = 104355.84 [m³/day]
Total IN = 862582.88 [m³/day]
OUT:
Storage = 17772.95 [m³/day]
Constant Head = 51752.93 [m³/day]
Wells = 2327.20 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20318.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 548338.19 [m³/day]
General-Head = 224429.58 [m³/day]

Additive Analysis – SC00304507DA
(Analysis Well Y)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1247810.38 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33394116.00 [m³]
General-Head = 27710024.00 [m³]
Total IN = 223760064.00 [m³]
OUT:
Storage = 2790943.00 [m³]
Constant Head = 13442995.00 [m³]
Wells = 3872824.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874041.25 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 6882.68 [m³/day]
Constant Head = 136245.56 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129452.36 [m³/day]
General-Head = 104344.45 [m³/day]
Total IN = 865972.06 [m³/day]
OUT:
Storage = 17761.11 [m³/day]
Constant Head = 51754.12 [m³/day]
Wells = 3324.50 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20323.97 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549085.00 [m³/day]
General-Head = 224429.52 [m³/day]

Additive Analysis – SC00404713AC
(Analysis Well K)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1324481.63 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33394084.00 [m³]
General-Head = 27710028.00 [m³]
Total IN = 223836704.00 [m³]
OUT:
Storage = 2786178.75 [m³]
Constant Head = 13442995.00 [m³]
Wells = 3954606.75 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874041.00 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 7430.77 [m³/day]
Constant Head = 136245.56 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129449.80 [m³/day]
General-Head = 104344.61 [m³/day]
Total IN = 866517.81 [m³/day]
OUT:
Storage = 17652.82 [m³/day]
Constant Head = 51754.12 [m³/day]
Wells = 3989.40 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20323.97 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549083.19 [m³/day]
General-Head = 224429.86 [m³/day]

Additive Analysis – SC00304703BC
(Analysis Well V)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1493576.00 [m³]
Constant Head = 35186536.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33394686.00 [m³]
General-Head = 27710020.00 [m³]
Total IN = 224006400.00 [m³]
OUT:
Storage = 2790886.00 [m³]
Constant Head = 13442965.00 [m³]
Wells = 4118172.75 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874023.75 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 8870.52 [m³/day]
Constant Head = 136245.58 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129446.20 [m³/day]
General-Head = 104344.42 [m³/day]
Total IN = 867953.75 [m³/day]
OUT:
Storage = 17759.52 [m³/day]
Constant Head = 51753.96 [m³/day]
Wells = 5319.20 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20323.92 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549081.13 [m³/day]
General-Head = 224429.75 [m³/day]

Additive Analysis – SC00404618BA
(Analysis Well J)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1491227.63 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33394234.00 [m³]
General-Head = 27710022.00 [m³]
Total IN = 224003600.00 [m³]
OUT:
Storage = 2789556.75 [m³]
Constant Head = 13442980.00 [m³]
Wells = 4118172.75 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874033.50 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 8822.19 [m³/day]
Constant Head = 136245.56 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129448.77 [m³/day]
General-Head = 104344.46 [m³/day]
Total IN = 867908.00 [m³/day]
OUT:
Storage = 17728.69 [m³/day]
Constant Head = 51754.01 [m³/day]
Wells = 5319.20 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20323.93 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549083.75 [m³/day]
General-Head = 224429.89 [m³/day]

Additive Analysis – SC00404608DD
(Analysis Well Q)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1246582.13 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33389750.00 [m³]
General-Head = 27710036.00 [m³]
Total IN = 223754480.00 [m³]
OUT:
Storage = 2790225.25 [m³]
Constant Head = 13443023.00 [m³]
Wells = 3872824.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874056.00 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 6872.48 [m³/day]
Constant Head = 136245.56 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129437.63 [m³/day]
General-Head = 104344.91 [m³/day]
Total IN = 865947.63 [m³/day]
OUT:
Storage = 17748.07 [m³/day]
Constant Head = 51754.25 [m³/day]
Wells = 3324.50 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20324.06 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549090.56 [m³/day]
General-Head = 224429.89 [m³/day]

Additive Analysis – SC00404715DC
(Analysis Well L)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1244320.00 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33385566.00 [m³]
General-Head = 27710024.00 [m³]
Total IN = 223748032.00 [m³]
OUT:
Storage = 2788107.25 [m³]
Constant Head = 13443039.00 [m³]
Wells = 3872824.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874056.00 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 6813.58 [m³/day]
Constant Head = 136245.56 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129442.02 [m³/day]
General-Head = 104344.45 [m³/day]
Total IN = 865892.63 [m³/day]
OUT:
Storage = 17694.93 [m³/day]
Constant Head = 51754.28 [m³/day]
Wells = 3324.50 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20324.07 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549106.75 [m³/day]
General-Head = 224429.91 [m³/day]

Additive Analysis – SC00404618AA
(Analysis Well O)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1246024.88 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33385664.00 [m³]
General-Head = 27710026.00 [m³]
Total IN = 223749824.00 [m³]
OUT:
Storage = 2789719.75 [m³]
Constant Head = 13443039.00 [m³]
Wells = 3872824.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874055.75 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 6858.23 [m³/day]
Constant Head = 136245.56 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129447.28 [m³/day]
General-Head = 104344.62 [m³/day]
Total IN = 865942.75 [m³/day]
OUT:
Storage = 17734.78 [m³/day]
Constant Head = 51754.28 [m³/day]
Wells = 3324.50 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20324.07 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549113.94 [m³/day]
General-Head = 224429.89 [m³/day]

Additive Analysis – SC00404729AA
(Analysis Well P)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1418706.75 [m³]
Constant Head = 35186536.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33386766.00 [m³]
General-Head = 27725264.00 [m³]
Total IN = 223938864.00 [m³]
OUT:
Storage = 2773750.75 [m³]
Constant Head = 13443047.00 [m³]
Wells = 4077287.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874070.25 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 7954.67 [m³/day]
Constant Head = 136245.61 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129433.31 [m³/day]
General-Head = 104613.35 [m³/day]
Total IN = 867294.00 [m³/day]
OUT:
Storage = 17437.40 [m³/day]
Constant Head = 51754.44 [m³/day]
Wells = 4986.80 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20324.19 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549108.31 [m³/day]
General-Head = 224428.00 [m³/day]

Additive Analysis – SC00304705AA
(Analysis Well X)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1245621.25 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33385808.00 [m³]
General-Head = 27710022.00 [m³]
Total IN = 223749568.00 [m³]
OUT:
Storage = 2790971.25 [m³]
Constant Head = 13443082.00 [m³]
Wells = 3872824.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874094.25 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 6884.06 [m³/day]
Constant Head = 136245.58 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129427.07 [m³/day]
General-Head = 104344.41 [m³/day]
Total IN = 865948.13 [m³/day]
OUT:
Storage = 17762.40 [m³/day]
Constant Head = 51754.73 [m³/day]
Wells = 3324.50 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20324.44 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549202.44 [m³/day]
General-Head = 224426.03 [m³/day]

Additive Analysis – SC00304704AC
(Analysis Well W)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1494498.38 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33392144.00 [m³]
General-Head = 27710020.00 [m³]
Total IN = 224004784.00 [m³]
OUT:
Storage = 2790898.25 [m³]
Constant Head = 13442942.00 [m³]
Wells = 4118172.75 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874010.25 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 8890.40 [m³/day]
Constant Head = 136245.47 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129394.41 [m³/day]
General-Head = 104344.43 [m³/day]
Total IN = 867921.75 [m³/day]
OUT:
Storage = 17760.12 [m³/day]
Constant Head = 51753.48 [m³/day]
Wells = 5319.20 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20323.63 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549180.13 [m³/day]
General-Head = 224429.50 [m³/day]

Additive Analysis – SC00404718BB
(Analysis Well C)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 887912.88 [m³]
Constant Head = 35263432.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33350778.00 [m³]
General-Head = 27710156.00 [m³]
Total IN = 223433872.00 [m³]
OUT:
Storage = 2791543.25 [m³]
Constant Head = 13442959.00 [m³]
Wells = 3709259.25 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2873734.25 [m³]

Rates for Time Step Report [%s]

IN:
Storage = 3773.12 [m³/day]
Constant Head = 136895.89 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129058.41 [m³/day]
General-Head = 104346.02 [m³/day]
Total IN = 863120.50 [m³/day]
OUT:
Storage = 17773.21 [m³/day]
Constant Head = 51754.11 [m³/day]
Wells = 1994.70 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20320.58 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 548852.56 [m³/day]
General-Head = 224429.63 [m³/day]

Additive Analysis – SC00404720CD
(Analysis Well N)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1207139.38 [m³]
Constant Head = 35186648.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33384186.00 [m³]
General-Head = 27745176.00 [m³]
Total IN = 223744736.00 [m³]
OUT:
Storage = 2789275.25 [m³]
Constant Head = 13443124.00 [m³]
Wells = 3872824.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874120.25 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 6353.45 [m³/day]
Constant Head = 136248.83 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129417.38 [m³/day]
General-Head = 104820.07 [m³/day]
Total IN = 865886.75 [m³/day]
OUT:
Storage = 17721.05 [m³/day]
Constant Head = 51755.31 [m³/day]
Wells = 3324.50 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20324.87 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549414.06 [m³/day]
General-Head = 224429.92 [m³/day]

Additive Analysis – SC00404714AB
(Analysis Well D)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 1239232.50 [m³]
Constant Head = 35186532.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33390082.00 [m³]
General-Head = 27710024.00 [m³]
Total IN = 223747456.00 [m³]
OUT:
Storage = 2790712.25 [m³]
Constant Head = 13442987.00 [m³]
Wells = 3872824.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2874031.00 [m³/day]

Rates for Time Step Report [%s]

IN:
Storage = 6697.35 [m³/day]
Constant Head = 136245.45 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 129325.48 [m³/day]
General-Head = 104344.45 [m³/day]
Total IN = 865659.81 [m³/day]
OUT:
Storage = 17754.29 [m³/day]
Constant Head = 51753.95 [m³/day]
Wells = 3324.50 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20323.71 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 549322.88 [m³/day]
General-Head = 224429.89 [m³/day]

Subtractive Analysis – All On

Time(days): 257.99997

Output Time: 3

Stress Period: 10

Cumulative Volumes Report [%s]

IN:

Storage = 38719736.00 [m³]

Constant Head = 35379544.00 [m³]

Wells = 0.00 [m³]

Drains = 0.00 [m³]

Recharge = 126221584.00 [m³]

ET = 0.00 [m³]

River Leakage = 0.00 [m³]

Stream Leakage = 33223864.00 [m³]

General-Head = 29713570.00 [m³]

Total IN = 263258304.00 [m³]

OUT:

Storage = 3175298.25 [m³]

Constant Head = 13440877.00 [m³]

Wells = 44778600.00 [m³]

Drains = 0.00 [m³]

Recharge = 0.00 [m³]

ET = 2870584.50 [m³/d]

Rates for Time Step Report [%s]

IN:

Storage = 289545.59 [m³/day]

Constant Head = 138234.28 [m³/day]

Wells = 0.00 [m³/day]

Drains = 0.00 [m³/day]

Recharge = 489047.03 [m³/day]

ET = 0.00 [m³/day]

River Leakage = 0.00 [m³/day]

Stream Leakage = 127688.86 [m³/day]

General-Head = 136911.13 [m³/day]

Total IN = 1181426.88 [m³/day]

OUT:

Storage = 80.74 [m³/day]

Constant Head = 51729.55 [m³/day]

Wells = 364053.66 [m³/day]

Drains = 0.00 [m³/day]

Recharge = 0.00 [m³/day]

ET = 20278.12 [m³/day]

River Leakage = 0.00 [m³/day]

Stream Leakage = 540778.19 [m³/day]

General-Head = 208146.25[m³/day]

Subtractive Analysis – SC00304419CD (Analysis Well A)

Time(days): 257.99997

Output Time: 3

Stress Period: 10

Cumulative Volumes Report [%s]

IN:

Storage = 38691948.00 [m³]

Constant Head = 35379544.00 [m³]

Wells = 0.00 [m³]

Drains = 0.00 [m³]

Recharge = 126221584.00 [m³]

ET = 0.00 [m³]

River Leakage = 0.00 [m³]

Stream Leakage = 33205762.00 [m³]

General-Head = 29713568.00 [m³]

Total IN = 263212400.00 [m³]

OUT:

Storage = 3176270.50 [m³]

Constant Head = 13441747.00 [m³]

Wells = 44484988.00 [m³]

Drains = 0.00 [m³]

Recharge = 0.00 [m³]

ET = 2871682.75 [m³/d]

Rates for Time Step Report [%s]

IN:

Storage = 289594.53 [m³/day]

Constant Head = 138234.28 [m³/day]

Wells = 0.00 [m³/day]

Drains = 0.00 [m³/day]

Recharge = 489047.03 [m³/day]

ET = 0.00 [m³/day]

River Leakage = 0.00 [m³/day]

Stream Leakage = 127536.58 [m³/day]

General-Head = 136911.09 [m³/day]

Total IN = 1181323.63 [m³/day]

OUT:

Storage = 81.74 [m³/day]

Constant Head = 51738.46 [m³/day]

Wells = 361666.56 [m³/day]

Drains = 0.00 [m³/day]

Recharge = 0.00 [m³/day]

ET = 20290.43 [m³/day]

River Leakage = 0.00 [m³/day]

Stream Leakage = 542813.69 [m³/day]

General-Head = 208146.52[m³/day]

Subtractive Analysis – SC00304704AC
(Analysis Well W)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38067116.00 [m³]
Constant Head = 35379548.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33233776.00 [m³]
General-Head = 29713566.00 [m³]
Total IN = 262615584.00 [m³]
OUT:
Storage = 3175306.25 [m³]
Constant Head = 13441032.00 [m³]
Wells = 44124340.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870769.00 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 284274.63 [m³/day]
Constant Head = 138234.20 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127642.98 [m³/day]
General-Head = 136911.08 [m³/day]
Total IN = 1176109.88 [m³/day]
OUT:
Storage = 80.86 [m³/day]
Constant Head = 51733.04 [m³/day]
Wells = 358734.47 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20282.19 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 542561.44 [m³/day]
General-Head = 208146.64[m³/day]

Subtractive Analysis – SC00404718AA
(Analysis Well B)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38638716.00 [m³]
Constant Head = 35366476.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33283036.00 [m³]
General-Head = 29712602.00 [m³]
Total IN = 263222416.00 [m³]
OUT:
Storage = 3175333.00 [m³]
Constant Head = 13441267.00 [m³]
Wells = 44492356.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2871307.50 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 289333.31 [m³/day]
Constant Head = 138109.78 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 128267.30 [m³/day]
General-Head = 136899.47 [m³/day]
Total IN = 1181656.88 [m³/day]
OUT:
Storage = 80.91 [m³/day]
Constant Head = 51734.63 [m³/day]
Wells = 361726.47 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20287.33 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 542717.63 [m³/day]
General-Head = 208146.36[m³/day]

Subtractive Analysis – SC00404718BB
(Analysis Well C)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38678100.00 [m³]
Constant Head = 35302684.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33263410.00 [m³]
General-Head = 29713426.00 [m³]
Total IN = 263179200.00 [m³]
OUT:
Storage = 3175320.25 [m³]
Constant Head = 13441132.00 [m³]
Wells = 44533256.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2871061.00 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 289537.31 [m³/day]
Constant Head = 137584.41 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 128088.85 [m³/day]
General-Head = 136909.30 [m³/day]
Total IN = 1181166.88 [m³/day]
OUT:
Storage = 80.91 [m³/day]
Constant Head = 51732.97 [m³/day]
Wells = 362058.97 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20284.26 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 542077.75 [m³/day]
General-Head = 208146.31 [m³/day]

Subtractive Analysis – SC00304703BC
(Analysis Well V)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38073888.00 [m³]
Constant Head = 35379544.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33231514.00 [m³]
General-Head = 29713568.00 [m³]
Total IN = 262620096.00 [m³]
OUT:
Storage = 3175379.75 [m³]
Constant Head = 13440950.00 [m³]
Wells = 44124340.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870679.00 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 284317.72 [m³/day]
Constant Head = 138234.20 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127840.10 [m³/day]
General-Head = 136911.13 [m³/day]
Total IN = 1176350.13 [m³/day]
OUT:
Storage = 81.13 [m³/day]
Constant Head = 51731.60 [m³/day]
Wells = 358734.47 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20280.62 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 541229.50 [m³/day]
General-Head = 208146.41 [m³/day]

Subtractive Analysis – SC00404719AA
(Analysis Well F)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]
IN:
Storage = 38550776.00 [m³]
Constant Head = 35363500.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33243212.00 [m³]
General-Head = 29713228.00 [m³]
Total IN = 263092304.00 [m³]
OUT:
Storage = 3175303.50 [m³]
Constant Head = 13440906.00 [m³]
Wells = 44512808.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870704.75 [m³/d]

Rates for Time Step Report [%s]
IN:
Storage = 288748.81 [m³/day]
Constant Head = 138016.88 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127992.41 [m³/day]
General-Head = 136903.88 [m³/day]
Total IN = 1180709.00 [m³/day]
OUT:
Storage = 80.74 [m³/day]
Constant Head = 51730.24 [m³/day]
Wells = 361892.75 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20280.70 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 541327.31 [m³/day]
General-Head = 208146.25[m³/day]

Subtractive Analysis – SC00404717CD
(Analysis Well E)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]
IN:
Storage = 38535336.00 [m³]
Constant Head = 35363500.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33239144.00 [m³]
General-Head = 29713228.00 [m³]
Total IN = 263072800.00 [m³]
OUT:
Storage = 3175308.75 [m³]
Constant Head = 13440904.00 [m³]
Wells = 44512808.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870682.25 [m³/d]

Rates for Time Step Report [%s]
IN:
Storage = 288477.47 [m³/day]
Constant Head = 138016.88 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127911.67 [m³/day]
General-Head = 136903.88 [m³/day]
Total IN = 1180356.88 [m³/day]
OUT:
Storage = 80.74 [m³/day]
Constant Head = 51730.12 [m³/day]
Wells = 361892.75 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20280.13 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 541208.75 [m³/day]
General-Head = 208146.25[m³/day]

Subtractive Analysis – SC00404712CA
(Analysis Well G)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38632892.00 [m³]
Constant Head = 35379544.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33229228.00 [m³]
General-Head = 29713568.00 [m³]
Total IN = 263176816.00 [m³]
OUT:
Storage = 3175302.50 [m³]
Constant Head = 13440892.00 [m³]
Wells = 44655924.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870648.25 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 289139.78 [m³/day]
Constant Head = 138234.28 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127779.61 [m³/day]
General-Head = 136911.13 [m³/day]
Total IN = 1181111.88 [m³/day]
OUT:
Storage = 80.74 [m³/day]
Constant Head = 51729.98 [m³/day]
Wells = 363056.31 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20279.58 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 540987.81 [m³/day]
General-Head = 208146.25[m³/day]

Subtractive Analysis – SC00304705DA
(Analysis Well Y)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38324876.00 [m³]
Constant Head = 35379548.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33228682.00 [m³]
General-Head = 29713570.00 [m³]
Total IN = 262868272.00 [m³]
OUT:
Storage = 3175369.00 [m³]
Constant Head = 13440893.00 [m³]
Wells = 44369688.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870617.50 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 286424.88 [m³/day]
Constant Head = 138234.39 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127779.34 [m³/day]
General-Head = 136911.13 [m³/day]
Total IN = 1178396.75 [m³/day]
OUT:
Storage = 81.90 [m³/day]
Constant Head = 51730.25 [m³/day]
Wells = 360729.16 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20279.18 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 540857.06 [m³/day]
General-Head = 208146.67[m³/day]

Subtractive Analysis – SC00404511CD
(Analysis Well M)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38352860.00 [m³]
Constant Head = 35379544.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33227854.00 [m³]
General-Head = 29607074.00 [m³]
Total IN = 262788912.00 [m³]
OUT:
Storage = 3175335.25 [m³]
Constant Head = 13440882.00 [m³]
Wells = 44287900.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870635.25 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 287290.97 [m³/day]
Constant Head = 138234.28 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127737.35 [m³/day]
General-Head = 135487.59 [m³/day]
Total IN = 1177797.25 [m³/day]
OUT:
Storage = 80.74 [m³/day]
Constant Head = 51729.75 [m³/day]
Wells = 360064.25 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20279.49 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 540889.13 [m³/day]
General-Head = 208164.23[m³/day]

Subtractive Analysis – SC00404405DD
(Analysis Well S)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38128448.00 [m³]
Constant Head = 35379544.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33227798.00 [m³]
General-Head = 29734276.00 [m³]
Total IN = 262691648.00 [m³]
OUT:
Storage = 2901950.00 [m³]
Constant Head = 13440881.00 [m³]
Wells = 44476128.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870582.50 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 286026.03 [m³/day]
Constant Head = 138234.28 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127743.68 [m³/day]
General-Head = 135214.67 [m³/day]
Total IN = 1176265.63 [m³/day]
OUT:
Storage = 75.08 [m³/day]
Constant Head = 51729.70 [m³/day]
Wells = 358603.66 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20278.29 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 540870.88 [m³/day]
General-Head = 208121.52[m³/day]

Subtractive Analysis – SC00404404BD
(Analysis Well R)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38189536.00 [m³]
Constant Head = 35379544.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33227830.00 [m³]
General-Head = 29839536.00 [m³]
Total IN = 262858032.00 [m³]
OUT:
Storage = 2743065.25 [m³]
Constant Head = 13440881.00 [m³]
Wells = 44826472.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870587.25 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 286020.13 [m³/day]
Constant Head = 138234.28 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127741.20 [m³/day]
General-Head = 136573.80 [m³/day]
Total IN = 1177616.50 [m³/day]
OUT:
Storage = 70.55 [m³/day]
Constant Head = 51729.69 [m³/day]
Wells = 360064.25 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20278.34 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 540870.31 [m³/day]
General-Head = 208021.66[m³/day]

Subtractive Analysis – SC00404514DB
(Analysis Well Z1)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38409420.00 [m³]
Constant Head = 35379544.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33227852.00 [m³]
General-Head = 29504994.00 [m³]
Total IN = 262743392.00 [m³]
OUT:
Storage = 3175312.00 [m³]
Constant Head = 13440881.00 [m³]
Wells = 44242928.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870620.75 [m³]

Rates for Time Step Report [%s]

IN:
Storage = 287801.63 [m³/day]
Constant Head = 138234.28 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127734.91 [m³/day]
General-Head = 134596.83 [m³/day]
Total IN = 1177414.63 [m³/day]
OUT:
Storage = 80.74 [m³/day]
Constant Head = 51729.70 [m³/day]
Wells = 359698.56 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20279.09 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 540866.31 [m³/day]
General-Head = 208160.47[m³/day]

Subtractive Analysis – SC00404713AC
(Analysis Well K)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38244828.00 [m³]
Constant Head = 35379544.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33227598.00 [m³]
General-Head = 29713566.00 [m³]
Total IN = 262787120.00 [m³]
OUT:
Storage = 3175309.50 [m³]
Constant Head = 13440881.00 [m³]
Wells = 44287900.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870607.00 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 285837.34 [m³/day]
Constant Head = 138234.28 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127736.89 [m³/day]
General-Head = 136911.02 [m³/day]
Total IN = 1177766.50 [m³/day]
OUT:
Storage = 80.74 [m³/day]
Constant Head = 51729.70 [m³/day]
Wells = 360064.25 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20278.69 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 540868.69 [m³/day]
General-Head = 208146.27[m³/day]

Subtractive Analysis – SC00404514CB
(Analysis Well Z2)

Time(days): 257.99997
Output Time: 3
Stress Period: 10

Cumulative Volumes Report [%s]

IN:
Storage = 38324676.00 [m³]
Constant Head = 35379544.00 [m³]
Wells = 0.00 [m³]
Drains = 0.00 [m³]
Recharge = 126221584.00 [m³]
ET = 0.00 [m³]
River Leakage = 0.00 [m³]
Stream Leakage = 33227694.00 [m³]
General-Head = 29413080.00 [m³]
Total IN = 262566576.00 [m³]
OUT:
Storage = 3175296.75 [m³]
Constant Head = 13440881.00 [m³]
Wells = 44063000.00 [m³]
Drains = 0.00 [m³]
Recharge = 0.00 [m³]
ET = 2870620.75 [m³/d]

Rates for Time Step Report [%s]

IN:
Storage = 287302.78 [m³/day]
Constant Head = 138234.28 [m³/day]
Wells = 0.00 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 489047.03 [m³/day]
ET = 0.00 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 127734.23 [m³/day]
General-Head = 133676.06 [m³/day]
Total IN = 1175994.38 [m³/day]
OUT:
Storage = 80.74 [m³/day]
Constant Head = 51729.71 [m³/day]
Wells = 358235.75 [m³/day]
Drains = 0.00 [m³/day]
Recharge = 0.00 [m³/day]
ET = 20279.09 [m³/day]
River Leakage = 0.00 [m³/day]
Stream Leakage = 540879.94 [m³/day]
General-Head = 208200.95[m³/day]