A MODELING INVESTIGATION OF GROUND AND SURFACE WATER FLUXES FOR KONZA TALLGRASS PRAIRIE

by

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Abstract

Konza Prairie is one of the few areas in the United States were natural landscape of the area is still intact. Human action on changing the landscapes in this area is limited and much of the land remains as native grassland. In spite of its natural existence, this area is not completely isolated from the rest of the world. Changes that are taking place in climate will eventually have the same effect to this region as well as other human populated areas. Increase in carbon concentration in the air has resulted to increase in temperature, this increase in temperature increases the evaporation from the sea, oceans and the ice capes. As the atmospheric water vapor changes the precipitation pattern also change.

Changes in precipitation due to climate change will result to change in hydrology and hydraulics of the streams and groundwater flow regime. Precipitation provides surface runoff and groundwater infiltration, which recharge the cracked limestone aquifer present in the Konza area. The infiltration water moves trough the cracked rocks and eventually reach the creeks such as Kings Creek and flow to the Kansas River. Increase in precipitation will result to increase in surface runoffs and more groundwater recharge. Decrease in precipitation will result to decrease in both surface and groundwater.

To examine changes in groundwater elevation as recharge change in Konza, a groundwater model was developed based on erosion impact calculator (EPIC) ecological model and SLIT groundwater model. EPIC model estimates the deep percolation (recharge) as 12% and total runoff to about 24% of the annual average precipitation. The annual average recharge values from EPIC were used in SPLIT to simulate results for the groundwater elevation at Konza prairie. Field wells elevation were use to calibrate the SPLIT results. By estimating the hydraulic permeability value to 0.546m/d the field well measurements and SPLIT simulated groundwater elevation results provide a good match. After calibration max and min recharge together with a 5-years moving average were used to examine the changes in groundwater elevation as recharge changes. Future study intends to use the calibrated Konza groundwater model and the forecasted climate data to simulate result for groundwater elevation as climate changes.

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Dedication

To my dear Dad, Yesse Lauwo, my mom Frida Makele, and all members of my family who live in Tanzania, and all friends who give me company during my time at Kansas State University, in Kansas, U.S.A.

CHAPTER 1 - INTRODUCTION

1.1 Background Information

This thesis examines groundwater flow in a natural tallgrass prairie ecosystem and its response to change in climate. This study will focus on Konza Prairie area. Konza Prairie lies in the eastern part of Kansas, between Latitude $39^{0}05$`N, and Longitude $96^{0}35$`W, with an area of about 3487 hectares. See Figure 1.1. Its elevation range between 318 and 448 meters, with an average elevation of 396.5 meters above sea level. It is owned by the Nature Conservancy and Kansas State University and operated as a field research station by K-State Division of Biology. Konza Prairie landscape was produced after millions of years of exposure to weathering and to stripping by streams tributaries that flows to the Kansas River (Ovitt, 1998).

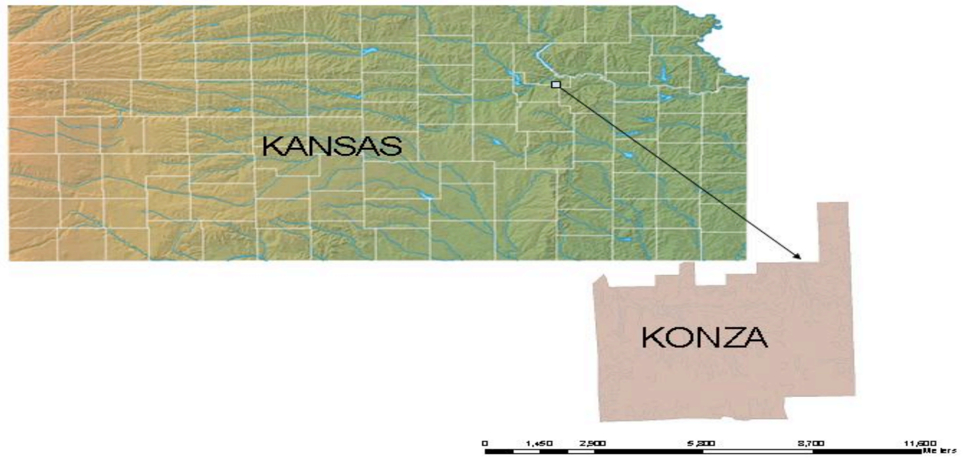

Figure 1.1 Location of Konza tallgrass prairie in the state of Kansas

1.2 Problem Statement

The fractured limestone rock present in Konza prairie act as an aquifer that provides storage for the groundwater during and after rain season. The stored water is slowly released to the stream and part of it is used by vegetation through transpiration. Changes in climate will result to changes in surface and groundwater fluxes. Increase in precipitation will result to more recharge to the groundwater this increase will result to higher groundwater elevation and more stream and river flows that may result to more flooding. Decrease in precipitation and increase in temperature will reduce the recharge to groundwater aquifer and this will result to lower groundwater levels. Precipitation decrease and temperature increase will also cause decrease in stream and river flows, it will also cause increase in evapotranspiration. As the groundwater level decreases many native plants will fail to reach the groundwater during dry season of the year. This will cause short root vegetation to die and new invasive species with long roots to develop and dominate the Konza natural tallgrass prairie.

1.3 Objective of this study

To develop a groundwater model for the Konza natural tallgrass prairie that will serve as a framework for the study of groundwater level changes as the climate changes. This study will link climate, soil, crop and management practices information to understand changes in groundwater recharge and couple these results with a groundwater model and subsequent changes in stream baseflow.

1.4 Approach

This groundwater model was developed using, EPIC (Erosion Productivity Impact Calculator) ecological model, ArcAEM and SPLIT models were used. The EPIC model provides a room for surface water and vegetation interaction. The ArcAEM provide tools that extraction information from ArcGIS shape and grid files of streams and DEM. SPLIT provides two dimensions solution for the groundwater elevation and stream flow using the Analytical Element Method. EPIC model requires weather data, soil data, and crop management data to generate the recharge to the groundwater. SPIT model requires recharge data, stream information, and aquifer parameters to generate groundwater elevation and stream flow results.

Daily weather historic data from Jan, 1985 to Dec, 2005 that includes precipitation, maximum and minimum temperature, solar radiation, relative humidity, and wind speed were obtained from North Agronomy farm weather station located near Manhattan town. The Northern Agronomy farm station was considered to be the nearest station from Konza that happen to have all the weather historical data required by EPIC model and for the period of interest which were not available from the Konza weather stations.

Soil data for Konza and its vicinity were obtained from US Soil data mart website owned by United States Department of Agriculture (USDA) under National Resources Conservation Service (NRCS). Stream and river information were obtained from National Hydrologic Data (NHD) website. The ground elevation (DEM) information were obtain from National Elevation Dataset (NED). Aquifer parameters were estimated based on previous geological studies conducted for this area. The hydraulic permeability value for Konza was estimated during this study using ad hoc method performed during the model calibration.

Recharge results generated by EPIC model were combined with stream information, and aquifer parameters to generate the SPLIT input file. The SPLIT model was used to generate the groundwater elevation for the Konza natural tallgrass prairie for different recharge scenarios. The groundwater elevation results from SPLIT groundwater model were adjusted by changing the hydraulic permeability value until the groundwater elevation contours generated by SPLIT model match the field well measured from Konza deep wells.

1.5 Order of the thesis

Background information about our study area Konza, which includes location and historical information, the problem statement, objective of the study, approach to solve the problem and order of the thesis are discussed in Chapter one of this thesis. Chapter two focus on the literature review for the study area. The literature review presents the general information about Konza, the climate, vegetation, existing soils, surface water hydrology, groundwater hydrology, water budget, previous studies on grassland modeling using EPIC and previous studies using ArcAEM and SPLIT groundwater models.

Chapter three of this thesis cover the Methodology. The methodology was divided into two parts. Part one talks about the models used in this study and part two discusses on how the input data for the models were prepared to meet the models requirements. The main models discussed in this chapter were EPIC model, ArcAEM model, and SPLIT model. EPIC model is made up of different models which were also discussed under model part of this thesis. The discussed EPIC sub-models were surface runoff model, peak runoff rate, evapotranspitation, snow melt, plant water use, biomass production, and deep drainage model. The approach used in generating the input file for SPLIT using ArcAEM is presented under model part. Analytical Element Method and groundwater equations used for the two dimension solution for unconfined aquifer were also discussed under model part. Data preparation sub chapter provide information on the existing Konza and its surrounding soils, how the soils were classified, how the dominant soil types were selected, how the Konza soil conceptual model was developed, procedure on estimating the EPIC model input parameters, Konza and its surrounding streams and rivers simplification and lastly the chapter ends with the aquifer parameter estimation section.

Chapter four presents the EPIC model results and SPLIT model results. EPIC results includes annual recharge results from year 1985 to year 2005 for the selected soil types, the classification of recharge into three groups, development of the recharge conceptual model, surface water runoff results, and biomass production. SPLIT results presented in this chapter includes; no recharge groundwater level contours, average recharge contours, maximum recharge groundwater elevation contours. Other SPLIT results includes depth to water, the comparison between no recharge groundwater elevation and average recharge groundwater elevations, the comparison between the maximum recharge groundwater elevations and average recharge groundwater elevation. The last part of chapter four presents the procedure used in the Konza groundwater model calibrations.

Chapter five presents the discussion of the results section. This chapter is divided into two parts, one about EPIC results and the other presents discussion on SPLIT results and their interpretation. Chapter six presents the conclusion drown from this study and the future studies intended to be conducted after completion of Konza groundwater model framework. Chapter seven covers the reference used during this study. The reference presents existing studies about Konza natural tallgrass prairie and also the reference used for the Models used in this study including EPIC, ArcAEM and SPLIT. Chapter eight focus on appendixes. The appendixes part provides a sample of the EPIC ecological model input files for the selected soil types present in Konza area.

CHAPTER 2 - **LITERATURE REVIEW**

2.1 General Information

Konza prairie is located on the Flint Hills region of North America. See Figure 2.1. The Flint Hill region is a part of the largest contiguous area of natural tallgrass prairie of 1.6 million hectare that extends from United States of America to Canada. See Figure 2.2.

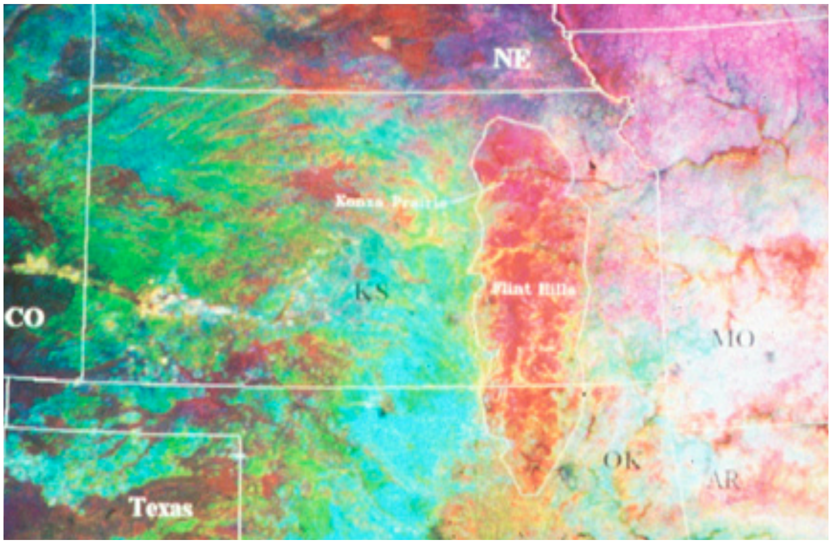

Figure 2.1. Location of Flint hills in the state of Kansas (source www.konza.ksu.edu)

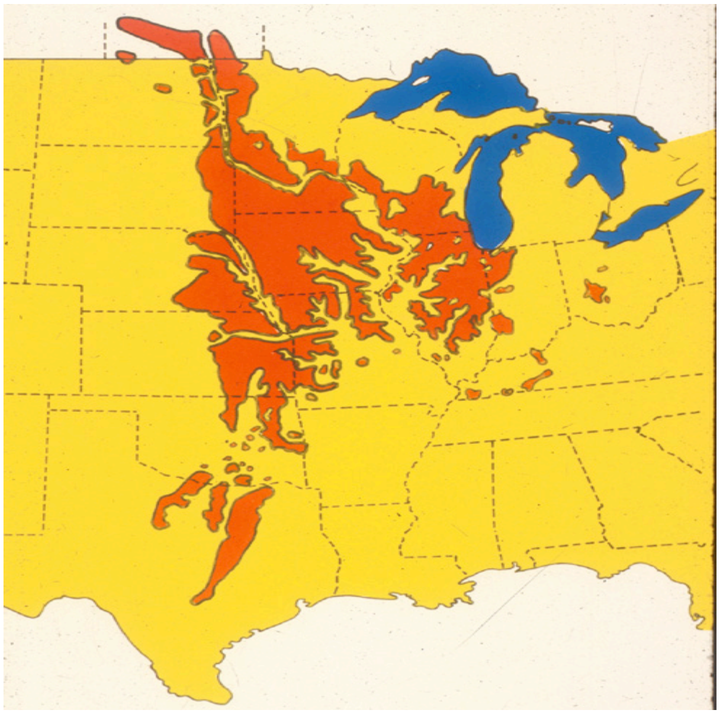

Figure 2.2 The natural tallgrass prairie in Norht America (Source www.konza.ksu.edu 2007)

The major drainage basins on Konza area are Kings Creek, Shane Creek, Pessee Branch, Swede Creek and Deep Creek. Kings Creek drainage area cover the large area of land, its basin occupy about 1059 hectares of land. Surface water flow in Kings Creek is influenced by climate, geology, and vegetation. The annual precipitation in Konza Prairie averages 835mm. This precipitation has a probability of once in hundred years to be less than 460mm or to be more than 1400mm in a year. Most of the Konza rain occurs in wormer months, because of this snow is not considered part of the water budget. Annual evaporation is about 1300mm in average, the annual moisture deficit obtained by taking the difference between evaporation and precipitation averages 525mm. The range of moisture deficit is between -280 and 1140mm. This extreme variation can result in annual water yield from zero to over 510mm. (Knapp et. al, 1998).

There are two major important geological influences on Konza streams surface flow, the high infiltration capacity and high water storage capacity of Konza soils. Konza soils are rich in clay, because of this they crack when dry and swell when wet. This causes relative high infiltration rates when the soils are dry to wet. Previous studies have shown that, when the soils are dry a 50mm rainfall event applied at the rate of 60mm/h, will not produce any runoff. To return the streams flow to normal conditions after a long dry period, about 120mm of precipitation is needed. Fractured limestones and grain size alluvium behave as aquifer at Konza Prairie area. The grain size alluvium, the fractures in the limestones beds and intervening shales permit rapid infiltration of precipitation, and substantial storage and attenuation of infiltration water. The cracked limestone is believed to be shallow, but the outcrop shows evidence of well connected joints that result to natural springs and seeps along the main channels (Knapp et. al, 1998).

Stream flow in Konza Prairie is also affected by water demand of the native vegetation. Previous studies has shown that an additional water of about 350mm/yr in average is needed to satisfy the evapotranspiration from native plants. This high demand by the vegetation, combine with the low rainfall in later summer and early fall, leads to low flows in Kings Creek. In Kings Creek watershed, residual layer of plants act as a mulch on the soil this material reduce evaporation and increase infiltration. This high infiltration gives Kings Creek about 15% more water yield than from the near by watersheds.

Burning and animal grazing in some part of Konza Prairie is a common practice. In some watersheds burning is performed yearly, in some burning is done after several years and in some no burning practice at all. Bison’s and cow grazing is practiced in a smaller area of land compared to the area left untouched. Despite of the steep slopes throughout the Creeks, soil erosion is limited. Previous studies have also shown that burning does not increase the soil losses in Konza either (Knapp et al. 1998).

2.2 Konza Climate

Konza Prairie is considered to have a continental climate characterized by warm, wet summer and dry, cold winters. Konza Prairie receives about 835mm of rainfall annually, with much of its rains occurring during spring and summer seasons. The annual average temperature at Konza is 13^0C. The annual historic precipitation data obtain from a nearby station at Manhattan shows that annual average precipitation is about 833mm, from 1891 to 2004 shows a range between 400mm to 1500mm (see Figure 2.3).

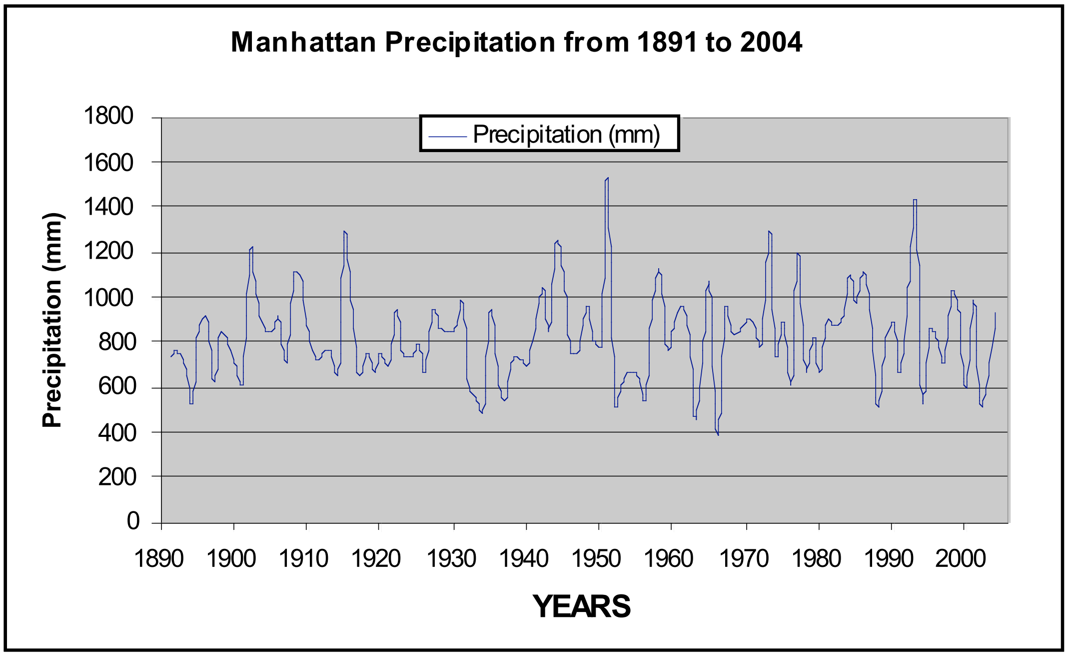

Figure 2.3 Manhattan weather station historic precipitation

The yearly average temperature range between 11.1^{0}C and 15.4^{0}C, and the annual mean for the historic record is 12.95^{0}C based on the temperature data recoded from a near by station in Manhattan, Kansas for year 1891 to 2006 (see Figure 2.4).

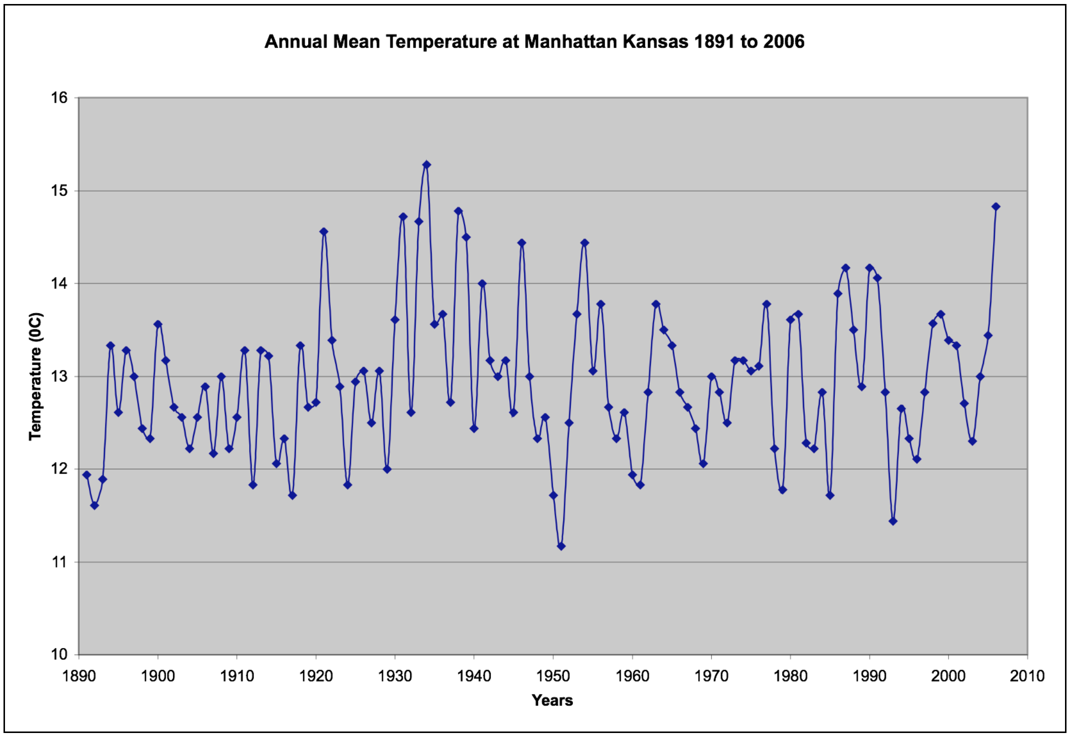

Figure 2.4 Manhattan weather station historic Temperature.

2.3 Konza Flora and Fauna

The flora of Konza Prairie is primarily 90% native tallgrass, dominated by the perennial warm-season grasses big bluestem, Indiangrass, and switchgrass. See Figure 2.5. The tall grass canopy reaches over 2.5m in height in the most productive years. Few woody species such as buckbrush and smooth sumac are locally common, cool season grasses, composites, legumes, and other forbs are also present in this region. Along King's Creek a forest dominated by bur and chinquapin oaks and hackberry cover approximately 7% of the preserved area. Several agriculture fields and restored prairie on former cultivated field occurs on the deep soil lowlands along the lower stretches of Kings Creek. The large remain part of the land is overlain by shallow limestone soils unsuitable for cultivation.

Figure 2.5.Konza native tallgrass

More than 600 species of fauna live in Konza Prairie, these include fish, amphibians, reptiles, and mammals such as Bison's, see Figure 2.6. Also more than 200 spices of resident and migratory birds have been reported seen in this area (Figure 2.7).

Figure 2.6. A group of Bison's grazing in Konza Prairie on September 2007

Figure 2.7. A group of wild Turkey feeding in Konza Prairie on September 2007

2.4 Konza Prairie Research Natural Area Experiment Design

Konza Prairie ecosystem is influenced by fire, grazing and climatic variability. The Kansas State University Division of Biology has divided this area into different small watersheds as it is shown on figure 2.4.1. Different fire and grazing treatment are applied to different watersheds in the area. Watersheds open to Bison grazing are noted by letter ‘N’, Cattle grazed watersheds ‘C’, all other watersheds are un-grazed. Number in watershed codes designate fire return intervals for spring-burned watersheds, and the last letter of the watershed codes (A,B,C,D) is used to identify replicate watershed with similar treatment. Frequency of burning is indicated by a number and watershed with similar treatment are presented by similar color on the map, see Figure 2.8.

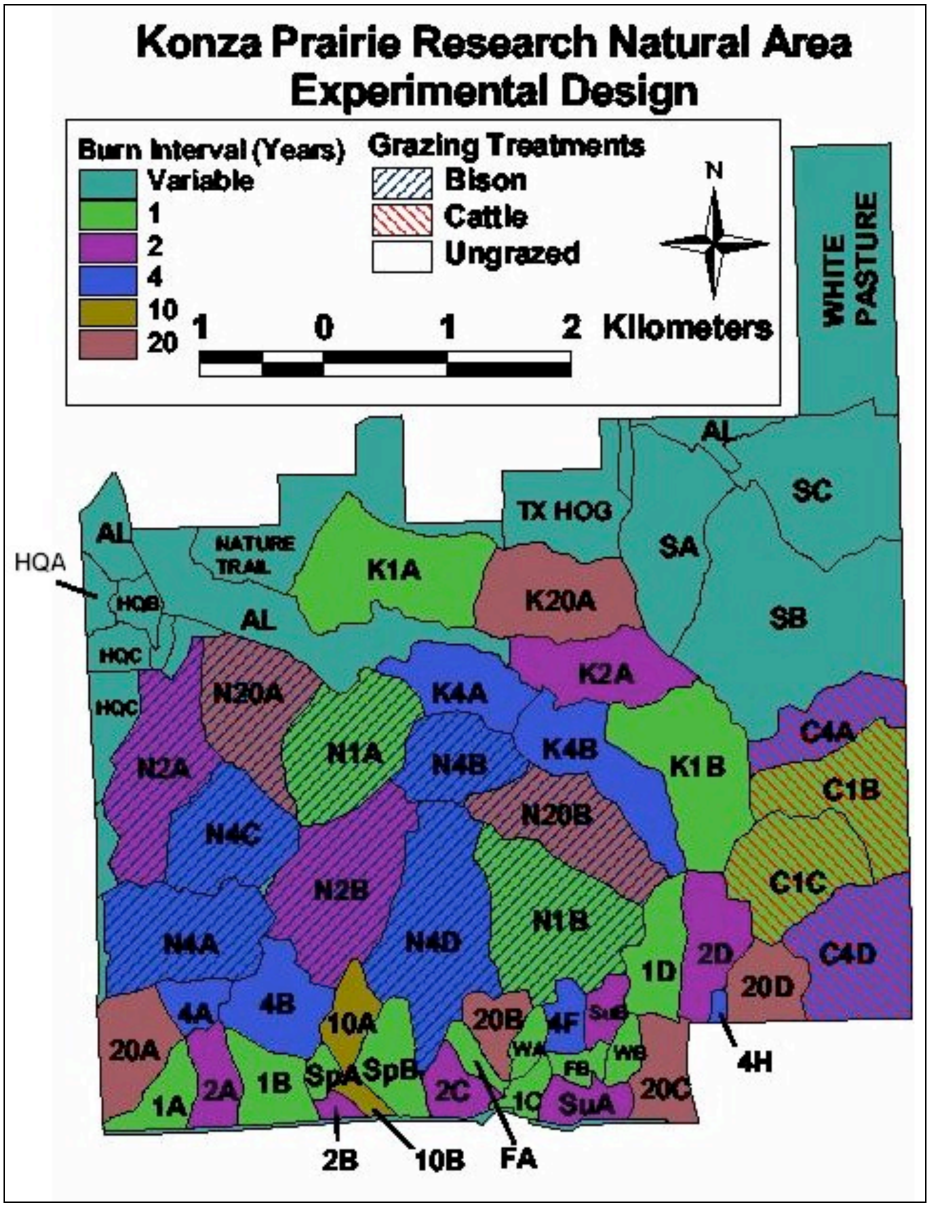

Figure 2.8. Konza Prairie Research Natural Area Experiment Design (Source www.konza.ksu.edu 2007)

2.5 Soils in Konza

Soils exists in Konza Prairie are associated with its landscapes present in this area. At the hills summit and interfluves three types of soils exist, these are Konza, Labette and Dwight soils. These three soils are considered moderate well drained and slowly permeable. See Figure 2.9.

At the shoulder Benches, Florence soils are dominant. The Florence is considered well drained and slowly permeable soils. Three soils exists on the side slopes of Konza hills these are Clime, Tuttle, and Benfield. These three soils are considered to be moderate deep, well drained and slowly permeable. On the foot slopes and toe slopes we have

Tully soil considered to be quaternary Alluvium-Colluvium, this soil is very deep, well drained and slowly permeability. On the terrace and in the flood plains Ivan soil is dominant. The Ivan soil is formed from the disintegration of shales and limestones through weathering processes. The content of rock fragment is as much as 50%, typically found closer to the stream channels. It is considered as deep soils, very well drained with high water permeability and it also provides a good storage for groundwater because it is rich in alluvium (Wehnueller, 1996).

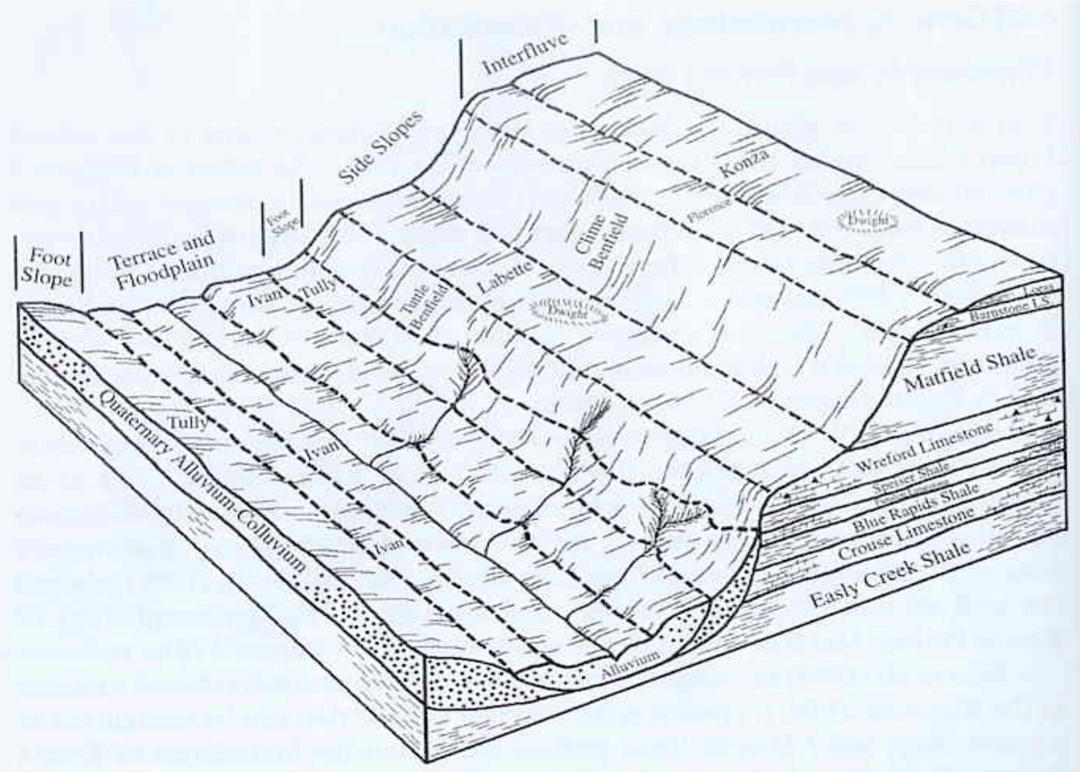

Figure 2.9. Soils in Konza area (source Wehnueller, 1996)

2.6 Surface water Hydrology

Surface water flow in Konza streams differ significantly, the driving factors been rainfall variability and the watershed area draining water in a particular creek. With exception of Kings Creek, other streams carry water only during rain season. What makes Kings Creek unique is the fact that it covers 30.4% of Konza Prairie area this makes it the largest watershed of all watersheds in Konza. In the Kings Creek a high degree of variability in discharge is evident between seasons and years. Different stream flow measurement stations are present in Konza. Figure 2.10, represent one of the stream flow measurement station located in Konza. The flow measurement at Kings Creek USGS station recorded as annual average from 1985 to year 2005 are shown on Figure 2.11.

Figure 2.10. Steams flow measurement station using a v-notch weir at Kings Creek

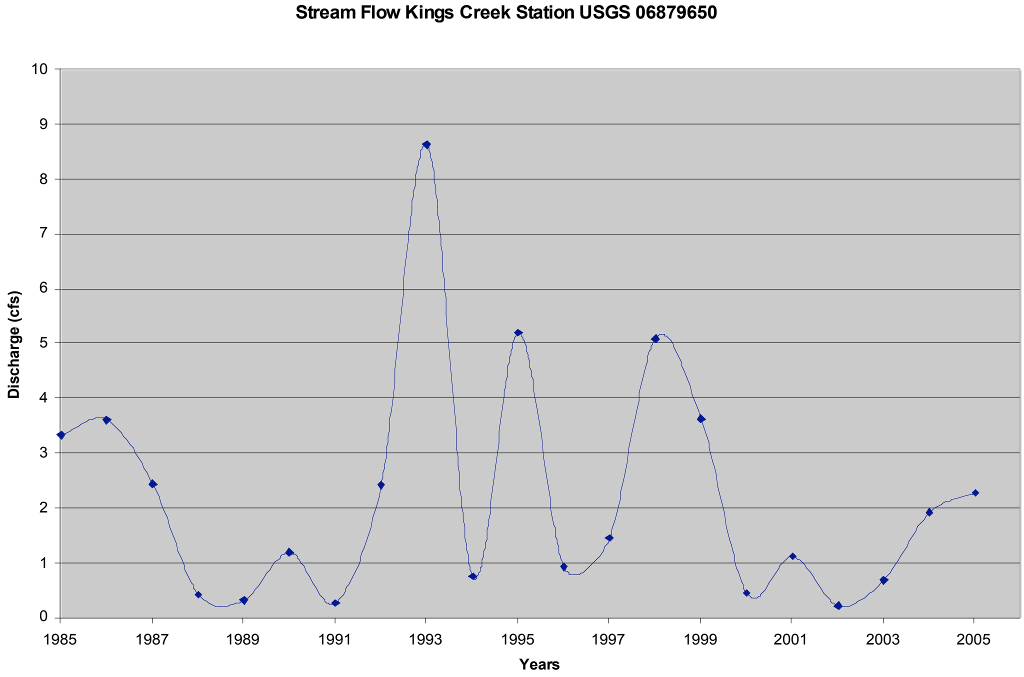

Figure 2.11. Annual average stream flow measurement at Kings Creek USGS Station.

The total water yield measured at the USGS gauging station at Kings Creek is about 25% of the total precipitation on this watershed. The lowest average flow occurs in late summer and again in winter, when the stream dries completely except for isolated pools near springs and seeps. The longest period of continuous measurable flow reported from September of 1985 to July 1987 (673days) and the longest period of no flow occurred from June 1988 to September 1989 (442days). On average the discharge pattern in Kings Creek at the USGS gauge station consists of about 200 days of measurable flow, with no flow for the rest of the year. The greatest amount of discharge generally occurs in April, May, and July. Peak flow during floods measured at USGS gauge station occurred on 1 July 1982 (128 m3/s), 22 July 1992 (164m3/s), and 17 July 1993 (233m3/s). A discharge of 153 m3/s represents an estimate of a 100-year peak discharge for a drainage area the size of Kings Creek (Knapp et al. 1998).

2.7 Groundwater Hydrology

During 1988 – 1990 period thirty monitoring wells were installed in two locations of N04D sub-watershed within the Kings Creek watershed, some of the wells are installed in selected limestone and other in the alluvium potion of the N04D watershed. In the limestone area the wells are located in the Morrill Limestone, and in the Eiss Limestone, the rest are located in the alluvium fill along the streams. The wells located in the Morrill, Eiss Limestone and the alluvium its depth range between 2 and 36m. There are two deep wells located in the Morrill Limestone site, these are well 4-6 Mor, and 4-7 Mor with a depth of 12 and 36m respectively. Measurements of water levels in the local limestone and alluvium aquifers in the watershed N04D since 1991 shows that, the response of aquifer to recharge event (rainfall) in the limestone wells is uneven. Several periods of precipitation close together were more likely to affect recharge to the aquifer than an isolated rainfall event (Knapp et al. 1998).

Water level response to recharge in the alluvium was generally very fast and may be less than a day. This rapid response may indicate either the fast propagation of pressure wave in the aquifer system from a recharge event or rapid physical movement of the recharge water to the observation point (Macpherson 1992b, 1996).Water in alluvium, whether the alluvium is gravel or silt, is linked closely to adjacent streams. Alluvium aquifers fill before the stream begins flowing and empty fully after stream flow ceases. Most of the recharge for the limestone aquifer is believed to occur vertically through overlying units and through the streams. Measurement indicates that groundwater mounds had a peak elevation of 1 to 2m below the elevation of the stream valley. (Pomes 1995; Macpherson 1993, 1996). Based on observations of water level elevations the limestone aquifers behaved as either unconfined or confined units. Unconfined alluvium aquifers shows large changes in water level throughout the year, suggesting a strong hydraulic connection between the alluvium and the alluvium aquifer (Knapp et al. 1998).

2.8 Konza Water Budget

In 1988, Barlett simulated the water budget for Kings Creek, his results indicates that the average annual dispensation of the 835mm of precipitation varies with landscape position. High infiltration results on the hill slopes as 25% of annual precipitation, followed by ridges 17% and valleys 11%. Actual Evapotranspiration (AET) was highest in valleys (65% of annual precipitation, followed by ridges 57% and slopes 49%. The surface runoff was slightly higher along the slopes, and it was assumed to be caused by the shallow soils, but overall runoff did not vary much in the landscape. About two third of the water yield was from infiltration, which appears as base flow at the USGS station in Kings Creek (Knapp et al. 1998).

2.9 Modeling using EPIC

EPIC model was developed for and has been frequently used on cultivated lands, but it was intended to be applicable for all major land resources areas in the United States. Rangeland including forested grazing land, represent about 50% of the land area in the Unite States. Because of this it was important for EPIC to be evaluated for use under range condition. A study was conducted to evaluate the EPIC model on a sagebrush range site in the southwestern Idaho (Cooley et al. 1990).

A site called Lower Sheep Creek was chosen because of data availability. The site was described to have shallow-clay-pan between 305 to 406mm, annual precipitation in form of snow was 354mm which occurs between the months of November and March, runoff was produced by snow melt, actual temperature, precipitation, radiation, and forage yield data for the 1976 to 1981 period were used for the model calibration. Several parameters were used to calibrate the EPIC model; mean simulated forage yields for the test period were compared with the mean measured yields, values for percolation and total evapotranspiration simulated by EPIC were compared to corresponding values simulated by ERHM and SPAW models, annual runoff and soil water stored in the total soil profile at the end of each year were compared with measured values. EPIC model calibration was assumed to be complete when mean simulated values match the mean measured values (Cooley et al. 1990).

EPIC model was used in Arlington, Wisconsin to simulate long-term and residual effects of Nitrogen fertilization and corn yields, soil carbon sequestration, and soil nitrogen dynamics form 1958 to1991. The soil carbon sequestration (SCS) has a potential to attenuate increase in atmospheric carbon dioxide and mitigate green house warming. Results from EPIC indicated that the correlation between simulated and actual corn yield was 96%, simulated soil organic carbon and SCS match with the measured values. Simulated Nitrogen mineralization rates were lower than the laboratory incubation. (He et al., 2006).

In the southeastern USA broiler litter a mixture of excreta and bedding material is used as a fertilizer for the grassland. Previous studies have shown that use of broiler litter may increase the level of phosphorus (P) in surface runoffs. In this study EPIC ability to simulate event and annual surface runoffs volume and losses of dissolved phosphorus was evaluated. Results form EPIC model tend to underestimate runoff volume for events >30mm and under estimate annual runoff volume > 100mm. There was a strong association between the measured and the simulated runoffs but calibration need to be performed to get correct results. The relationship between the simulated and observed dissolved reactive phosphorus loss was very poor ($r = 0.65$) on an event but was very stronger for annual basis (r = 0.75). This study suggests that additional work is needed to improve EPIC in its simulation of Phosphorus in the area were broiler litter is applied as fertilizer. (Pierson, 2000).

2.10 Groundwater Modeling using ArcAEM/SPLIT

ArcAEM is a GIS based interface developed to facilitate analytical element groundwater model (AEM) construction and output visualization with ArcGIS. This interface tool is used to prepare the input file for SPLIT model. The SPLIT model uses Analytical Element Method to perform calculations for the groundwater flow systems. Analytical Element method has been used in both small scale and large scale (regional) groundwater modeling. Several papers have been presented in the scientific journals giving the wide rage of application of Analytical Element method. (5th International Conference on the Analytic Element Method-Kansas State university, 2006. Papers by Strack, Steward, Hunt, Jankovic, and Baker).

The Analytical Element Method based on SPLIT groundwater model was used to enhance the aquifer vulnerability indexing method for the purpose of establishing guidelines for the protection of groundwater resources in the western New York State. The basic principle of the indexing method is to rank influence of groundwater to determine overall vulnerability of an aquifer to groundwater contaminations. The ArcAEM graphical user interface allows automatic convention of hydrography vector data into analytical elements(Fredrick, et al., 2004).

An object oriented approach that associate groundwater models based on Analytical Element Method (AEM) with Geographic Information System (GIS) geodatabase features that uses AEM model Interface can be developed to establish a link between groundwater to a variety of natural and social process (Steward et. al, 2006). Analytical Element Method (AEM) used for modeling of divergence-free and irrotational flow in both two and three dimensions, including the description of the superblock approach, which makes it possible to deal with very large models both in terms of accuracy and speed, solving multiaquifer problems was presented by Strack, (2003).

This new approach has been presented for improving the computational efficiency of regional-scale groundwater model based on the AEM. The algorithm was developed as an extension of the existing superblock algorithm, which combines the effects of multiple analytical elements into Laurent series and Taylor series. With a nested superblock approach, the complex potentials and discharge functions that contain large number of analytical elements can easily be solved (Craig et al., 2006). Regional groundwater model for Yucca Mountain site was performed based on Analytical Element Method (AEM). The Yucca Mountain consists of large distance to hydrological boundary of up to 500km away, and a large aquifer thickness of up to 5000m thick. This aquifer was modeled as a single layer, the simulated results matched the field measured values. This was only possible by using AEM (Bakker et al., 2000).

A study was conducted to support the development of a cooling water supply for gas-fired generation facility 20km south of the Muddy River spring in Nevada. The AEM was used to establish a better understanding of regional fluxes and boundary conditions and provide a framework for examine the local transient effect of using MODFLOW. The AEM was applied to a 15,000km^2 area of the Paleozoic carbonate rock terrain of Nevada. The Muddy River receives about 51ft3/s from the groundwater aquifer. The AEM simulated results were calibrated by using monitoring wells exists in this area. The AEM provided more information and facilitate the stepwise development of multiple conceptual models of the site (Johnson et al., 2006)

By using analytical elements to model steady state, two-dimensional, Dupuit-Forchheimer groundwater flow and its contribution to surface flow, average base flows and groundwater flows in a groundwater and surface water system can be model without substantial increase in model complexity or data requirement (Haitjema, 1996). Groundwater and surface water interaction of the Northern Highland Lakes region of Wisconsin, USA were examined by using remote sensing, and AEM. The remote sensed elevation data for lakes and wetlands were used to construct regional scale groundwater models. The Elevation data were then utilized in ArcAEM to perform the groundwater model development for Wisconsin area (Fredrick et al., 2006).

A paper on the application of the Analytical Element Method was presented by Hunt, 2006. This paper point out the overview of the applications of this method in comparison to other methods like finite-difference or finite element methods. This paper list the historic applications of the AEM as it has been used in regional, two dimension steady state models, analyses of groundwater-surface water interaction, quick analyses and screening models, wellhead protection studies. Others were grid sensitivity analysis, estimating effective conductivity and dispersion in highly heterogeneous systems. This paper also point out where more method development is needed in AEM including a three dimensional and transient simulation (Hunt, 2006).

Analytical Element method can be used for examine groundwater flow in multiaquifer system. Differential equations are developed based on AEM and each equation represent a physical feature such as well, line-sink, and circular infiltration. Solution to these equations can be used to simulate results for the aquifer head, discharge and leakage between aquifers at any point. If these AEM differential equations are superimposed, a solution to a regional multiaquifer flow can be simulated (Bakker et al., 2002). The Analytic Element Method (AEM) is a prominent technique used for modeling local detail within a large regional system.

In summary, EPIC is an established ecological model that may be used for studies of grassland hydrologic fluxes. Data will be used in this study region to predict and forecast these hydrologic responses. For the past 20 years the Long-term ecological research (LTER) program at Konza natural tallgrass prairie has focused on grassland ecology studies. Those ecological studies and experiments by LTER program integrate fire, grazing, and climate variability as essential and interactive factors responsible for the structural and function of tall grass prairie. Prof Gwen Macpheson from the University of Kansas, has conducted groundwater chemistry studies and she has published several professional paper on this topic. A clear need exists to use this information to study the groundwater hydrology of Konza natural tallgrass prairie. This thesis fills this need.

CHAPTER 3 - METHODOLOGY

3.1 MODELS

The EPIC, (Erosion Productivity Impact Calculator) ecological models, ArcGIS, ArcAEM and SPLIT groundwater model were used to investigate groundwater fluxes at Konza natural tallgrass prairie (see Figure 3.1). This framework will save as a framework for examining changes that will take place in groundwater as climate change in the future.

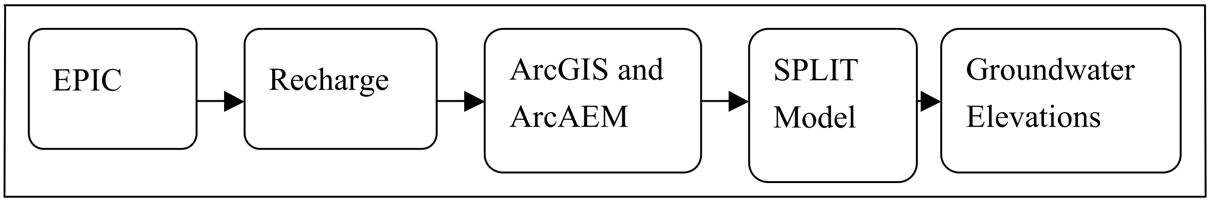

Figure 3.1. Flow diagram for the models used in the investigation and results produced.

3.1.1 EPIC Model

The EPIC model was originally designed for the purpose of determining the relation ship between soil erosion and soil productivity. But for many years it has been used in broad range of applications. The reason for this is its ability to simulate results for processes that took place over a long period of time. This model consists of different component models that pertain to the following major aspects of the soil erosion/productivity relationship: hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, economics, and plant environment control.

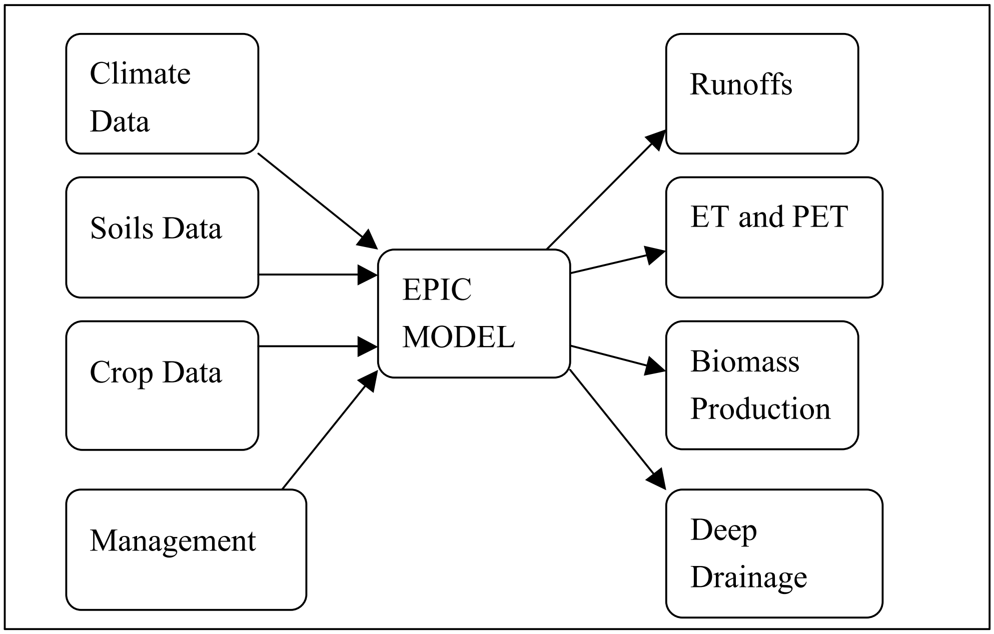

Figure 3.2. EPIC input and out put data production,

The application of EPIC model for Konza study area will only focus on few components that were used in the process of estimating the required outputs for the fields of interest. Figure 3.2, shows the input and out put data for EPIC model. Climate data, soil data, crop data and management practice were required by the EPIC input files. The EPIC model used this input files to generate surface runoffs, ET, PET, biomass lateral drainage and deep drainage.

The main equations involved in the process of estimating the output results by EPIC model are discussed here under. The Table 1, below shows the notation and units used in the EPIC model.

Table 1. Symbols, and units for different variables

Notation		
Runoff notation		
Symbols	Units	Variable
Q	mm	Daily runoff
R	mm	Daily rainfall
CN		Curve Number
s		Retention parameter
FFC		Fraction field capacity
SW	kPa	Soil water content
WP	kPa	Wilting point water content
FC	kPa	Field capacity
q_p	m^3/s	Peak runoff rate
ρ		Runoff coefficient
r	mm/h	Rainfall intensity
A	ha	Drainage area
t_c	h	Time of concentration
α		Proportion of total rainfall
λ	m	Surface slope length
v_s	m/s	Surface flow velocity
σ	m/m	Average channel slope
n		Manning’s number
S	m/m	Land surface slope
Evapotranspiration notation		
E_0	mm	Potential evaporation
δ	kPa/^{0}C	Slope of saturated vapor pressure

		curve
γ	kPa/^{0}C	Psychrometer constant
h_0	MJ/m^2	Net radiation
G	MJ/m^2	Soil heat flux
HV	MJ/kg	Latent heat of vaporization
f(V)	mm/d/kPa	Wind speed function
e_a	kPa	Saturated vapor pressure
e_d	kPa	Vapor pressure
T	^{0}C	Mean daily temperature
RH		Relative humidity
PB	kPa	Barometric pressure
ELEV	m	Site Elevation
RA	MJ/m^2	Solar radiation
AB		Albedo
EA		Soil cover index
CV	t/ha	Sum of the above ground biomass
RAB	MJ/m^2	Net outgoing long wave radiation
RAMX	MJ/m^2	Maximum solar radiation possible
LAT	Degrees	Latitude of the site
SD	Radians	Sun's declination angle
V	m/s	Mean daily wind speed
E_p	mm/d	Predicted plant water evaporation rate
Es	mm/d	Potential soil water evaporation rate
EV	mm	Total soil water evaporation
SEV	mm	Potential soil evaporation for a layer *l*
SEV*	mm	Adjusted soil water evaporation estimate

Snowmelt and Plant water use notations		
SML	mm/d	Snow melting rate
T_{max}	^0C	Daily maximum temperature
SNO	mm	Water content of snow before melt
E_p	mm	Potential water use
LAI		Leaf area index
U_p	mm/d	Total water use rate
RZ	m	Root zone depth
Λ		Water use distribution parameter
u_k	mm/d	Actual water use rate
UC		Water deficit compensation factor
Biomass production notations		
ΔB	t/ha	Daily potential increase in biomass
BE	kg/MJ	Crop parameter change energy to biomass
PAR	MJ/m^2	Photosynthesis active radiation
HRLT	h	Daily length
HUD		Heat unit factor
REG		Minimum crop stress factor
HUI		Heat unit index
PHU		Potential heat unit
T_{min}	^0C	Minimum daily temperature
HU		Daily heat unit accumulation
T_b	^0C	The crop-specific base temperature
Deep Drainage or Recharge notations		
SW		Soil water content at the end of 24h
SW		Soil water content at the start of 24h
TT	h	Water travel time through a layer

O_l	mm/d	Percolation rate for a layer l
PO	mm	Porosity of a layer
FC	mm	Field capacity
SC	mm/h	Saturated conductivity
CLA	%	Clay in soil layer l
SS		Soil strength factor
Lateral Subsurface flow notation		
SW_{ol}		Initial soil water content for a layer
FCl		Field capacity
OR	mm/d	Lateral flow rate soil layer
O	mm/d	Deep drainage

3.1.1.1 Surface Runoff

Daily rainfall amount is used as an input to the EPIC model which simulates surface runoff volume and peak runoff rates. The modified Soil Conservation Service (SCS) curve number technique is used to estimate the runoff volume. This technique is reliable and it has been used in U.S.A for many years, it is also computationally efficient, and the required input data are generally available. All of the EPIC equations presented below were obtained from (**EPIC Model Document by Sharpley et. al, 1990**).

$$Runoff\ Volume, Q = \frac{(R-0.2s)^2}{(R+0.8s)} \qquad R > 0.2s$$

$$Q = 0.0, \quad \text{if} \qquad R \leq 0.2s$$

where Q is the daily runoff, R is the daily rainfall, and s is the retention parameter.

The retention parameter s, varies among watersheds depending on soils, land use, management, and slope.

$$s = 254 \frac{(100)}{(CN - 1)}$$

The constant 254, the variable R and Q they are all expressed in millimeters.

CN is the curve number.

It was also assumed that CN_2 is appropriate for a 5% slope, CN_2 is the curve number for moisture condition II, or the average curve number. EPIC use the following equation below to adjust that value for other slopes.

$$CN_{2s} = \frac{1}{3}(CN_3 - CN_2)\,[1 - 2\exp(-13.86\,S)] + CN_2$$

CN_{2s} is the curve number two (CN2) value from SCS hydrology handbook modified for other slope, CN_3 is the curve number at wet condition, and S is the watershed average slope. The value of CN_1, which represents the curve number at dry condition and CN_3 corresponding to CN_2 are also available in SCS handbook. In calculation, CN_1 and CN_3 can be related to CN_2 with the following equations

$$CN_1 = CN_2 - \frac{20(100 - CN_2)}{100 - CN_2 + \exp[2.533 - 0.0636\,(100 - CN_2)]}$$

$$CN_3 = CN_2\,\exp[0.00673(100 - CN_2)]$$

Variations in soil water content will cause the relation parameter to change, the new soil water content can be calculated using the following equation,

$$s = s_1 \left(1 - \frac{FFC}{FFC + \exp[w_1 - w_2(FFC)]}\right)$$

From the above equation s_1 is the value of s associated with CN_1, while *FFC* is the fraction of field capacity, and w_1 and w_2 are the shape parameters.

The following equation is used to compute *FFC*

$$FFC = \frac{SW - WP}{FC - WP}$$

The *SW* represents soil water content in the root zone, *WP* is the water content at wilting point and *FC* is the field capacity water content. The values for the parameter w_1 and w_2 are obtained from the modified retention equation noted as ***s***, presented earlier for the varying water content and by making assumptions that $s = s_2$ when $FFC = 0.5$ and $s = s_3$ when $FFC = 1.0$ and solve the equations simultaneously.

$$w_1 = \ln\left(\frac{1.0}{1.0 - \frac{s_3}{s_1}} - 1.0\right) + w_2$$

$$w_2 = 2.0\left(\ln\left(\frac{0.5}{1 - \frac{s_2}{s1}}\right) - 0.5 - \ln\left(\frac{1.0}{1 - \frac{s_3}{s_1}}\right)\right)$$

the parameter, s_3 is the retention parameter for the CN_3.

The *FFC* value calculated by the previous equation represents soil water uniformly distributed through the top 1.0 m of soil profile. But water distribution near surface will result to more runoffs than the same volume of water uniformly distributed throughout the top meter of soil profile. To correct this depth effect on distribution on runoff the depth weighting function is used

$$FFC^{*} = \frac{\sum_{l=1}^{M} FFCl\left(\frac{Z_l - Z_{l-1}}{Z_l}\right)}{\sum_{l=1}^{M} \frac{Z_l - Z_{l-1}}{Z_l}}, \qquad Z_l \leq 1.0 \text{ m}$$

where *FFC** is the depth weighted *FFC* value, *Z* is the depth (m) to the bottom of soil layer l, and *M* is the number of soil layers.

3.1.1.2 Peak Runoff Rate

The Rational formula is used in EPIC model to predict the peak runoff rate. It is expressed by the formula below,

$$q_p = \frac{(\rho)\,(r)\,(A)}{360}$$

the parameter q_p is the peak runoff rate (m^3/s), ρ is a runoff coefficient expressing the watershed infiltration characteristics, *r* is the rainfall intensity (mm/h) for the time of concentration, and A is the drainage area (ha). If the amount of rainfall and runoff are known, the runoff coefficient can be estimated by the formula,

$$\rho = \frac{Q}{R}$$

The parameter R is the daily rainfall and Q is the daily runoff, then by knowing these two parameters, ρ can easily be calculated. The equation used to compute the rainfall intensity is presented below;

$$r = \frac{R_{tc}}{t_c}$$

where R_{tc} is the amount of rainfall (mm) during the time of concentration, t_c (h) of the watershed. The value of R_{tc} can be calculated by developing a relationship with total daily rainfall R. The Weather Service's TP-40 provides accumulated rainfall amounts for various durations and frequencies. The R_{tc} and R_{24} are proportional for various frequencies. The 24-h duration is recommended for the daily time step model.

$$R_{tc} = \alpha R_{24}$$

α is a dimensionless parameter for the proportion of total rainfall during the time of concentration, t_c.

To calculate the peak runoff, the equation below is used

$$q_p = \frac{(\alpha)\,(Q)\,(A)}{360\,(t_c)}$$

For the calculation of time of concentration the surface and channel flows are added together

$$t_c = t_{cc} + t_{cs}$$

the parameter t_{cc} represents the time of concentration for channel flow and t_{cs} is the time of concentration for surface flow (h). The t_{cc} is calculated by equation:

$$t_{cc} = \frac{L_c}{v_c}$$

the parameter L_c is the watershed (km) average channel flow length and v_c is the average channel velocity (m/s). To estimate the average channel flow length, the formula below was used,

$$L_c = \sqrt{(L)\,(L_{ca})}$$

parameter L is the channel length of the longest distance point of the watershed (km) and L_{ca} is the distance along the channel to the watershed centroid (km). The Manning's equation can be used to estimate the average velocity assuming a trapezoidal channel with 2:1 side slopes and a 10:1 bottom width/depth ratio. The time of concentration can then be estimated by the formula:

$$t_{cc} = \frac{\sqrt{(L)\,(L_{ca})}}{0.489\,(q_c)^{0.25}\,(\sigma)^{0.375}}\,(n)^{0.75}$$

the parameter n is Manning's number, qc is the average flow rate (m^3/s), and σ is the average channel slope (m/m). By making an assumption that $L_{ca} = 0.5L$ and that the average flow rate to be about 6.35 mm/h considered to be a function of the square root of drainage area, result to an equation for t_{cc} as;

$$t_{cc} = \frac{1.1\,(L)\,(n)^{0.75}}{(A)^{0.125}\,(\sigma)^{0.375}}$$

For the estimation of t_{cs} the formula below is used

$$t_{cs} = \frac{\lambda}{v_s}$$

the parameter λ is the surface slope length (m) and v_s is the surface flow velocity (m/s). Making a consideration of a strip *1* m wide down the slopping surface and applying Manning's equation the surface flow velocity can be estimated as:

$$v_s = \frac{(q_s)^{0.4}\,(S)^{0.3}}{(n)^{0.6}}$$

the parameter q_s is the average surface flow rate and S is the land surface slope (m/m). If we assume the average flow rate to be 2.23 and convert it from m^3/s to mm/h and from s to h, we can develop an equation for t_{cs}

$$t_{cs} = \frac{(\lambda\, n)^{0.6}}{18\,(S)^{0.3}}$$

3.1.1.3 Evapotranspiration

The EPIC model comes with two different formulas for the computation of potential evapotranspiration, these options are Priestley Taylor (1972) and Penman (1948) method. Parameters required by Penman method are relative humidity, air temperature, solar radiation, and wind speed. Priestley Taylor method can be used as an alternative method incase wind speed and relative humidity data are not available.

The required input data for the Penman were available so Penman Method was used for the Konza study area. EPIC model computes evaporation from soils and plants separately, the potential soil water evaporation is estimated as a function of potential evaporation and leaf area index (*LAI).* Actual soil water evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is calculated as a linear function of potential evaporation and leaf area index.

3.1.1.2.1 Potential Evaporation

The Potential Evaporation is calculated based on Penman equation below

$$E_0 = (\frac{\delta}{\delta + \gamma})(\frac{h_0 - G}{HV}) + (\frac{7}{\delta + \gamma})\, f(V)\, (e_a - e_d)$$

the parameter E_0 is the potential evaporation (mm), δ is the slope of the saturated vapor pressure curve (kPa/^{0}C), γ is a psychrometer constant (kPa/^{0}C), h_0 is the net radiation (MJ/m^2), G is the soil heat flux (MJ/m^2), HV is the latent heat of vaporization (MJ/kg), $f(V)$ is a wind speed function (mm/d/kPa), ea is the saturation vapor pressure at mean air temperature (kPa), and is the vapor pressure at mean air temperature (kPa). The latent heat of vaporization is calculated by the temperature function

$$HV = 2.50 - 0.0022T$$

where T is the mean daily air temperature (^{0}C). The saturation vapor pressure is estimated as a function of temperature by using the equation below

$$e_a = 0.1 \exp\left(54.88 - 5.03 \ln(T + 273) - \frac{6791}{T + 273}\right)$$

The vapor pressure is calculated by considering the saturated value and the relative humidity.

$$e_d = (e_a)\,(RH)$$

the parameter RH is the relative humidity expressed as a fraction. The slope of the saturation vapor pressure curve is calculated using the equation

$$\delta = (\frac{e_a}{T + 273})\,(\frac{6791}{T + 273} - 5.03)$$

The psychrometer constant is estimated with the equation $\gamma = 6.6 \text{ X } 10^{-4}$ PB where PB is the barometric pressure (kPa). The barometric pressure is estimated as a function of elevation by using the equation

$$PB = 101 - 0.0115\ ELEV + 5.44\ X\ 10^{-7}\ ELEV^2$$

where ELEV is the site elevation (m). The soil heat flux is calculated by using air temperature on that day under consideration plus 3 days prior.

$$G = 0.12 \left(T_i - (\frac{T_{i-1} + T_{i-2} + T_{i-3}}{3}) \right)$$

the parameter T is the mean daily air temperature on day i (^{0}C). Solar radiation is adjusted to calculate net radiation by using the equation

$$h_{0i} = RA_i\ (1.0 - AB_i) - RAB_i\ (\frac{0.9\ RA_i}{RAMX_i} + 0.1)$$

the parameter RA is the solar radiation (MJ/m^2), AB is albedo, RAB is the net outgoing long wave radiation (MJ/m^2) for clear days, and $RAMX$ is the maximum solar radiation possible (MJ/m^2) for the location on day i.

Penman method consider the soil, crop, and snow cover to estimate the albedo. For a snow cover with 5mm or greater water content, the value of albedo is set to 0.6. If the snow cover happen to be less than 5mm and no crop is growing, the soil albedo value is used. During the normal crop growth the albedo is determined by using the equation

$$AB = 0.23\ (1.0 - EA) + (AB_s)\ (EA)$$

where 0.23 is the albedo for plants, Abs is the soil albedo, and EA is a soil cover index. The value of EA ranges from 0 to 1.0 according to the equation

$$EA = \exp(-0.1\,CV)$$

the parameter *CV* is the sum of the above ground biomass and crop residue (t/ha). The solar radiation *RAB* value is estimated with the equation

$$RAB_i = 4.9\ X\ 10^{-9}\ (0.34 - 0.14\sqrt{e_d})\ (T_i + 273)^4$$

The maximum possible solar radiation is computed with the equations

$$RAMX = 30\left(1.0 + 0.0335\sin[\frac{2\pi}{365}(i + 88.2)]\left(XT\sin(\frac{2\pi}{360}LAT)\sin(SD) + \cos(\frac{2\pi}{360}LAT)\cos(SD)\sin(XT)\right)\right)$$

$$XT = \cos^{-1}\left(-\tan(\frac{2\pi}{360}LAT)\tan(SD)\right) \qquad 0 \le XT \le \pi$$

where *LAT* is the latitude of the site in degrees, *SD* is the sun's declination angle (radians), and *i* is the day of the year. The sun's declination angle is calculated with the equation

$$SD_i = 0.4102\sin[\frac{2\pi}{365}(i - 80.25)]$$

The wind function of the Penman equation is estimated with the relationship

$$f(V) = 2.7 + 1.63\,V$$

where V is the mean daily wind sped at a 10 m height (m/s).

3.1.1.2.2 Soil and Plant Evaporation

EPIC model computes evaporation from soil and plants separately by using Ritchie (1972) approach. The potential plant water evaporation is estimated with the equations

$$E_p = \frac{(E_0)\,(LAI)}{3.0} \qquad 0 \le LAI \le 3.0$$

$$E_p = E_0, \qquad LAI > 3.0$$

where E_p is the predicted plant water evaporation rate (mm/d).

The equation used to estimate the potential soil water evaporation based on soil cover is given below

$$E_s = \min[\,(E_0)\,(EA),\, E_0 - E_p\,]$$

where E_s is the potential soil water evaporation rate (mm/d)

The top 0.2 m of soil and snow cover is used to estimate the actual soil water evaporation. The snow is evaporated at the rate equals to potential soil water evaporation. The potential soil water evaporation begins after snow evaporation ends. The water evaporation is governed by soil depth and water content as presented by the equation

$$EV_z = E_s\left(\frac{\frac{Z}{0.2}}{\frac{Z}{0.2} + \exp[-2.92 - 1.43\,(\frac{Z}{0.2})]}\right)$$

the parameter *EV* is the total soil water evaporation (mm) from soil of depth *Z* (m). The difference between *EV*'s at the layer boundaries are used to estimate the potential soil water evaporation for a layer

$$SEV_l = EV_{z(l)} - EV_{z(l-1)}$$

where *SEV* is the potential soil evaporation for layer *l* (mm).

If the soil water is limited in a layer the depth distribution estimate of the soil water evaporation is reduced by the formula

$$SEV_l^* = SEV_l \exp\left(\frac{2.5\,(SW_l - FC_l)}{FC_l - WP_l}\right), \qquad SW_l < FC_l$$

where SEV^*_l is the adjusted soil water evaporation estimate (mm).

$$SEV_l^* = SEV_l, \qquad SW_l \geq FC_l$$

The equation below is used to adjusting the evaporation estimate to assure that the soil water supply is adequate to meet the demand:

$$SEV_l^* = \min(SEV_l^*, SW_l - 0.5\,WP_l)$$

3.1.1.3 Snowmelt

Snow is melted on days when the maximum temperature exceeds 0.0 ^{0}C by using the equation

$$SML = 4.57\, T_{\max}\,, \qquad\qquad SML < SNO$$

where *SML* is the snowmelt rate (mm/d), T_{mx} is the daily maximum air temperature (^{0}C), and *SNO* is the snow water content before melting (mm). During calculation the melted snow is treated the same as rainfall for the calculation of runoff volume and deep drainage or recharge, but rainfall energy is set to 0.0 and peak runoff rate is calculated by assuming that in a 24h duration the rainfall was uniformly distributed.

3.1.1.4 Plant Water Use

In 1972 Ritchie develop a plant water use equation, E_p, as a fraction of the potential evaporation by using the leaf-area-index relationship

$$Ep_i = E_{0i}\,(\frac{LAI_i}{3}), \qquad\qquad E_{pi} \leq E_{0i}$$

the parameter E_0 is the potential evaporation and *LAI* is the leaf area index on day *i.* The potential water use from the soil surface to the root depth is calculated using the formula

$$Up_i = \frac{Ep_i}{1.0 - \exp(-\Lambda)}\left(1.0 - \exp[-\Lambda\,(\frac{Z}{RZ})]\right)$$

where U_p is the total water use rate (mm/day) to depth Z (m) on day i, RZ is the root zone depth (m), and Λ is a water use distribution parameter. The amount used in a layer can be estimated by taking the difference between U_{pi} values at the layer boundaries.

$$u_{pl} = \frac{E_{pi}}{1 - \exp(-\Lambda)} \left(\left(1 - \exp[-\Lambda\, (\frac{Z_l}{RZ})] \right) - \left(1 - \exp[-\Lambda\, (\frac{Z_{l-1}}{RZ})] \right) \right)$$

where u_{pl} is the potential water use rate from layer l (mm/d). This equation applies to a soil that provides poor conditions for root development when Λ is set to high value as 10. The high Λ value gives high water use near the surface and very low use in the lower part of the root zone. Based on this equation there is no provision for water deficiency compensation in a layer, if the above equation is used the water stress may be incorrect. To correct this problem, the above equation was modified to allow plants to compensate for water deficiency in a layer by using more water from other layers. Total compensation can be accomplished by taking the difference between U_{pi} at the bottom of a layer and the sum of water use above a layer.

$$u_{pl} = \frac{E_{pi}}{1 - \exp(-\Lambda)} \left(1 - \exp[-\Lambda\, (\frac{Z_l}{RZ})] \right) - \sum_{K=1}^{l-1} u_k$$

where u_k is the actual water use rate (mm/d) for all layers above layer l. Thus, any deficit can be overcome if a layer above that is encountered has adequate water storage.

Both of these two equations are inadequate to simulate a wide range of soil conditions. A combination of these two equations can provide a better calculation of water use.

$$u_{pl} = \frac{E_{pi}}{1 - \exp(-\Lambda)} \left(1 - \exp[-\Lambda\,(\frac{Z_l}{RZ})] - (1 - UC)\left(1 - \exp[-\Lambda\,(\frac{Z_{l-1}}{RZ})] \right) \right) - UC \sum_{k=1}^{l-1} u_k$$

where *UC* lies between a range (0. and -1.) and is the water deficit compensation factor. A soils with a good rooting environment, *UC*=1. for total compensation. The other extreme, poor conditions allow no compensation (*UC*=0)

When the soil water is less than 25% of plant available soil water the potential water use in each soil layer simulated by the above equation is reduced by the equation below

$$u_l = u_{pl}\ \exp\left(5.\left(\frac{4\,(SW_{li} - WP_l)}{(FC_l - WP_l)} \right) \right), \quad \text{if} \quad SW_l < \frac{FC_l - WP_l}{4} + WP_l$$

$$u_l = u_{pl}\ , \quad \text{if} \quad SW_l \geq \frac{FC_l - WP_l}{4} + WP_l$$

where *SW* is the soil water content in layer *l* on day *i* (mm) and *FC* and *WP* are the soil water contents at field capacity and wilting point for layer *l*.

3.1.1.5 Biomass Production

The daily potential increase in biomass is calculated by the following formula;

$$\Delta B_{p,i} = 0.001\,(BE)_j\,(PAR)_i\,(1 + \Delta HRLT_i)^3$$

where ΔB_p is the daily potential increase in biomass (t/ha), *BE* is the crop parameter for converting energy to biomass (kg/MJ), *PAR* is the photosynthetic active radiation (MJ/m^2), *HRLT* is the daily length (h), and $\Delta HRLT$ is the change in daily length (h/d). There is more biomass produced during the spring than during the fall season.

The photosynthetic active radiation is calculated by the equation;

$$PAR_i = 0.5\,(RA)_i\,[1 - \exp(-0.65\,LAI)]_i$$

where *RA* is the solar radiation (MJ/m^2), *LAI* is the leaf area index, and the subscript *i*, is the day of the year.

The day length is calculated by the formula

$$HRLT_i = 7.64\cos^{-1}\left(-\tan(\frac{2\pi}{365}LAT)\tan(SD)_i\right)$$

where *LAT* is the latitude of the watershed measured in degrees and *SD* is the sun declination angle defined by equation

$$SD_i = 0.4102\sin\left[\frac{2\pi}{365}(i - 80.25)\right]$$

The leaf area index (*LAI*) is initially zero and it increases as the plant grow. The *LAI* is simulated as a function of heat units, crop development stage and crop stress. The general equation for the *LAI*

$$LAI_i = LAI_{i-1} + \Delta LAI$$

$$\Delta LAI = (\Delta HUF)\,(LAI_{mx})\,\left(1 - \exp\left[5\,(LAI_{i-1} - LAI_{mx})\right]\right)\sqrt{REG_i}$$

LAI is the leaf area index, *HUF* is the heat unit factor, and *REG* is the value of the minimum crop stress factor. Subscript *mx* is the maximum value and Δ is the daily change.

To compute the heat unit factor the following equation is used

$$HUF_i = \frac{HUI_i}{HUI_i + \exp\left[ah_{j,1} - (ah_{j,2})\,(HUI_i)\right]}$$

where $ah_{j,1}$ and $ah_{j,2}$ are parameters of crop j, and HUI is the heat index.

The *HUI* can be calculated by the following formula

$$HUI_i = \frac{\left(\sum_{k=1}^{i} HU_k\right)}{PHU_j}$$

where *HUI* is the heat unit index for day *i* which range between 0 at planting to 1 at maturity. *PHU* is the potential heat unit required for the maturation of crop *j*. This value can be inputted or calculated by EPIC model. *HU* is the daily heat unit accumulation. It can be calculated by using the following formula.

$$HU_k = \left(\frac{T_{mx,k} + T_{mn,k}}{2} \right) - T_{b,j} \quad , \qquad\qquad HU_k \geq 0$$

where HU, T_{mx}, and T_{mn} are the value of heat units, maximum temperature, and minimum temperature (^{0}C) on day k, and T_b is the crop-specific base temperature (^{0}C) and no growth occurs at or below T_b of crop j.

3.1.1.6 Deep Drainage or Percolation

To simulate flow through soil layer and estimate the deep percolation or recharge to the groundwater the EPIC model uses a storage routing technique. Water leaves a soil layer when soil water content exceeds field capacity. Water continues to drains from the soil layer until the storage returns to field capacity. Recharge from a soil layer is simulated with the routing equation.

$$SW_l = (SW_{ol} - FC_l)\exp(-\Delta t / TT_l) + FC_l$$

where SW and SW_0 are the soil water contents at the end and the start of time interval Δt (24 h) and TT is travel time through layer l (h).

The daily percolation can be computed by taking the difference between SW and SW_0

$$O_l = (SW_{ol} - FC_l)\,[1.0 - \exp(\frac{-\Delta t}{TT_l})]$$

where O is the percolation rate for layer l given in mm/d.

The linear storage equation is used to compute travel time through a layer

$$TT_l = \frac{PO_l - FC_l}{SC_l}$$

where *PO* is the porosity (mm), *FC* is field capacity (mm), and *SC* is saturated conductivity, which means the rate of water drainage through a saturated layer (mm/h).

To estimate the deep percolation the routing technique is applied starting from the soil surface layer following the next layer through the deepest layer. If the saturated conductivity of some layers results to much lower than that of others, the routing scheme can lead to an impossible situations. If that situation happens , a back pass process starts from the bottom layer and if a layer’s porosity is exceeded, the excess water is transferred to the layer above it. This process continues through the top layer.

The calculation of saturated conductivity may be estimated from each soil layer by using the equation

$$SC_l = \frac{12.7\ (100 - CLA_l)\ (SS_l)}{100 - CLA_l + \exp[11.45 - 0.097\ (100 - CLA_l)]}$$

where *CLA* is the percentage of clay in soil layer *l* and *SS* is the soil strength factor. During freezing conditions water can flow into a soil layer but no percolation or recharge from the layer is allowed.

3.1.1.7 Lateral Subsurface Flow

The lateral subsurface flow is calculated simultaneously with deep drainage/percolation. The lateral flow is simulated by the equation

$$QR_l = (SW_{0l} - FC_l)\,[1.0 - \exp(\frac{-1.0}{TT_{Rl}})]$$

where SW_{0l} is the initial soil water content of soil layer *l*, *FCl* is the field capacity, *QR* is the lateral flow rate soil layer *l* (mm/d) and TT_{Rl} is the lateral flow travel time *(d)*.

The lateral flow travel time is estimated for each soil layer by using the following function

$$TT_{Rl} = \frac{1000\,(CLA_l)\,(SS_l)}{CLA_l + \exp(10.047 - 0.148\,CLA_l)} + 10$$

Both deep drainage and lateral flow equation must be solved simultaneously to avoid one process dominating the other. An equation for the sum of deep drainage and lateral flow is written as

$$O_l + QR_l = (SW_{0l} - FC_l)\left(1.0 - \exp(\frac{-\Delta t}{TT_l})\,\exp(\frac{-1.0}{TT_{Rl}})\right)$$

Taking the ratio of *QR/O* and substituting the resulting *QR* into equation above this lead to the following equation

$$O + O\left(\frac{1.0 - \exp(\frac{-1.0}{TT_{Rl}})}{1.0 - \exp(\frac{-\Delta t}{TT_l})}\right) = (SW_{0l} - FC_l)\left(1.0 - \exp(\frac{-\Delta t}{TT_l})\exp(\frac{-1.0}{TT_{Rl}})\right)$$

Solving for *O*, the deep drainage the final equation will result to the equation below;

Deep Drainage,

$$O = \frac{(SW_{0l} - FC_l)\left(1.0 - \exp(\frac{-\Delta t}{TT_l})\exp(\frac{-1.0}{TT_{Rl}})\right)\left(1.0 - \exp(\frac{-\Delta t}{TT_l})\right)}{2.0 - \exp(\frac{-\Delta t}{TT_l}) - \exp(\frac{-1.0}{TT_{Rl}})}$$

The deep drainage *O,* value calculated above is then submitted to the equation for the sum of deep drainage and lateral flow ($O_l + QR_l$) to obtain the final estimates for lateral flow *QR*.

[All equations from EPIC Model Documentation, Sharpley et al., 1990]

3.1.2 ArcAEM and SPLIT models

ArcAEM ,ArcGIS, and groundwater flow simulator SPLIT were used for the development of a groundwater mode for Konza prairie (see Figure 3.3).

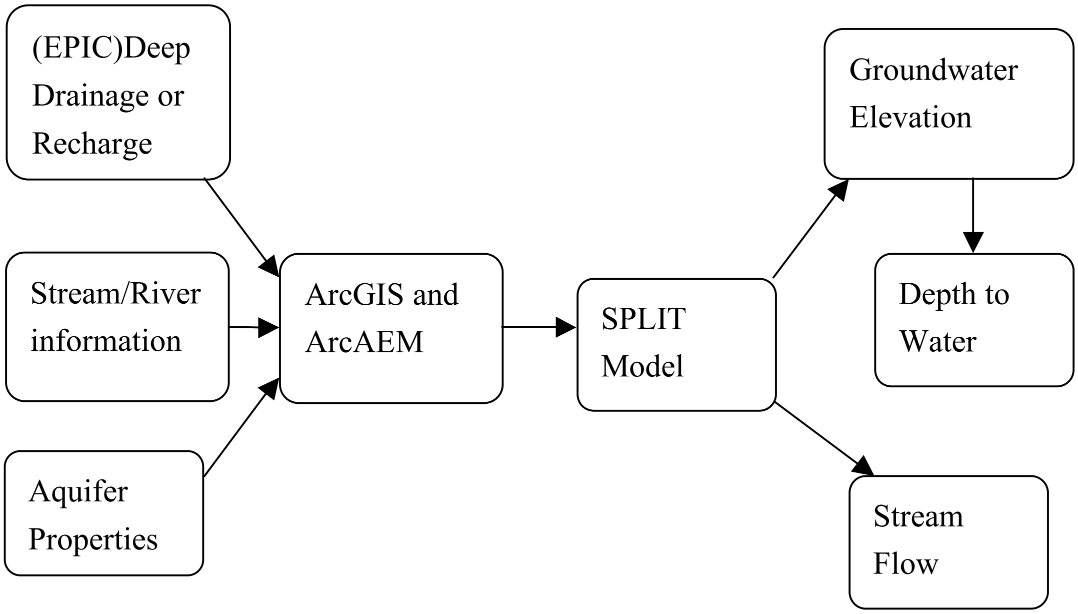

Figure 3.3. Input and output data for SPLIT groundwater model

SPLIT uses the Analytic Element Method (AEM) to simulate steady-state groundwater flow in a saturated single layer aquifer. ArcAEM is developed using Visual Basic and ArcObjects. The Analytic Element Method (AEM) represent real hydrologic objects as vectors; points, lines, or polygons. Representing hydrologic features as vectors provide a good representation of the actual object from the real world. Results for deep drainage obtained from EPIC ecologic model, stream information, and aquifer properties are combined together using ArcGIS and ArcAEM tools to create the input file for SPLIT. The SPLIT model uses Analytical Element Method to estimate groundwater head and stream recharge and discharge.

Steps involved in building a Groundwater Model using AEM

- Preparation of the hydrologic features to be included in the model
- Convension of features into analytic elements by adding appropriate element specific attribute fields to the geometries.
- Edit the element specifications for the analytic elements
- Assign aquifer parameters and other general information required by SPLIT
- Enter observation data for model calibration
- Execute Split
- Import the results from SPLIT into ArcGIS and create groundwater elevation maps and other maps as required.
- Adjust model parameters based on SPLIT results and re-execute the model as desired

3.1.2.1 Analytical Element Method

Analytical Element Method is a technique developed to solve partial differential equations for infinite or finite domains. Steps involved are

i.) The first step is to discretize boundaries within the domain into a set of analytical elements with defined geometry. The element can be geometrically points, lines or polygons

ii.) Second step is to develop a mathematical equation for the fundamental solution of the governing partial differential equation and its derivatives

iii.) Third step is to distribute the fundamental solution and/or its derivatives along the boundary of line elements and along the boundary or within the polygon elements.

iv.) The last step is to solve unknown strength coefficient to satisfy the boundary conditions.

3.1.2.1.1 Equations

The equations used in the formulation of the groundwater model were based on two- dimension unconfined aquifer with recharge values calculated from EPIC. Table 2 presents symbols used in EPIC equations and their description and units.

Table 2. Notations and units used in the two dimension groundwater formulas

Notations		
Symbols	Units	Description
q	m/d	Unit discharge
Q	m^3/d	Discharge
A	m^2	Cross section area
ø	m	Aquifer head
N	m/d	Recharge
Φ	m^3/d	Aquifer potential
k	m/d	Aquifer hydraulic permeability
H	m	Aquifer thickness
B	m	Aquifer base
Q_x	m/d	Discharge along x-axis
Q_y	m/d	Discharge along y-axis
k^*	m/d	Stream to aquifer hydraulic permeability
c^*	d	Stream to aquifer resistance
b^*	m	River bed thickness
ø*	m	Stream head
q_z	m/d	Stream inflow or outflow vs aquifer
Ψ	m^3/d	Stream function
Ω		Complex function

σ		Strength for line sink
W		Complex vector field
α	Degrees	Orientation angle
S_m		Strength for the line dipole
Z	m	Local coordinate
v_n	m/d	Normal component of vector field
V	m/d	Velocity in local coordinate
z		Cartesian coordinate

Basic equations;

Darcy's Law

Aquifer specific discharge $q = \frac{Q}{A} = -k(\frac{\partial \phi}{\partial l})$ where Q is the Discharge, A is the aquifer cross section area, *k* is the hydraulic permeability, and $\frac{\partial \phi}{\partial l}$ is the slope in the direction of flow.

Vertical fluxes from surface water to groundwater is modeled using the equation

$q_z = -k^* \left(\frac{-\phi + \phi^*}{b^*} \right)$ where q_z is the stream inflow or outflow, k* is the stream bed hydraulic permeability, ø* is the stream head, ø is the aquifer head, and b* is the river bed thickness

$q_z = \frac{-\phi^* - \phi}{c^*}$, but $c^* = \frac{b^*}{k^*}$ where c^* is the river or stream bed resistance.

Continuity Equation

The continuity of flow is given be equation

$\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = -N$,where *N* is the recharge varying with location

For the two dimension flow with deep drainage or recharge equation can be wrote as;

$$\frac{\partial^2\Phi}{\partial x^2} + \frac{\partial^2\Phi}{\partial y^2} = \nabla^2\Phi = -N$$

where operator ∇^2 stands for $\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$, N is the deep percolation rate which is a function of position and Φ is the potential.

Potential, $\Phi = \frac{1}{2}k(\phi - B)^2 + \Phi_0$

Where ϕ is the head at any point, B is the base of the aquifer and Φ_0 is the initial potential with a known value.

$\Phi_0 = \frac{1}{2}k(\phi_0 - B)^2$, where ϕ_0 is the initial head with a known value.

Discharge Q in a two dimension case is given by the following equations

$Q_x = -\frac{\partial\Phi}{\partial x}$ and $Q_y = \frac{\partial\Phi}{\partial y}$, where Q_x is a discharge along x-axis and Q_y is along y-axis

The *Laplace Equation* for two dimensional vector fields in complex form

$$\frac{\partial^2\Omega}{\partial x^2} + \frac{\partial^2\Omega}{\partial y^2} = -N$$

where the potential, Φ, and stream function, Ψ, are equal to the real and imaginary part of

$\Omega = \Phi + i\Psi$.

Line-Sink Element

A stream or a river is modeled by using line sinks; a line sink is a distribution of point sinks along a line. A line sink element is formed by placing fundamental solutions along the straight line connecting points along the line as z_l and z_{l+1}. Where z = x + iy. These points can be transferred to a local Z-coordinates using a distribution of point-sinks along the X – axis from X = -1 to 1.

This transformation is performed by the following formula;

$$Z = X + iY = \frac{z - \frac{1}{2}(z_1 + z_2)}{\frac{1}{2}(z_2 - z_1)}$$

The general expressions for a straight line-sink of polynomial strength is given by

$$\Omega = \sum_{m=1}^{n} \frac{\sigma}{2\pi} \ln(z - \delta_m)\Delta\xi$$

Where n is the number of uniformly spaced row of wells, Δξ is the distance between the wells, m indicate the mth well, located at z = δ_m, and σ is the strength of each well.

If we limit, $\Delta\xi \to 0$ *and* $n \to \infty$, the sum of all wells in a line will become

$$\Omega = \int_{-L}^{L} \frac{\sigma}{2\pi} \ln(z - \delta) d\xi$$

Solving the above integral, we will obtain a representation of a complex potential for a line sink of strength σ, and length *2L*, in the local complex variable Z as the following equation;

$$\Omega(Z) = \sum_{m=0}^{M} \frac{\sigma_m}{2\pi} \frac{1}{m+1} \left[Z^{m+1} \ln\frac{Z+1}{Z-1} + (-1)^m \ln(Z+1) + \ln(Z-1) - \sum_{j=\frac{1}{2}}^{\frac{m+1}{2}} \frac{Z^{m+1-2j}}{j} \right]$$

Line sink produces a vector field where Φ is continuous across the element and Ψ jumps. The normal component of the vector field v_n jumps by S.

An expression for the complex vector field for the line sink in local coordinates is given by the formula, $W = V_X + iV_Y = -\overline{\frac{d\Omega}{dZ}}$ is obtained by evaluating the derivative of the potential Ω

The general formula for the complex vector field is given as

$$W = -\sum_{m=0}^{M} \frac{\sigma_m}{2\pi} \left\{ \overline{ Z^m \ln\frac{Z+1}{Z-1} + \frac{1}{m+1}\left[\frac{Z^{m+1}-(-1)^{m+1}}{Z-(-1)} - \frac{Z^{m+1}-1}{Z-1} - \sum_{j=\frac{1}{2}}^{\frac{m}{2}} \frac{m+1-2j}{j} Z^{m-2j} \right] } \right\}$$

To obtain the vector field in physical coordinates we rotate and scale the local vector field by using the formula below

$w = W \times \frac{2}{\overline{z_{l+1} - z_l}} = \frac{W e^{-i\alpha}}{L}$, where the element is of length *2L* and orientation angle is α

Line doublet Element

Line doublets are used for boundaries across which aquifer parameters jumps (e.g) change in hydraulic conductivity or base elevation.

The line doublet element can be modeled using the equation below

$$\Omega(Z) = \sum_{m=0}^{M} \frac{iS_m}{2\pi} \left[Z^m \ln \frac{Z+1}{Z-1} - \sum_{j=1}^{\frac{m+1}{2}} \frac{2}{2j-1} Z^{m+1-2j} \right]$$

where Ω(Z) is the complex potential, S_m is the strength of the line doublet.

A line doublet produces a vector field where Φ jumps by an amount S and the normal component of the vector field continuous across the element.

An expression for the complex vector field for line doublet is given by the formula

$W(Z) = -\overline{\frac{d\Omega}{dZ}}$, where *W(Z)* is the complex vector field

$$W(Z) = \sum_{m=0}^{M} \frac{iS_m}{2\pi} \overline{\left(mZ^{m-1} \ln \frac{Z+1}{Z-1} + \frac{(-1)^m}{Z+1} - \frac{1}{Z-1} - m \sum_{j=1}^{\frac{m}{2}} \frac{2}{2j-1} Z^{m-2j} \right)}$$

3.2 DATA PREPARATION

3.2.1 Existing soils in Konza and its surroundings

Konza area is located near the border of three counties in Kansas; Riley, Wabaunsee, and Geary (see Figure 3.4). Our intension is to develop the regional groundwater model for Konza and its surroundings. To achieve this goal our study area was extend beyond the boundary of Konza area. County level Soils data for Riley, Wabaunsee and Geary were downloaded from United States Department of Agriculture website known as Soil Data Mart, under Agricultural Resources Conservation Service sub title.

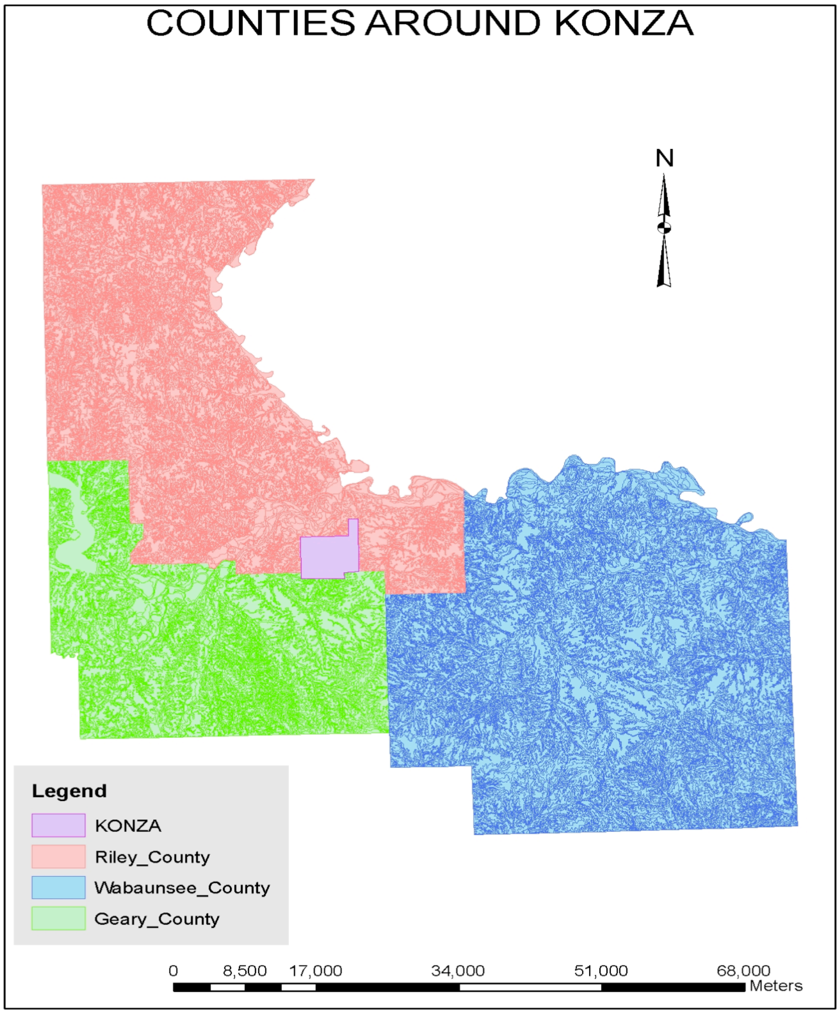

Figure 3.4. Location of Konza and the boundary of Riley, Wabaunsee and Geary Counties

Different format of data exists in this web page, the ones selected for this project were the tabular and spatial data and the other form was template database. Both data were brought in Arc Catalog and by using Microsoft access the geodatabase was populated with the tabular data. The soils shape files for the three counties were then brought to the Arc Map.

By using ArcMap Merge-tools these counties were all merge together. A new merged shape file was created. By using select tool a study area was selected from the shape file created after merge. A new shape file for all soils that exist within the study area was then created. See Figure 3.5. To connect the geodatabase with tabular data and the soils shape files, a tool called join table on the ArcMap was used. Another tool was also used to classify soils based on their name. Using name classification, different soils exist in this area some cover small area of land some cover big area of land.

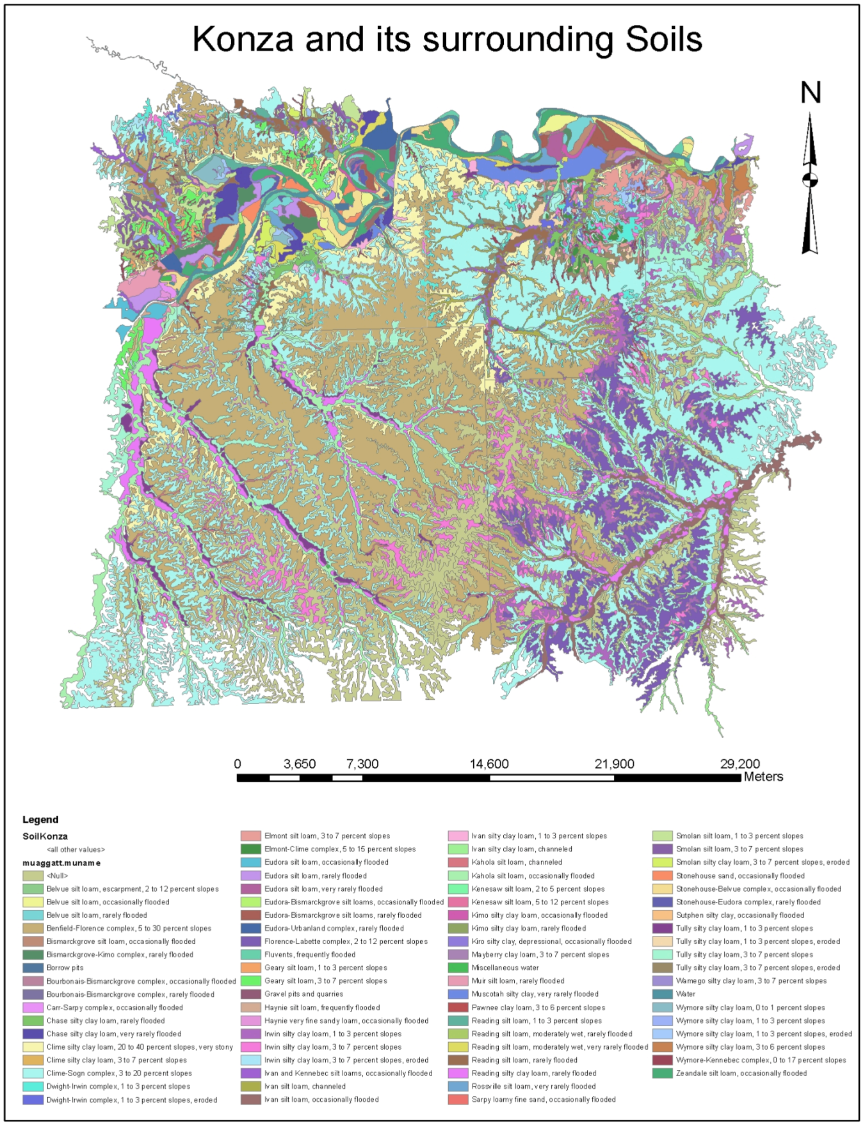

Figure 3.5. Names of all soils existing in Konza and around Konza

3.2.2 Classification of the soils into seven groups

This section presents and briefly describes the seven soil classes found in the study area. Based on soil texture and the percentage of surface slope, seven different soil groups were formed. These soil groups includes sand soil, complex with a slope greater than 3%, complex with a slope less than 3%, silt clay and silt clay loam with slope greater than 3%, silt clay and silt clay loam with the slope less than 3%, silt loam with slope greater than 3%, and silt loam with slope less than 3%. Figure 3.7, represent the location and the names of the soils groups. Table 3, represents the soil group name and surface percent slope.

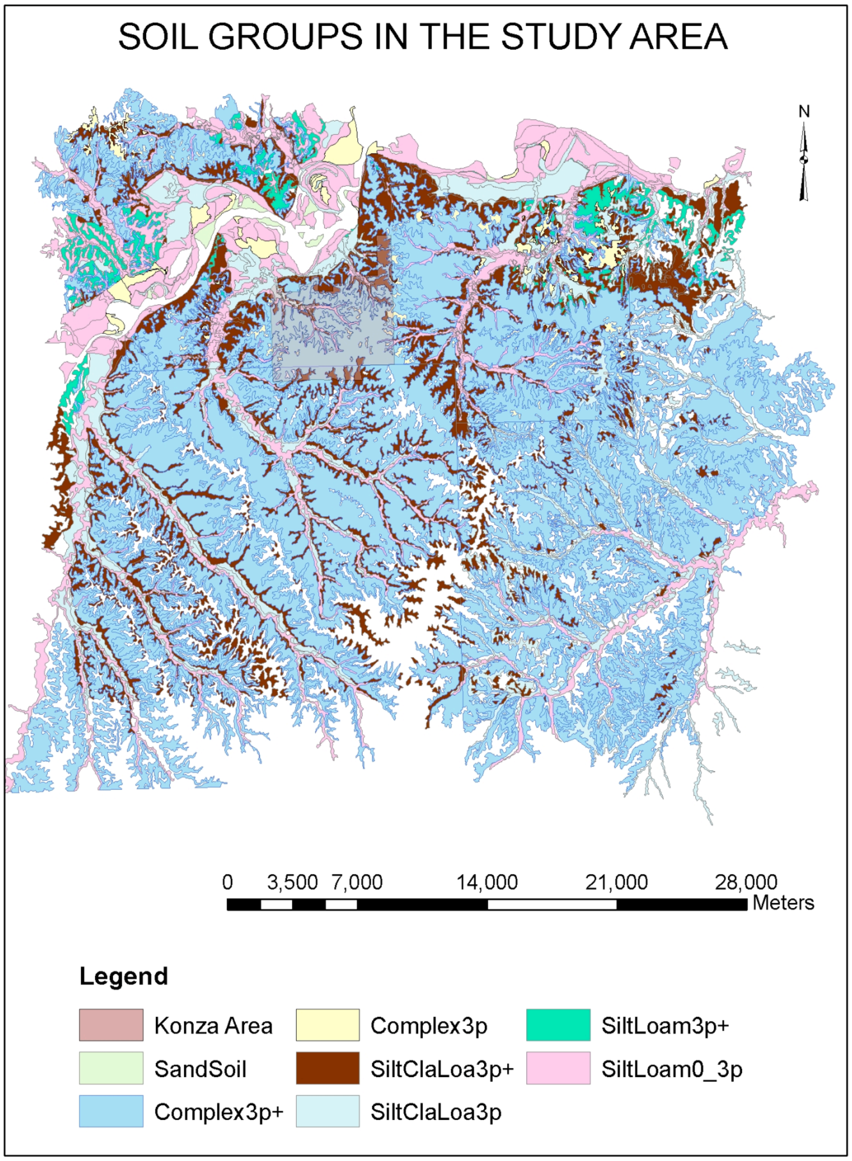

Figure 3.6. Classification of soils into seven groups

Using ArcMap tool called select by attribute, a new soil group was created. Other soil polygons with similar texture and percentage slope were added to this new soil group. After all soils with similar characteristics were added, a new shape files ware created. This procedure was repeated until all soils were classified. As a result seven soil groups which covers larger area of land were formed. Table 3, shows soil names based on their texture and their slope percentage.

Table 3. Soil names and their surface percentage slope

	Soil name	Slope percentage (%)
1	Silt loam	0 -3
2	Silt loam	>3
3	Silt Clay-Silt Clay Loam	0-3
4	Silt Clay-Silt Clay Loam	>3
5	Sandy Soils	
6	Complex	0-3
7	Complex	>3

The spatial location and the spatial area covered by silt loam soil with a percentage slope less than 3% is presented on Figure 3.7. From this figure it appears that silt loam with slope less than 3% in our study area is found in the low land areas and within the river valleys.

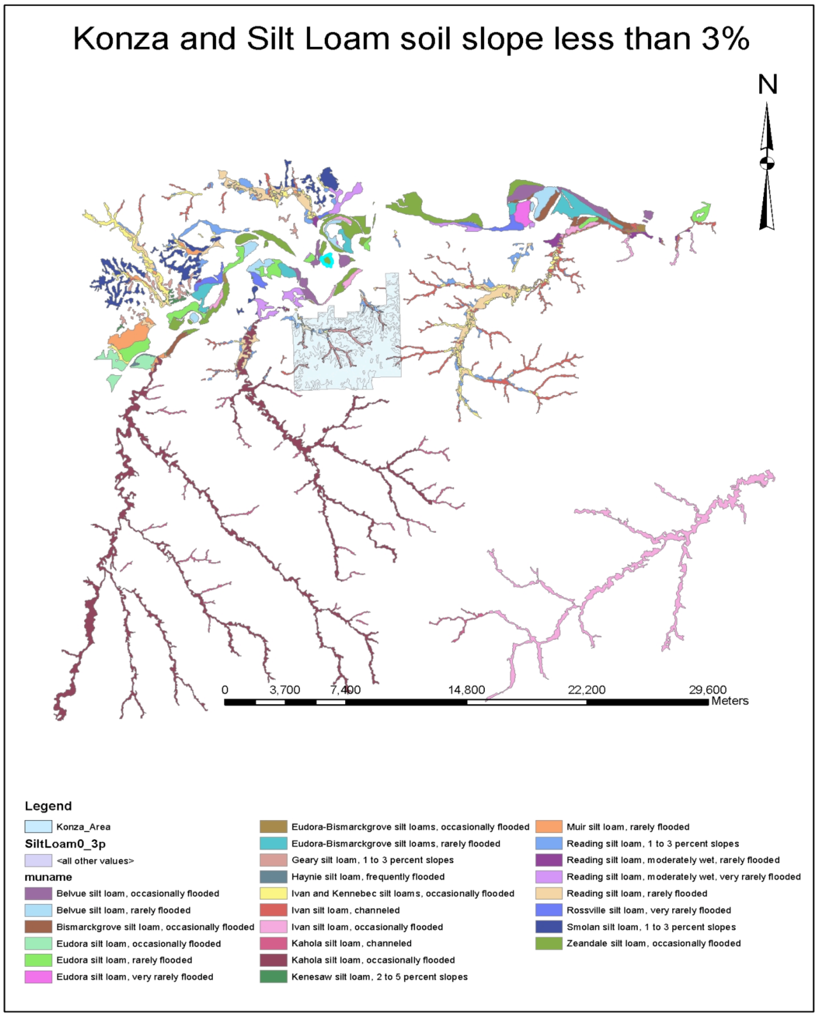

Figure 3.7. Silt loam Map with a percentage slope between 0 and 3%

This soil group is found in both small streams and in big river valleys including Neosho and Kansas River valley. Silt loam soil group with a percentage of slope greater than 3% scatter on the map (see Figure 3.8). Some of the soils in this group are appear to be located at the northwest and north east of our study area.

Figure 3.8. Silt loam soil with a percentage slope greater than 3%

The silt clay and silt clay loam with a percentage of slope less than 3% is found on the low land of our study area. It appears that both silt loam, silt clay and silt clay loam are found in the low land area and along river valleys. The spatial area covered by the silt clay and silt clay loam with slope less than 3%, in Figure 3.9, appear to be smaller compared to that covered by the silt loam with slope less than 3% see Figure 3.7.

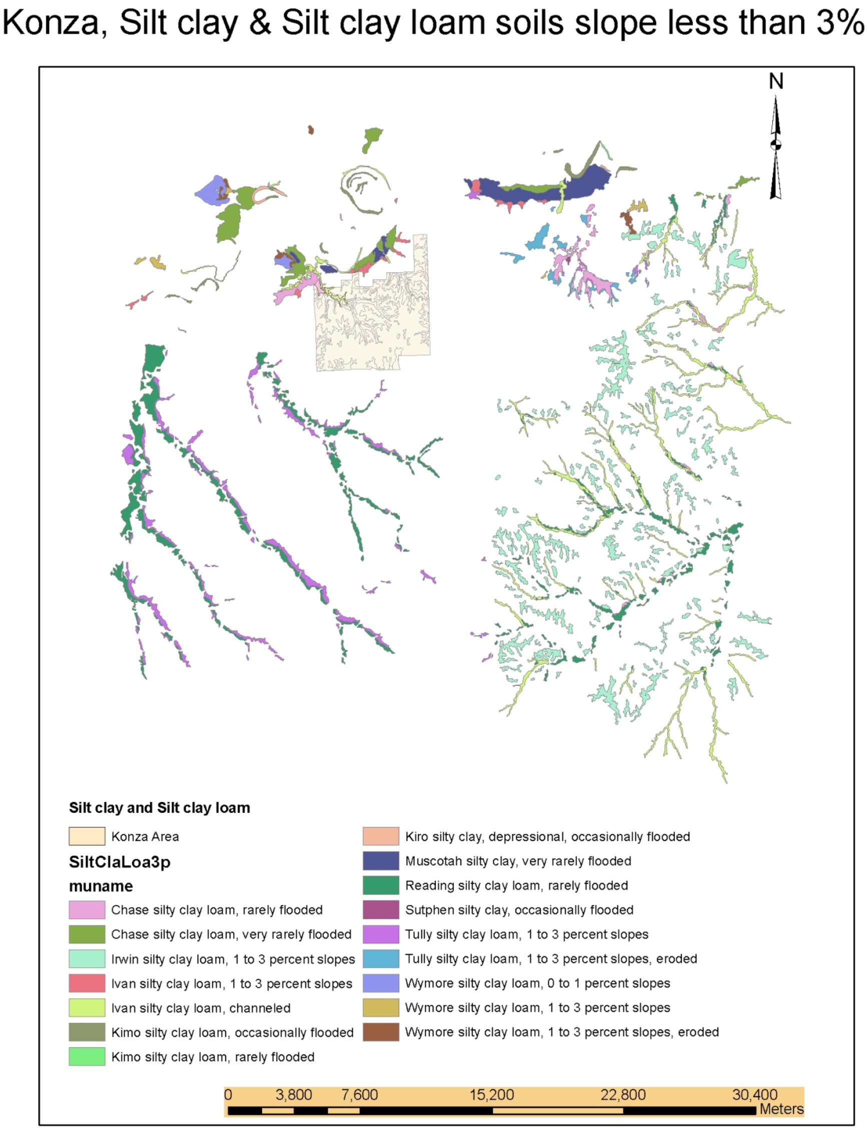

Figure 3.9. Silt Clay and Silt Clay Loam with percentage slope 0 to 3%

Silt clay and silt clay loam with slope greater than 3% is found along the slopes of the hills in the study area (see Figure 3.10). The soil names grouped in this group includes clime silt clay loam, Irwin silt clay loam, Mayberry clay loam, Pawnee clay loam, Smolan silt clay loam, Tully silt clay loam, Wamego silt clay loam and Wymore silt clay loam.

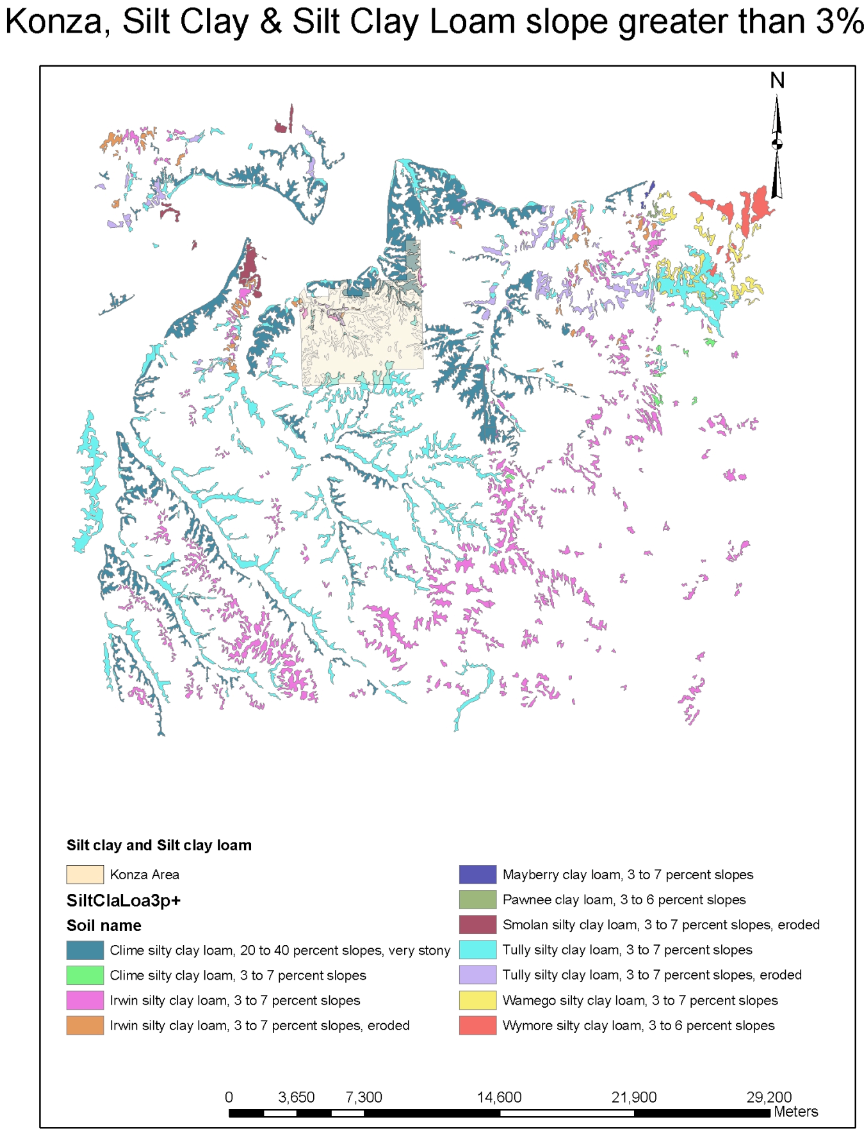
Konza, Silt Clay & Silt Clay Loam slope greater than 3%

Figure 3.10. Silt Clay and Silt Clay Loam with slope greater than 3%

Sand soils appear to be located in some small portion along Kansas River valley. Spatial area covered with sand soil appear to be smallest compare to other soil groups. See on Figure 3.11 no sand soil was located within Konza area.

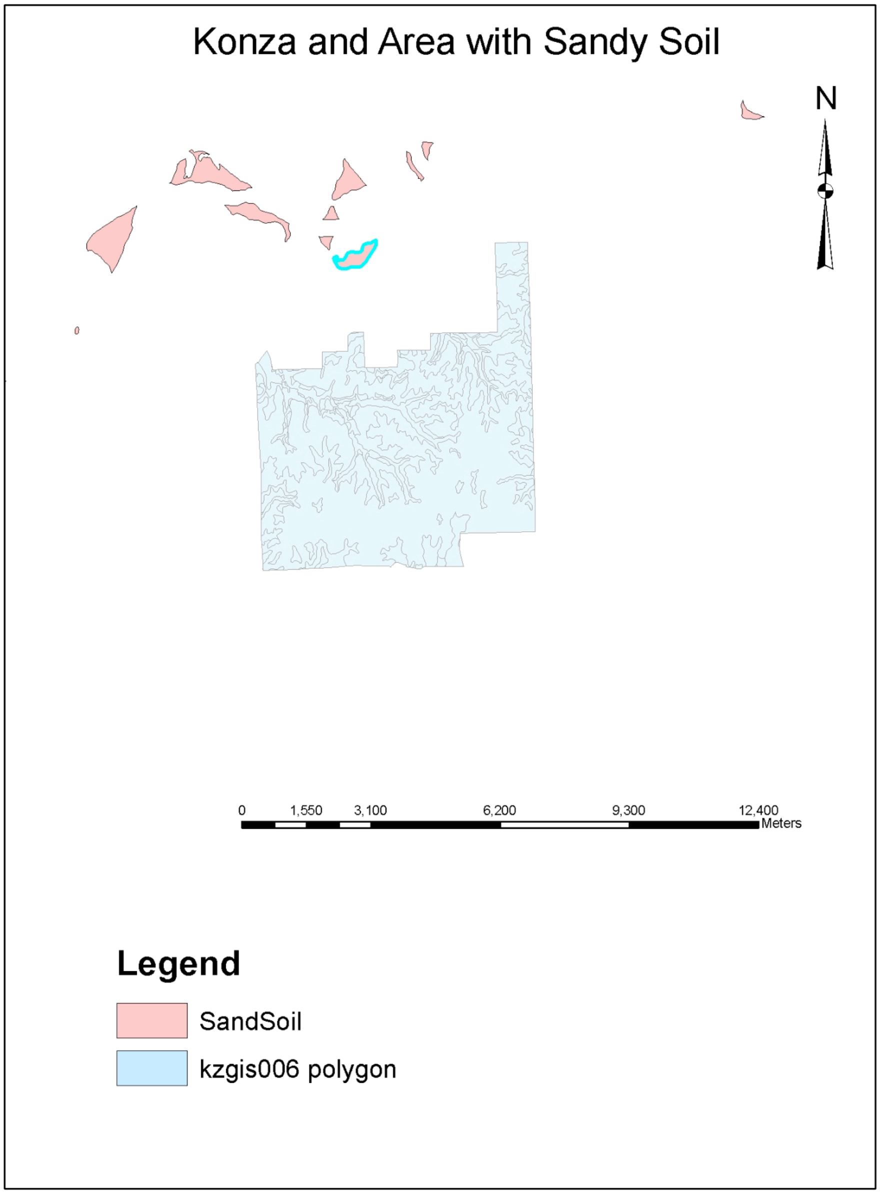

Figure 3.11. Sandy Soil

Complex soil with slope less than 3% is formed by small scattered polygons within and around Konza area (see Figure 3.12). Soil names within this group are Bismarckgrove-Kimo, Bourbonais, Carr-Sarpy, Dwight-Irwin, Eudora-Urbanland, Stonehouse-Eudora complex.

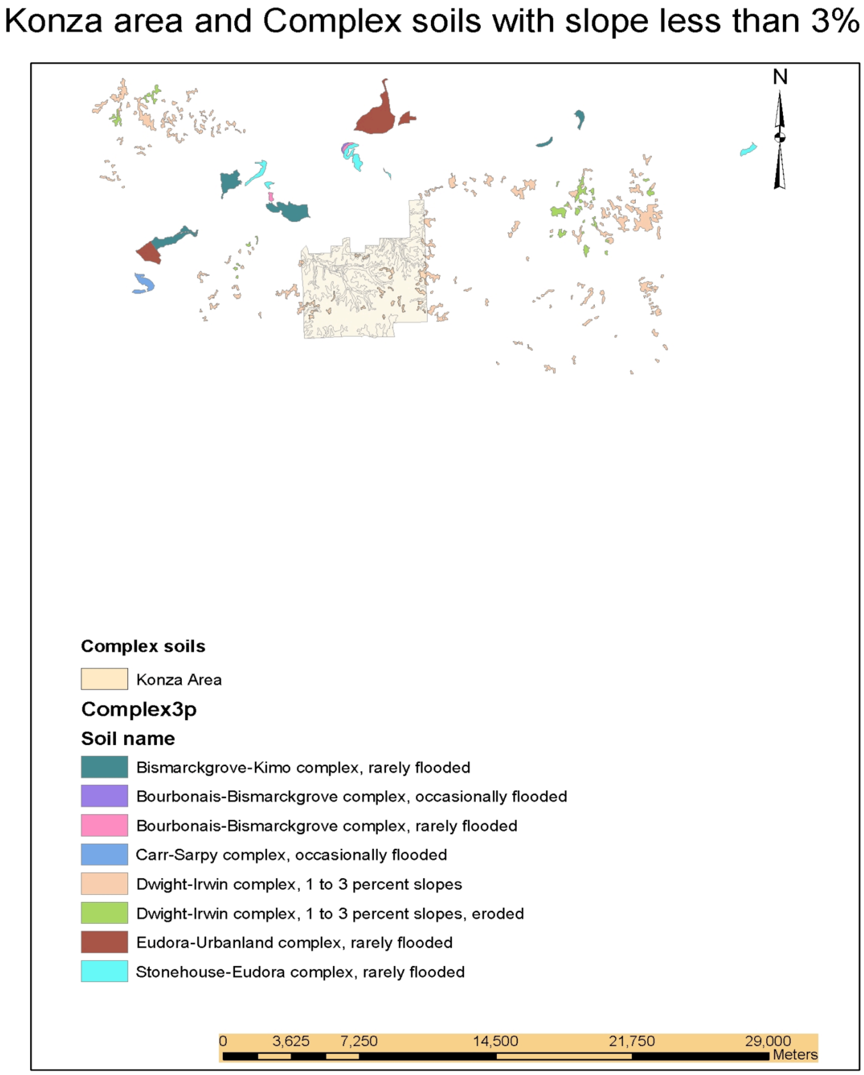

Figure 3.12. Complex soil with percentage slope 0 to 3%

The soil group complex with percentage slope greater than 3% is formed by Benfield-Florence complex, Clime-Sogn complex, Elmont-Clime complex, Florence-Labette complex and Wymore-Kennebec complex soil (see Figure 3.13). This group appears to be found on hill tops and along the hill slopes of the study area. The spatial area covered by this group appears to be larger than any of the previous soil groups.

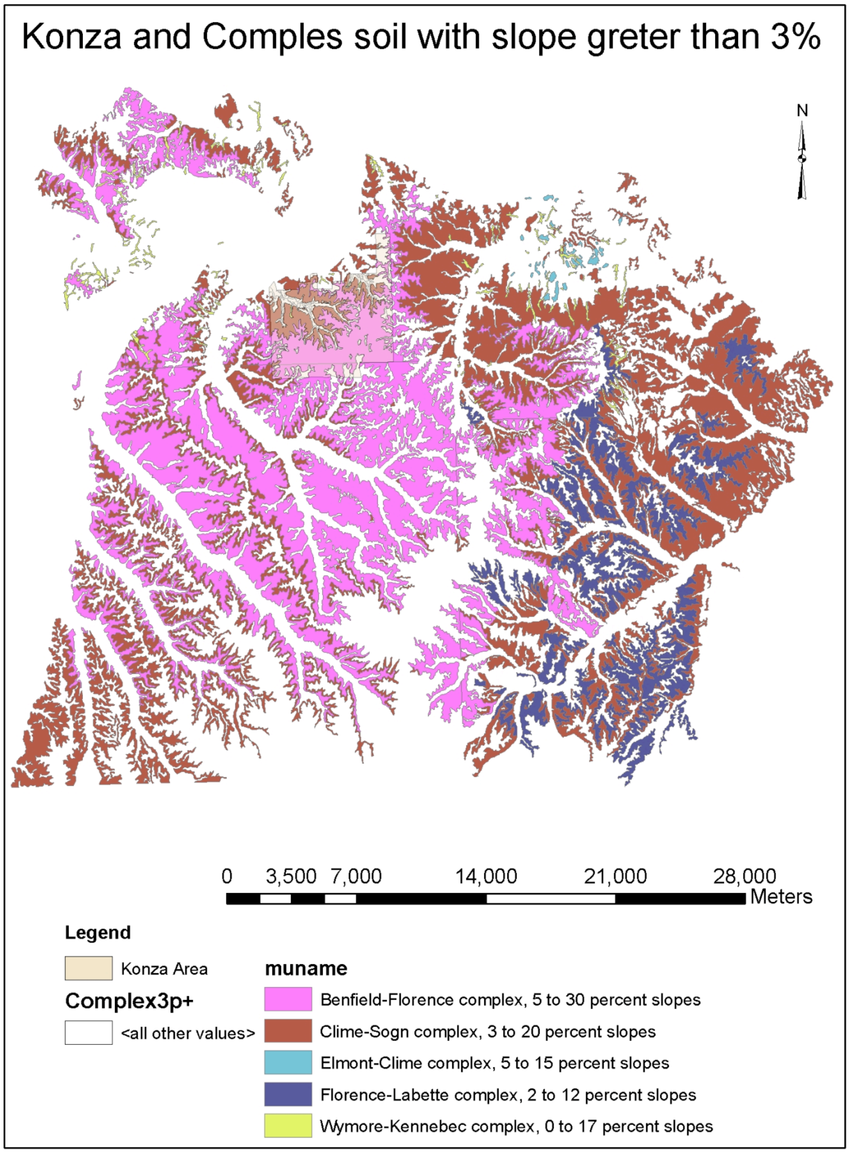

Figure 3.13. Complex soil group with slope greater than 3%

3.2.3 Selection of Dominant soil group

Through examining the spatial area of soil polygon covered by each soil group, (for all seven soil groups), it appears that some soils groups cover larger area of land and some cover small area of land. Complex soil group with slope greater than 3% cover the largest area of land than the rest. This soil group appears to dominate hilltops and hill slopes. Within this group several soils types exists. Examining the Complex group with slope greater than 3% three dominant soils were found. These soils are Clime, Benfield and Florence-Labbete (see Figure 3.14).

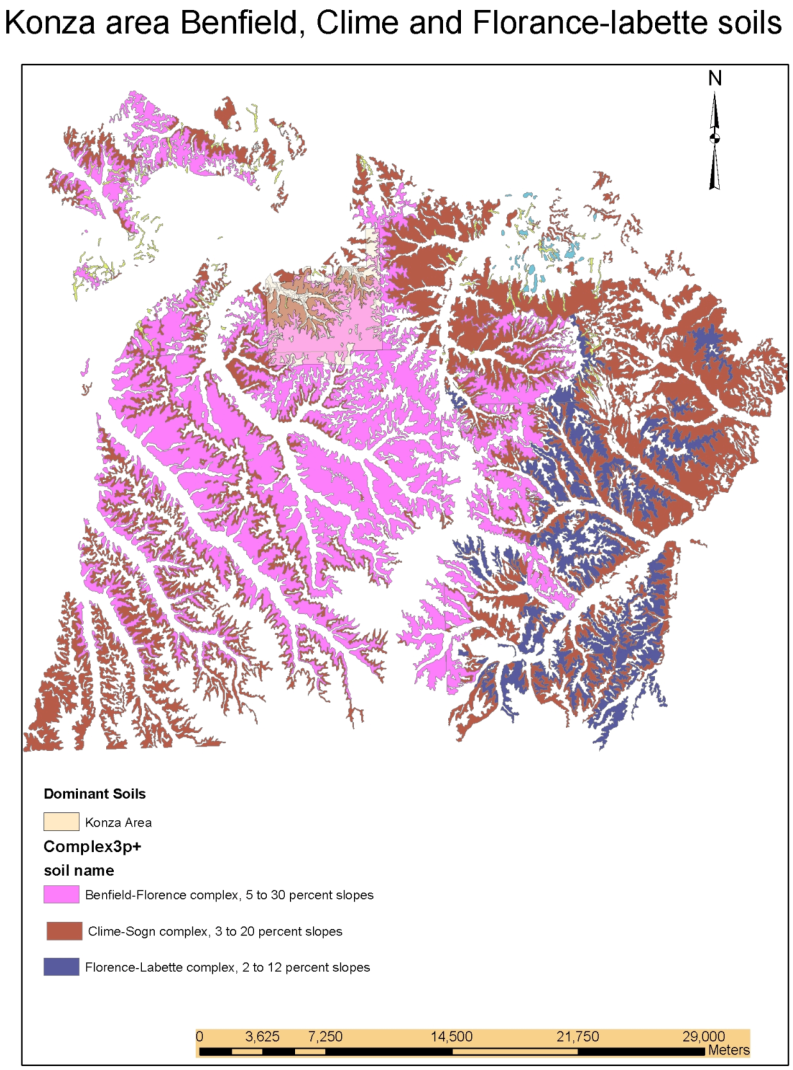

Figure 3.14. Dominant soils on the hill tops and along the hills slopes

On the other hand, the group with silt loam soil with slope less than 3%, found along the river valleys and low lands in Konza, appear to have different soil types that only covers small portions of land (Figure 3.7). Based on spatial area covered by each soil type no one soil type was found to standout as the dominant soil type in this group.

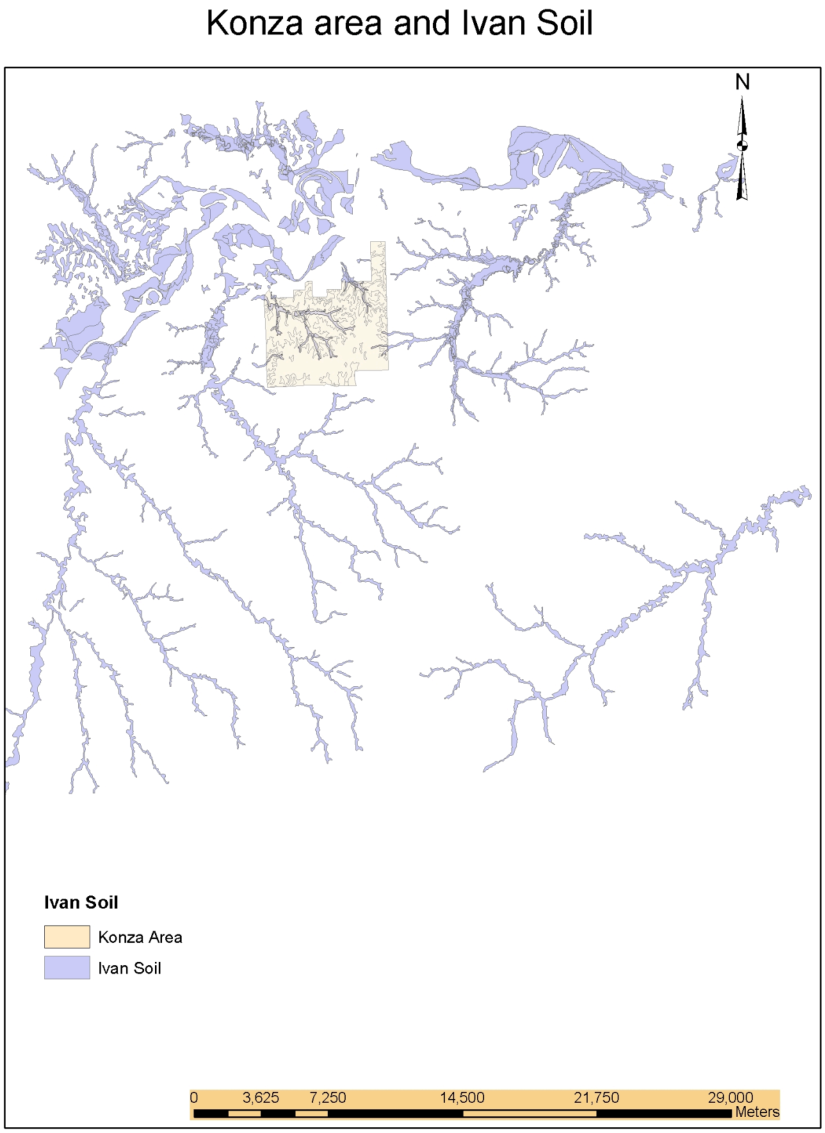

Figure 3.15. Silt loam soil group with percentage slope less than 3% represented by Ivan soil.

Based on literature review Ivan soil was reported to be dominant soil within the Konza river valleys and along low lands areas in Konza. This soil was reported to be very deep and well drained and was found in the alluvium areas. (Wehmueller, 1996). Since Konza is our ultimate area of interest, Ivan soil type was selected to represent the soils found in low land areas and along the river valleys in our study area see (Figure 3.15).

3.2.4 Development of Konza soil conceptual model

Based upon the dominant soil type in a group, the Konza conceptual soil model was developed. Clime, Benfield and Florence-Labette appears on the hilltops and slopes of the Konza area and its surrounding area. Ivan was selected to represent soil within the river valleys, flood plains, and low land areas. Based on this information a soil conceptual model was created by digitizing the areas polygon covered by these dominant soils. Edit ArcMap tools was used to digitize these areas and create the shape files. See the digitized map on Figure 3.16.

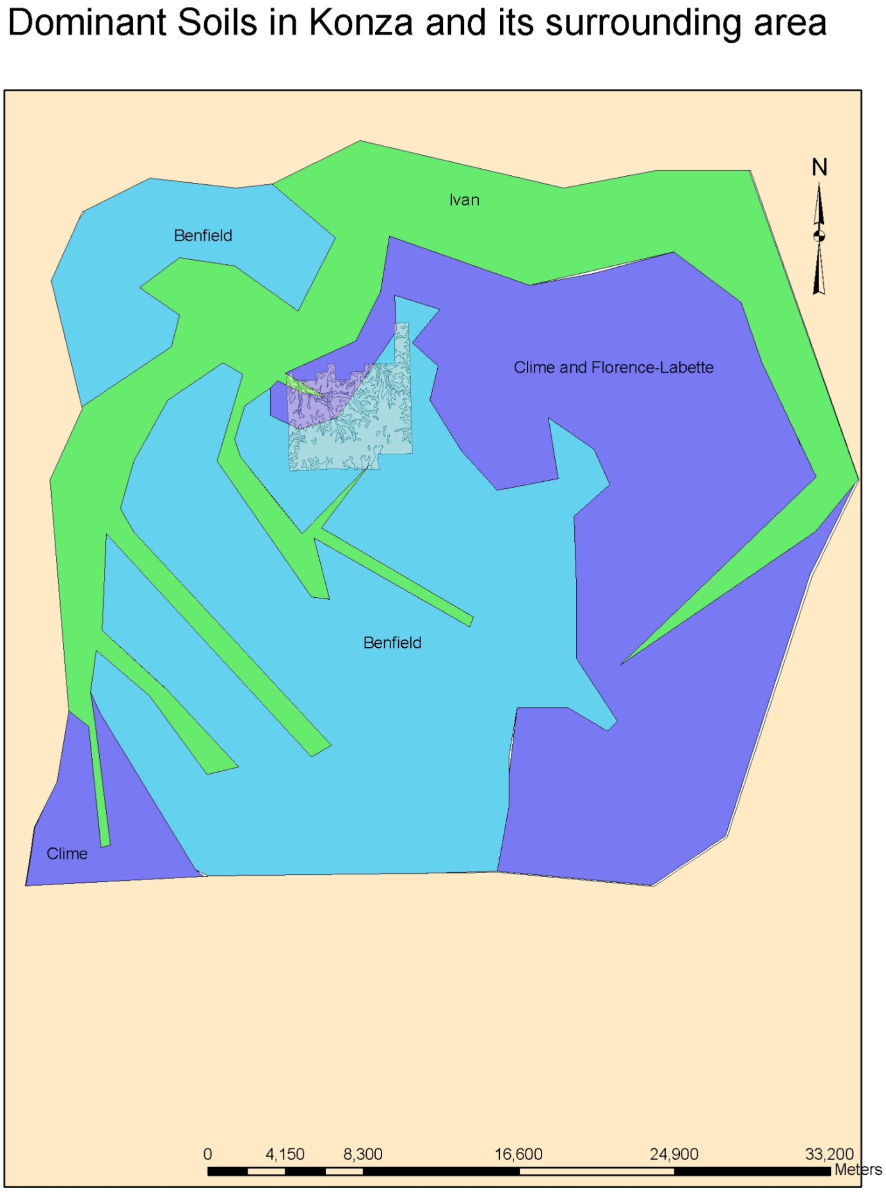

Figure 3.16. Digitized map to represent the dominant soils in the study area

To select the final soil type for EPIC model, a comparison between the dominant soils and the existing soils in EPIC soil data file was performed. Clime soil, was among the soils found in the EPIC database. Since Benfield and Ivan were not listed within the EPIC data file, I decided to contact a soil specialist from K-State Agronomy department

Dr. Mickey Ranson who suggested soils in EPIC list with similar physical, chemical and hydrologic characteristics to Benfield and Ivan. His suggestions are presented on the Table 4.

Table 4. Comparison between the dominant soil type and EPIC database soil type.

Original Soil	Match	Description
Ivan	Kennebec	Good match
Benfield	Irwin	Slightly match
Labette	Clime	Moderate match

Based on these suggestions, Florence Labette was combined with Clime soil group. The physical and chemical properties Kennebec were used to represent Ivan and those of Irwin to represent Benfield. Irwin and Kennebec soils are also found in the study area but they cover smaller area of land. Figure 3.17, represent the conceptual soil map after modification. The modified conceptual soils were then used as input data for EPIC model.

Modified Dominant Soils in Konza and its surrounding

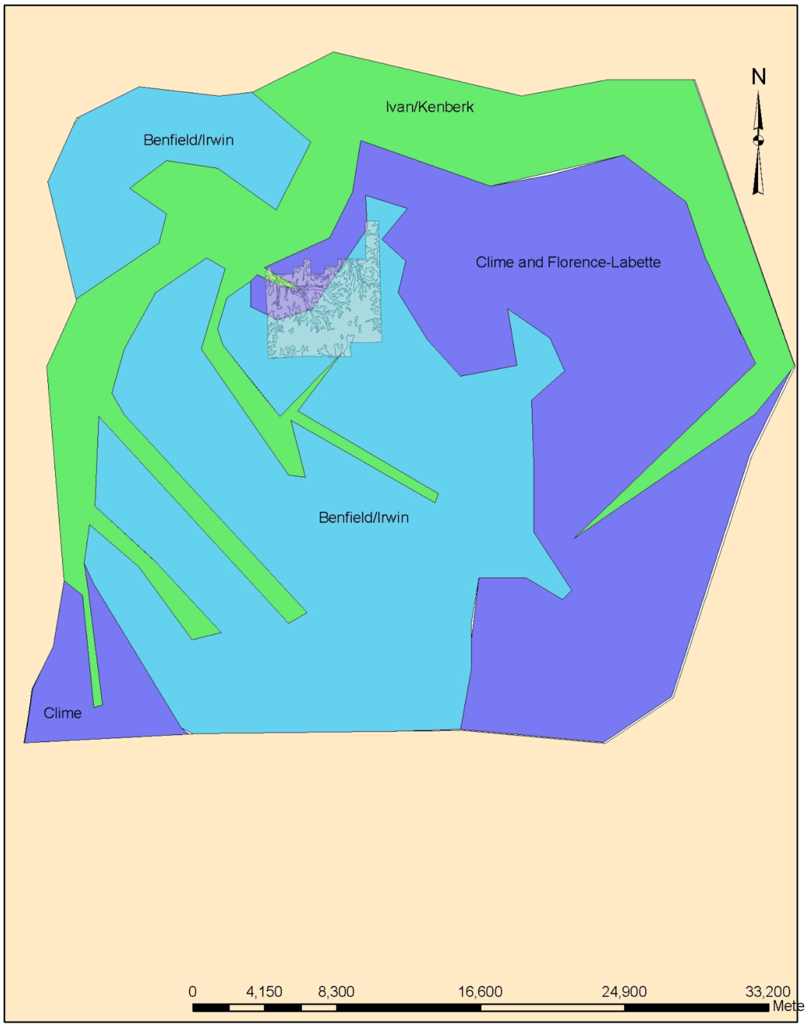

Figure 3.17. Digitalized soils for the study area after modification.

3.2.5 Estimation of EPIC model input parameters

Other input data required by EPIC model are discussed hare. The number of years of simulation was 21 years. The Simulation begins on year 1985, of January first to December 31, of year 2005. Weather data from Agronomy Northern Farm station, from year 1985 to 2005 were combined with Konza Precipitation data and used for EPIC simulations. These data includes; Year of the record, month of the record, day of the record, Daily Precipitation (mm), Maximum and Minimum daily temperature (0C), Solar radiation (MJ/m2), Daily Average wind speed (m/s), and Daily average Relative humidity (%). A decision on using Agronomy Northern Farm station data located in Manhattan town instead of Kings Creek USGS data was reached due to data availability problems. The Agronomy Northern farm station has all data required for EPIC while the Kings Creek and Konza stations has only few of the required data.

To calculate Potential Evapotranspiration (PET) the Penman-Monteith Equation was used. For erosion calculation, the small watershed version of the Modified Universal Soil Loss Equation (MUSLE) was used (MUSS). In EPIC model simulation, Watershed area is small because this model assumes homogeneous soil and management. EPIC requires numerous inputs to describe the soil and its behavior. Information to be supplied to this model must contain eleven variables that provide general information about the soil to be used in the simulation. Second, up to twenty variables are used to describe the physical and chemical characteristics of each identified layer in the soil profile. EPIC has a file containing about 737 different soils in a proper format. UTIL can be used to select a soil and its properties in a required format and enter them automatically into the EPIC data set being built. Soil data are also available in SCS soils database with data required for the model except for CaCo3. (Refer to EPIC user manual)

Different soils has different hydrologic properties. One of the important parameter required by EPIC model was curve number. Clime has a curve number of 86, Benfield has a curve number of 80, and Ivan curve number selected was 61. (These numbers were default numbers proposed in EPIC soil data file). For the peak rate estimation we selected Modified Rational EQ Peak rate Estimate. To estimate Runoff, a stochastic Curve number estimation method was used.

Other assumptions made for the EPIC model input parameters includes the selection of Range as a crop of interest in Konza. Since this area is a natural grassland with few trees and bushes we thought Range will be a good match. Since Konza is natural grassland prairie no pesticides was applied. The management practice adopted for this area was grazing and burning each year. Because EPIC requires a planting of crop for the model to work correctly we decided to locate year 1 as a year that plantation took place and we allowed 4-years of rotation before generation of any results. Other EPIC input variables used are presented on Table 5.

Table 5. Summary table for EPIC input data

Parameter	Value	Unit
Number of years of simulation duration	21	Years
Beginning year of simulation	1985 (1)	Year
Beginning month of simulation	1	Year
Beginning day of simulation	1	Year
Watershed Drainage area	1	Ha
Channel length	0.1	km
Average channel slope	2.5% to 5%	m/m
Channel roughness factor, Manning's number	0.05	Natural stream
Surface roughness factor, Manning's	0.6	Range

surface number		land
Average channel depth	0.5	m
Latitude of Konza area	39	Degrees
Average Watershed Elevation	396.5	m
Peak Runoff Rate-Rainfall Energy adjustment factor	1	
Snow on the ground at the stat of simulation	0	mm
Average concentration of Nitrogen in Rain fall	0.8	mg N/l
Number of years of cultivation before simulation starts	50	Years
Carbon dioxide concentration in the atmosphere	330	ppm
Irrigation parameters	No irrigation	
Lagoon parameters	No lagoon	
Watershed slope length	50	m
Average watershed slope	0.01	m/m
Erosion control factor	1	
Field length	2	km
Field width	2	km
Clockwise angle of field from north	96	Degrees
Standing dead crop residual	Unknown	
Wind erosion adjustment factor	1	
Crop rotation duration	4	Years
Irrigation codes	Dry-land	
Other irrigation codes	N/A	
Fertilizer codes	No fertilizer applied	
Lime code	No lime	
Furrow Dike code	No furrow dike	

Drainage code	No drainage system	
Irrigation management codes	No irrigation	
Fertilizer management codes	No fertilizer	
Farm operation schedule	Applicable	
Burning operation schedule	March	Each year
Planting schedule	April	Only one year
Grazing up to (20%)	June	Each year
Grazing up to (95%)	August	Each year

3.2.6 Simplification of Konza and its surrounding streams and rivers

Shape files for Streams and rivers were obtain from National Hydrologic Dataset (NHD) website. The streams and rivers elements were simplified to the order of 500 using ArcAEM tools. This simplification reduce the number of vertices per stream element, it also straight up the meandering river. This simplification helps to reduce the complexities of the model and hence reduce the computer time required for the model to run, converge and produce required results with the required accuracy. See Figure 3.18 to view the steams and rivers in our study area after simplification.

Streams and Rivers in and around Konza Prairie

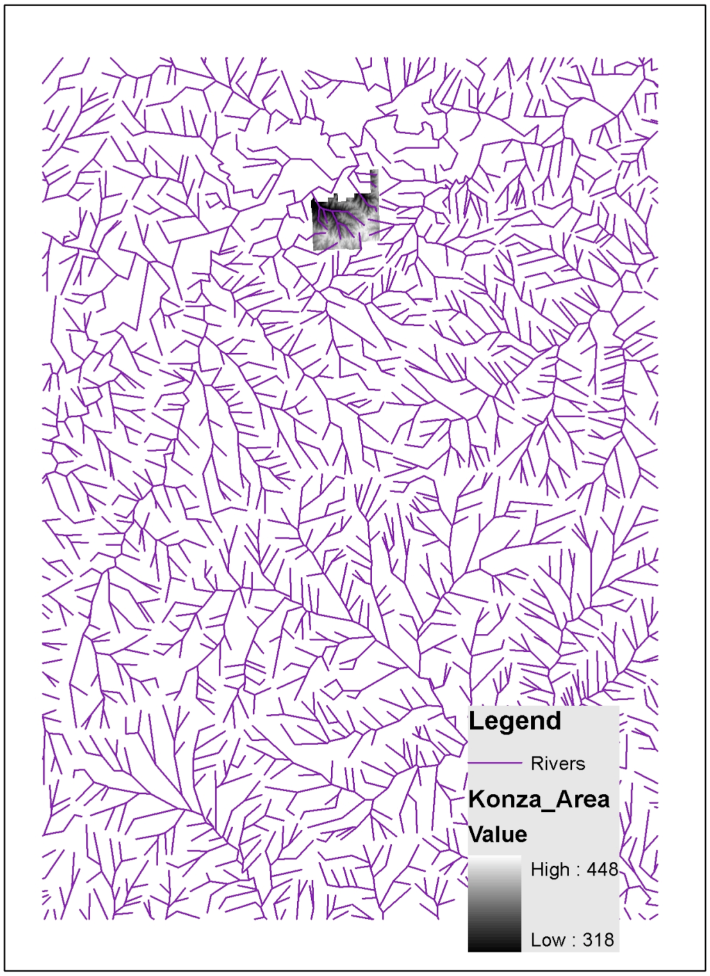

Figure 3.18. Simplified streams and river elements

3.2.7 SPLIT Groundwater parameters estimation

Stream and river information were combined with other aquifer information to prepare the input file for SPLIT model. The aquifer hydraulic permeability was assumed to be less than 1meter per day. The portion of aquifer along Kansas and Neosho river valleys were considered to have high hydraulic permeability than other part of the aquifer. Due to this Inhomogeneity, two polygons ware created with hydraulic permeability equals to 24m/d to represent the hydraulic permeability of this part of aquifer located along these river valleys. Other required parameters by SLIT model were obtained from past reports and previous studies that have been conducted for Konza. Table 6,gives the summary of the parameters used in the SPLIT groundwater model.

Table 6. Analytical Element Model Parameters

Model Parameters	Value used	Reference source for the data
Base Elevation (m)	250	Assumed
Bottom River Width (m)	10	Assumed
Bottom Stream Width (m)	5	Assumed
Aquifer Hydraulic conductivity (m/day)	0.546	Calibrated SPLIT Model
Recharge (m/day)	Varies based on soil type	EPIC Results
River Resistance (d)	1	(Pomes, 1995)
Stream Resistance (d)	100,000	(Pomes, 1995, table 3.2)
Top Elevation (m)	N/A	
Inhomogeneity polygons (hydraulic conductivity)(m/d)	24	(Suggested by Steward, 2007)
Unconfined Aquifer thickness (m)	2000	Assumed
Depth at each segment vertices (m)	1	Assumed
Head at each river vertices (m)	Varies	Digital Elevation Model (DEM)
River bed thickness (m)	1	Assumed
Stream bed thickness (m)	10	Assumed
Hydraulic conductivity at river bed (m/d)	1	Calculated
Hydraulic conductivity at stream bed (m/d)	0.0001	Calculated

CHAPTER 4 - **RESULTS**

4.1 EPIC RESULTS

4.1.1 Annual Recharge results from EPIC Model from year 1995 to 2005

The annual recharge results generate by EPIC ecological model varies yearly for Clime, Benfield (Irwin), and Ivan (Kenberk) soil type (see Figure 4.1). The annual recharge rate varies across the soil type for the same annual precipitation value. Generally, results show that years with high precipitation resulted to high recharge rate and the one with low precipitation results to low annual recharge rates. Year 1988, 1991, and 2000 resulted to no annual recharge for all three soil types. Year 1993 results to the highest annual recharge rates for all three soil types (see Table 7), this year happens to be the one with the highest annual precipitation of about 1292.37mm. The year 1993 received about 457mm of precipitation above average annual value of 835mm reported in the literature.

Table 7. Annual Recharge from 1985 to 2005

Year	Precipitation (mm/yr)	Recharge mm/yr		
		Clime Soil	Benfield	Ivan
1985	827.24	24.68	0.0	20.09
1986	1033.78	49.37	92.42	203.33
1987	726.29	73.48	109.27	159.75
1988	451.96	0.0	0.0	0.0
1989	701.34	19.44	0.0	0.0

1990	852.01	48.92	28.70	180.01
1991	602.3	0.0	0.0	0.0
1992	931.88	103.14	35.51	120.63
1993	1292.37	278.8	408.62	587.85
1994	534.78	0.0	8.48	55.30
1995	761.42	113.59	111.15	191.55
1996	637.98	17.69	0.0	0.0
1997	730.2	17.21	0.0	0.0
1998	935.17	69.68	24.73	149.05
1999	874.44	166.68	260.77	352.22
2000	561.49	0.0	0.0	0.0
2001	965.5	84.21	9.13	90.59
2002	637.69	9.23	29.36	56.21
2003	774.1	94.66	123.07	189.88
2004	876.3	131.83	201.10	304.22
2005	883.28	61.85	118.69	244.55
Average		64.97	74.33	138.82

Graphical comparison for the soils, precipitation and recharge rate is presented on Figure 4.1.

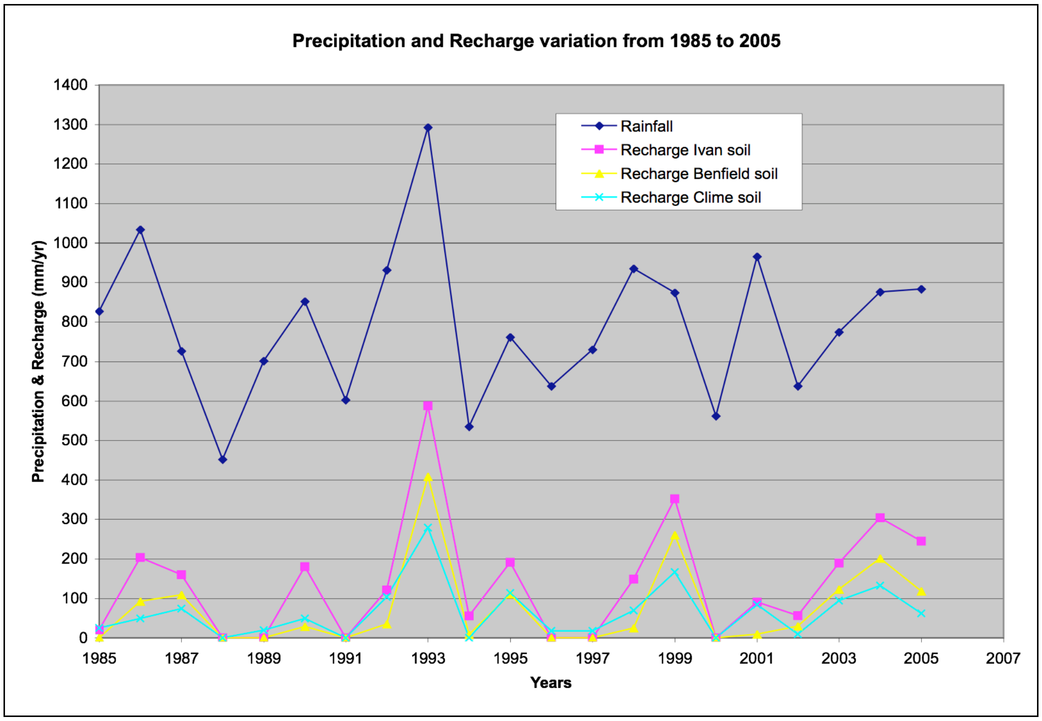

Figure 4.1. Precipitation, soils and recharge relation graphs

Based on the above results, recharge varies yearly depending on the precipitation received in a particular year. The recharge values also varies across the soil groups. With Ivan/Kenberk having the highest recharge followed by Benfild/Irwin and Clime the list. The average recharge value from 1985 to 2005 is about 12% of the average precipitation value. See Table 8. The ratio of runoff and precipitation is 11% and the ratio of ET and precipitation is 76%.

Table 8. Recharge, runoff, ET and precipitation comparison

Parameter	Value
Average precipitation (mm/y)	790
Average ET (mm/y)	601.8
Average Runoff (mm/y)	88
Average recharge (mm/y)	92.7
Average lateral flow (mm/y)	7.45

Ratio of recharge and precipitation	12%
Ratio of runoff and precipitation	11%
Ratio of ET and precipitation	76%

4.1.2 PET and ET results

Result generated by EPIC indicates that PET is the same for the three soil types (See Figure 4.2). The annual precipitation was less than annual PET for all years with exception of year 1993. The ET value was less than the PET value in all years. The ET value for different soil type were very close to one another. With Clime soil having the slightly lower ET value than the Benfield and Ivan soil types that appears to be a close match (see Figure 4.2).

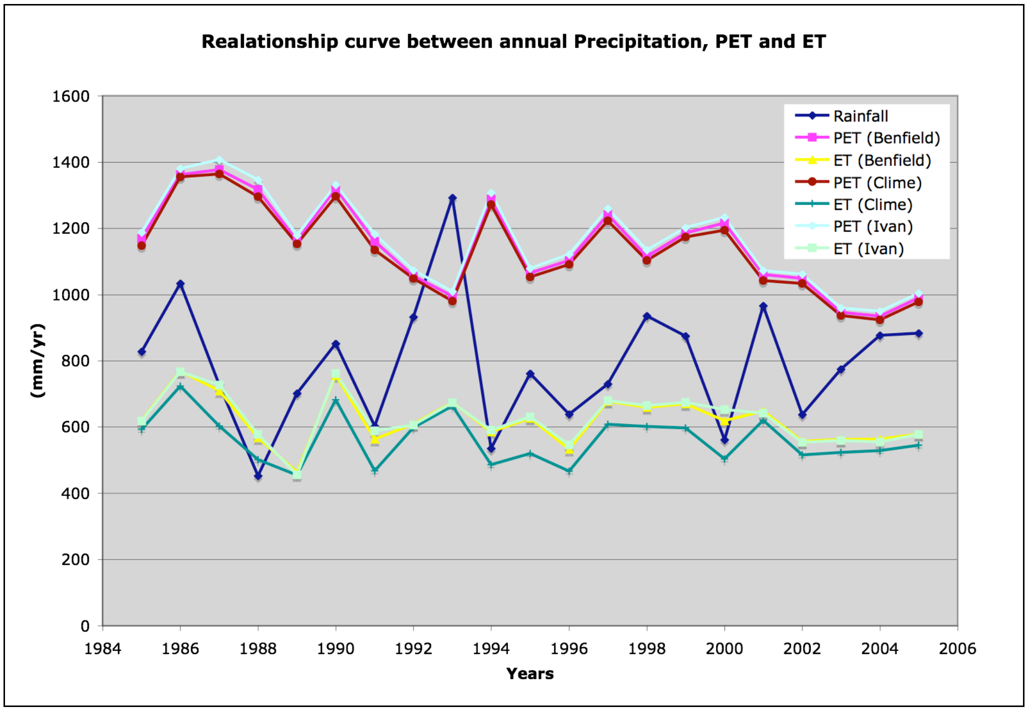

Figure 4.2. Precipitation, PET, ET, and Soils comparison.

4.1.3. Biomass production

The Biomass production depends on weather condition. Precipitation can be part of the reason for either less or higher biomass but it seams that it does not act alone. Temperature and other factor contribute to the quantity of biomass production. Figure 4.3 shows the relationship between precipitation and biomass production. From this graph it is clear that there is no direct relationship between precipitation and biomass production. Good example was year 1993 that happens to have the highest precipitation but the biomass production was very low compared to other year with lesser precipitation. The biomass production varies across the soil types. Ivan soil which was characterized in the literature to be deep and well drained soil appears on the graph to have higher biomass production than Benfield(Irwin) and Ivan(Kenberk).

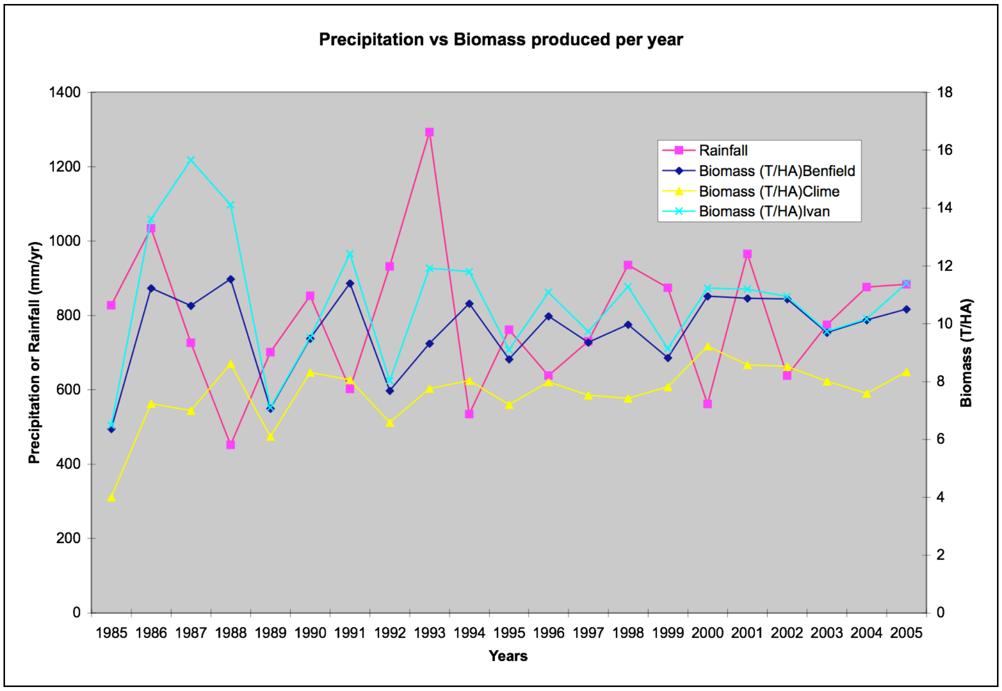

Figure 4.3. Relationship between precipitation and biomass production

4.1.4 Runoff results

Runoff generated annually appears to have direct relationship with precipitation. Year with high precipitation results to higher runoff and the one with lower precipitation results to low runoff. See Figure 4.4. Year 1993 appears to have the highest runoff for the three soil types.

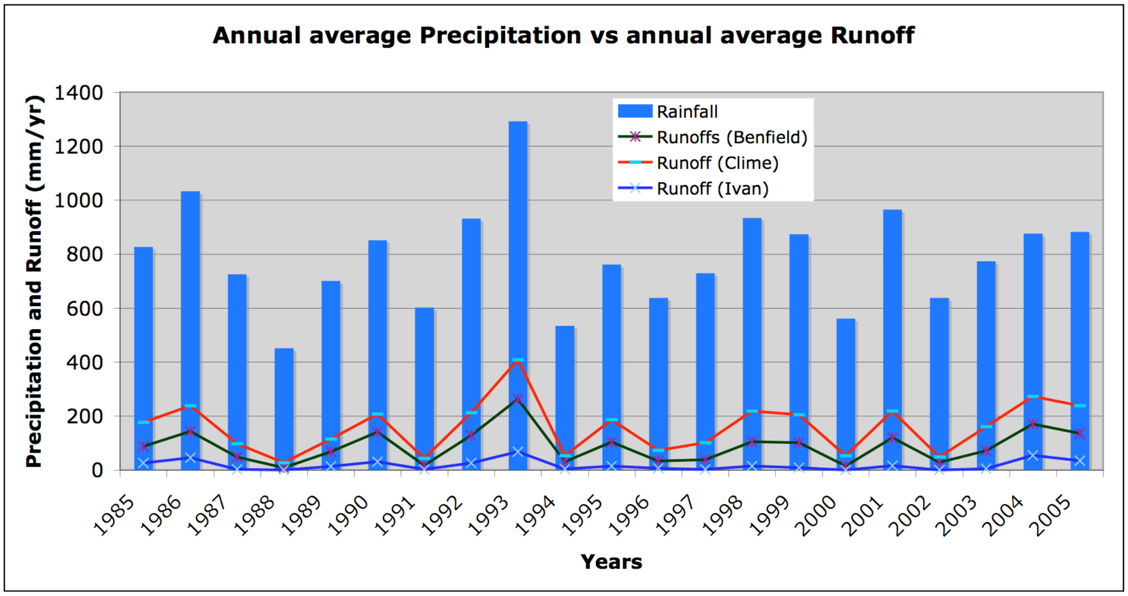

Figure 4.4. Relationship between precipitation and runoff.

Clime soil produce the highest runoff in 1993, followed by Benfield and the Ivan with the least runoff. These results appears to be the opposite of recharge results. Under recharge Ivan has highest recharge followed by Benfield and Clime was the lowest for year 1993.

4.1.5 Classification of Recharge results into five groups

For the development of the Konza groundwater model the recharge results were grouped into five groups. The classification was based on the average, extreme, five years high and low moving average recharge values.

Group one was made up of the average recharge value for each soil type for the period of year 1985 to 2005. The average recharge values for each soil type for the 21 years is presented on Table 9. This recharge values were considered as the average values generated by EPIC based on the 21years record used in this study. Ivan (Kenberk) soil appears to have the highest recharge value in average followed by Benfield (Irwin) and Clime came the list.

Table 9. The average recharge from year 1985 to year 2005

Dominant Soil Type	Recharge (mm/y)	Recharge (m/day)
Benfield/Irwin	74.33	0.000203
Clime	64.97	0.000180
Ivan/Kenberk	138.82	0.000379
Average	92.71	0.000254

The highest recharge was estimated by EPIC to be that occurred in 1993. (See Table 10). No other year come closer to this year. Given the uniqueness of this year, a recharge group two was created based on this extreme year. This recharge was considered to represent wet year, for our 1985 to 2005 record.

Table 10. Maximum recharge for year1985 to 2005

Soil group	Recharge in (mm/y)	Recharge in (m/day)
Benfield/Irwin	408.62	0.0011195
Clime	278.80	0.000764
Ivan/Kenberk	587.85	0.001611
Average	425.09	0.001165

Group three was made up of years with zero recharge values in all of the three soil types for the same precipitation event. Years with low recharge values represent dry years (see Table 11). Annual precipitation in those years were far below average.

Table 11. Years with the lowest recharge rate from 1985 to 2005

Year	Benfield/Irwin recharge (mm/y)	Clime soil recharge (mm/y)	Ivan/Kenberk recharge (mm/y)
1988	0	0	0
1991	0	0	0
2000	0	0	0
Average	No recharge	No recharge	No recharge

Recharge results estimated by EPIC model were classified using a 5-years moving average (See Table 12). Each soil type produces different results for the 5 years moving average.

Table 12. Annual recharge and five years recharge moving average.

					Five years Moving average Recharge		
Years	Rainfall (mm/yr)	Recharge Ivan soil (mm/yr)	Recharge Benfield soil (mm/yr)	Recharge Clime soil (mm/yr)	Ivan (mm/yr)	Benfield (mm/yr)	Clime (mm/yr)
1985	827.24	20.09	0	24.68			
1986	1033.78	203.33	92.42	49.37			
1987	726.29	159.75	109.27	73.48	76.634	40.338	33.394
1988	451.96	0	0	0	108.618	46.078	38.242
1989	701.34	0	0	19.44	67.952	27.594	28.368
1990	852.01	180.01	28.7	48.92	60.128	12.842	34.3
1991	602.3	0	0	0	177.698	94.566	90.06
1992	931.88	120.63	35.51	103.14	188.758	96.262	86.172
1993	1292.37	587.85	408.62	278.8	191.066	112.752	99.106
1994	534.78	55.3	8.48	0	191.066	112.752	102.644
1995	761.42	191.55	111.15	113.59	166.94	105.65	85.458
1996	637.98	0	0	17.69	79.18	28.872	43.634
1997	730.2	0	0	17.21	138.564	79.33	76.97
1998	935.17	149.05	24.73	69.68	100.254	57.1	54.252
1999	874.44	352.22	260.77	166.68	118.372	58.926	67.556
2000	561.49	0	0	0	129.614	64.798	65.96
2001	965.5	90.59	9.13	84.21	137.78	84.466	70.956
2002	637.69	56.21	29.36	9.23	128.18	72.532	63.986
2003	774.1	189.88	123.07	94.66	177.09	96.27	76.356
2004	876.3	304.22	201.1	131.83			
2005	883.28	244.55	118.69	61.85			
Average		138.82	74.33	64.97			

Plotting the graphs for the five years moving average, Ivan soil happens to have the highest five years recharge moving average followed by Benfield and Clime came the least (see Figure 4.5).

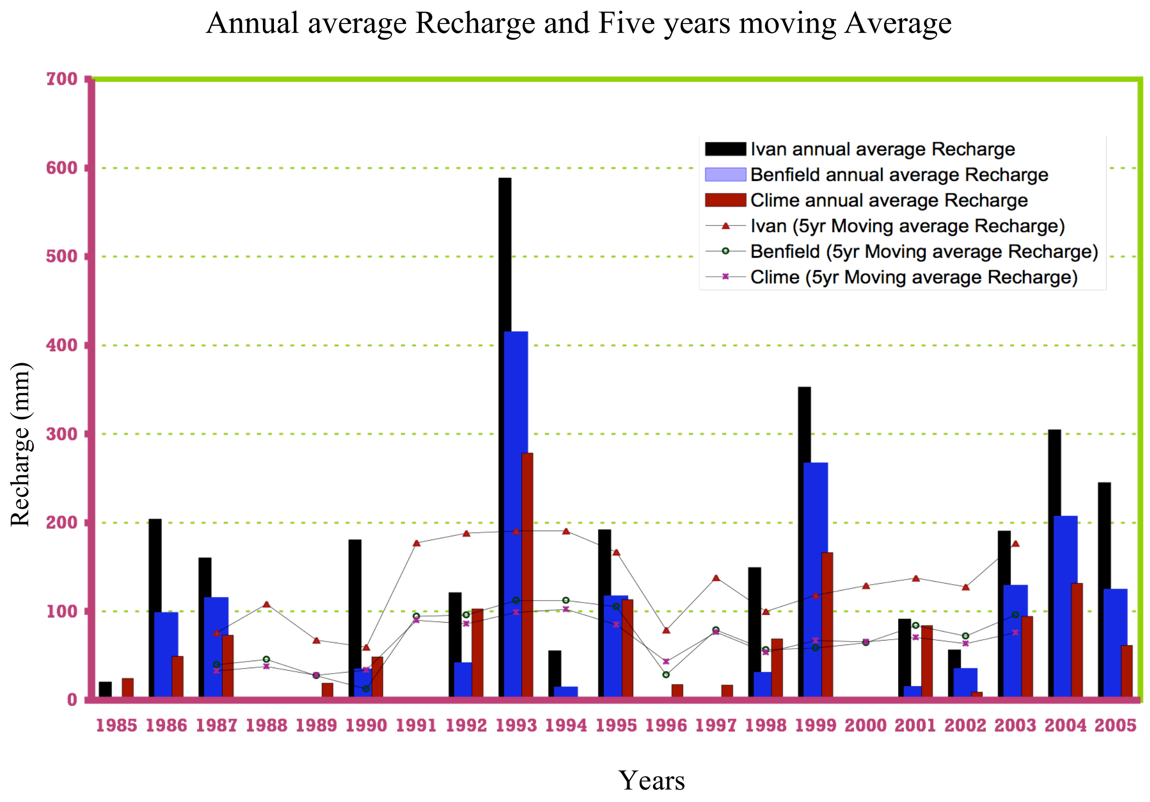

Figure 4.5. Plot of annual average Recharge and five years moving average recharge results

Group four was formed based on Highest recharge values generated from the five years moving average and group five was formed based on Lowest recharge values. Each soil type happens to have a different five years moving average recharge value. The results for the high and low five years moving average for the recharge results and different soil types are presented in Table 13.

Table 13. Highest and Lowest Recharge values based on 5yrs moving average

	Recharge based on 5 years Moving Average			
Soil Type	Highest Recharge		Lowest Recharge	
	(mm/yr)	(m/d)	(mm/yr)	(m/d)
Clime	102.644	0.0002812	28.368	0.00008
Benfield	112.752	0.000309	12.842	0.000035
Ivan	191.066	0.0005235	60.128	0.000165
Average		0.000371		0.0001

4.1.6 Development of the recharge conceptual model

The SPLIT groundwater model requires recharge to simulate results for the groundwater elevations. To achieve this requirement different recharge conceptual models were created. The recharge polygons were created using GIS software. One conceptual model was created based on the average recharge values generated by EPIC ecological model for the three soil types. The second was created based on the extreme recharge values of 1993 rain event, the third was created based on dry years of 1988, 1991 and 2000 which happens to have no annual recharge. The forth and fifth scenarios were based on high and low values of the moving average recharge.

4.1.6.1 Average recharge conceptual model

The conceptual model for the average recharge is presented on Figure 4.6. In this case recharge polygons were created to represent the average recharge calculated from EPIC model recharge results for each soil type for the 21years under consideration. An average value from the average recharge values was used for the area located outside our study area.

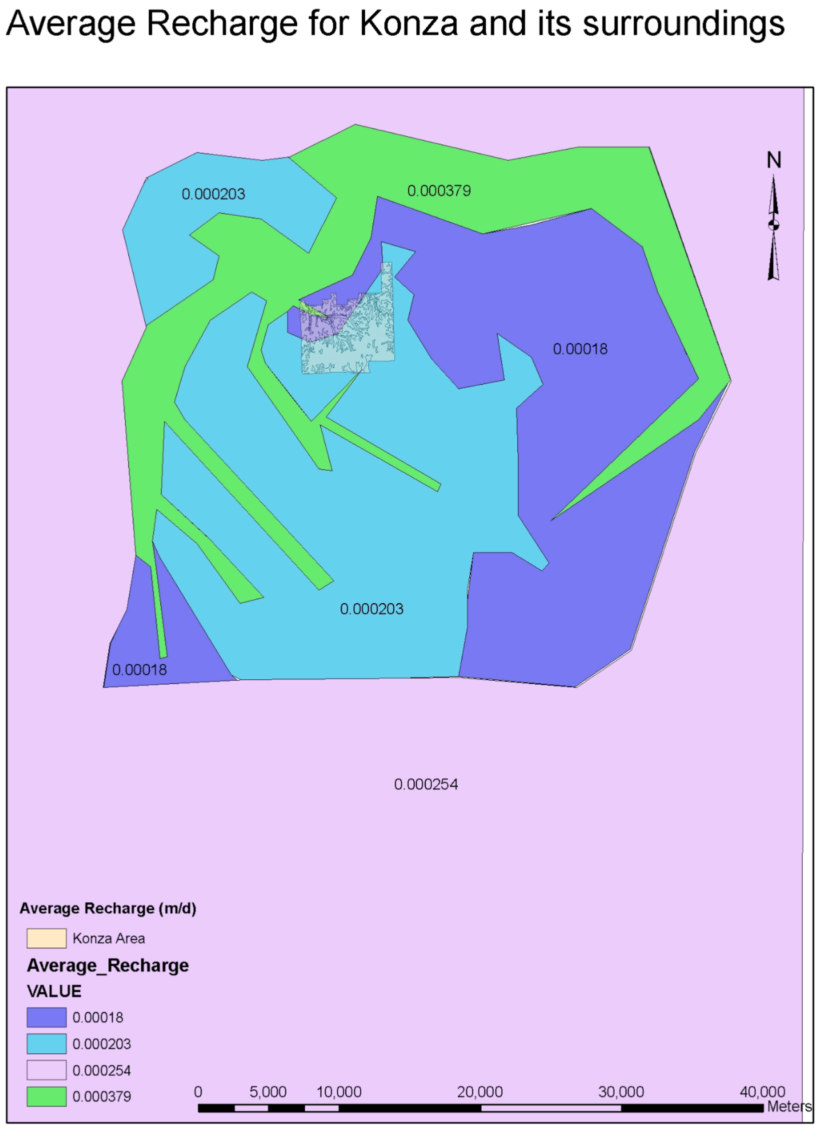

Figure 4.6. Average recharge conceptual model

4.1.6.2 Maximum Recharge conceptual model

The second recharge conceptual model was created based on extreme recharge values of year 1993. The same approach was used where by EPIC recharge results for year 1993 were used in creating polygons that represents each soil type, and an average value for the annual maximum recharge values was used on the area located outside the study area (see Figure 4.7).

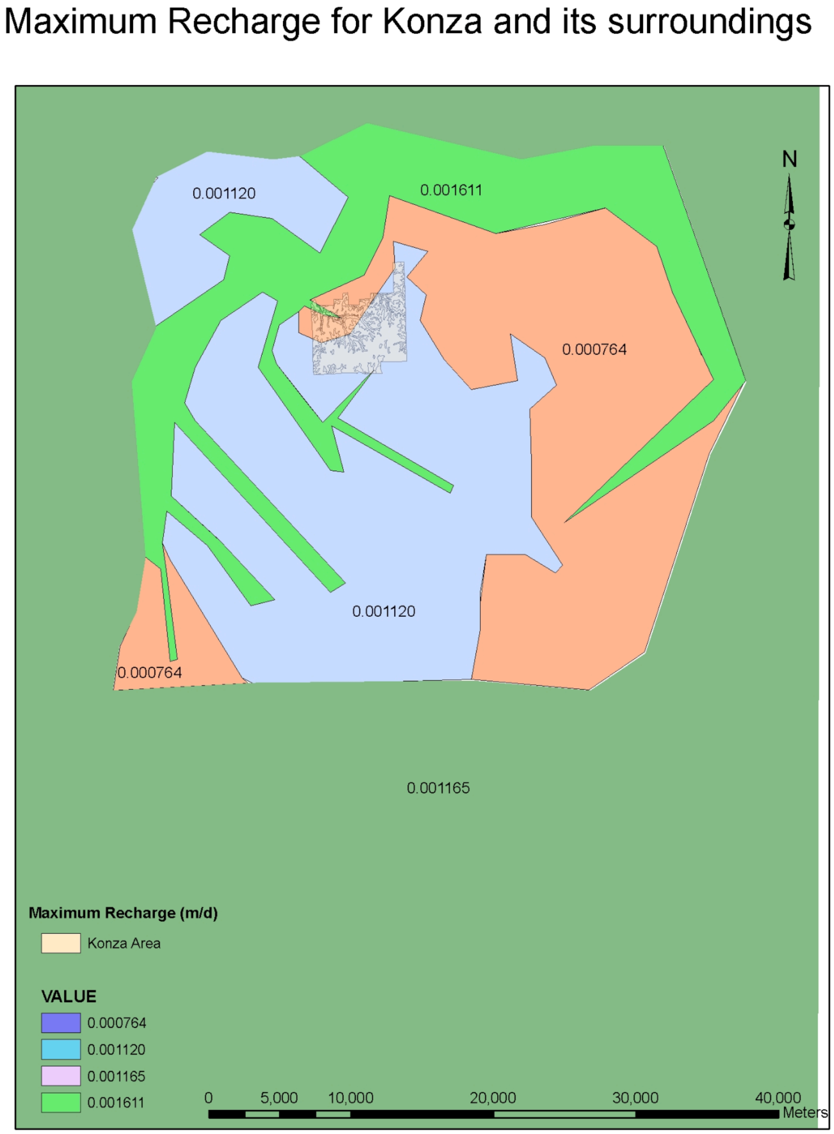

Figure 4.7. Maximum recharge recorded in year 1993.

4.1.6.3 Zero recharge conceptual model

Another case scenario considered for SPLIT groundwater model was for those years with zero annual recharge values. In this case no recharge polygons where created. In stead a value of zero was assigned during the creation of SPLIT input data file. These years with zero annual recharge rates were considered to represent dry years.

4.1.6.4 Five years moving average High recharge values conceptual model

Using the five years moving average, several high values were found for different soils. For the Clime soil the highest five years moving average for the 21years was 102.644 mm/yr, Benfield was 112.752mm/yr and for the Ivan soil was 191.066 mm/yr. A conceptual recharge model for the high recharge five years moving average was created based on these values after they were converted to meters per day. See Figure 4.8.

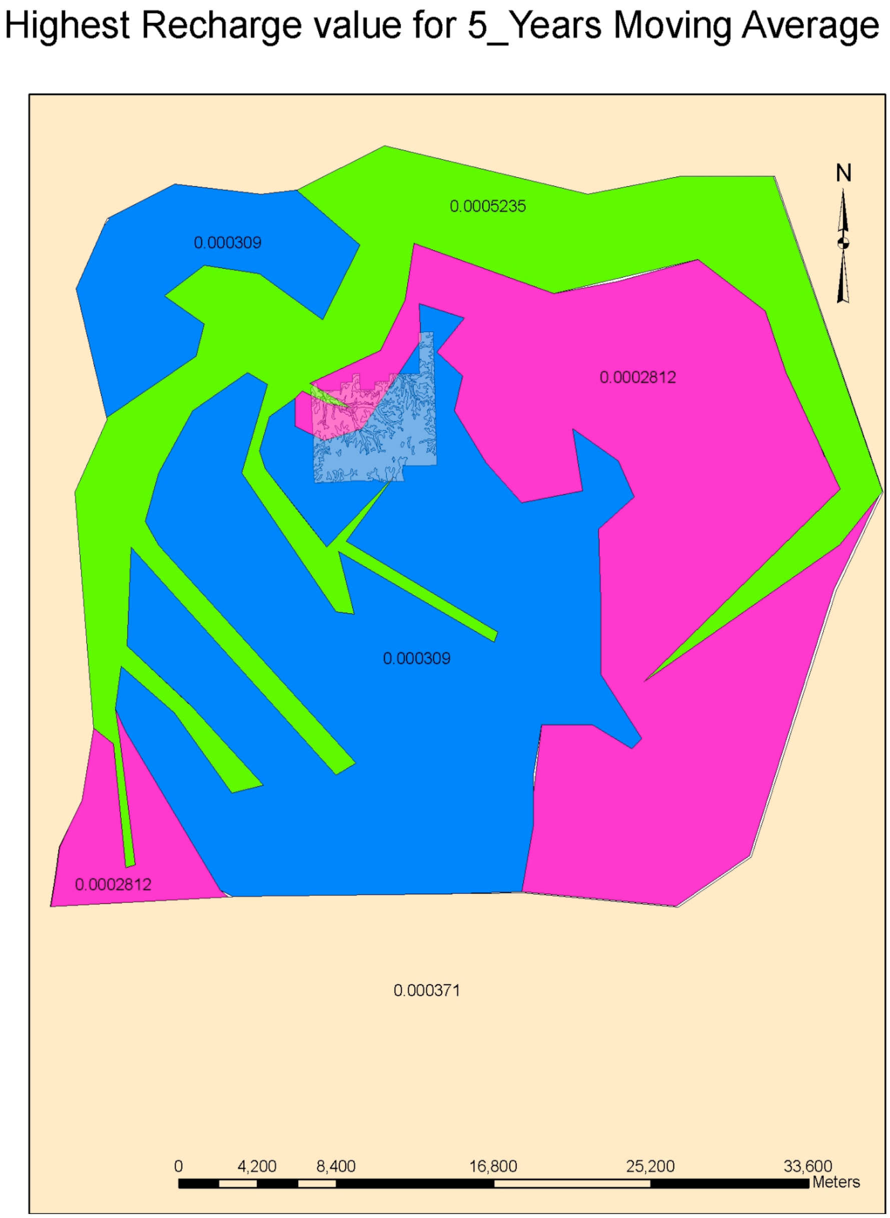

Figure 4.8. Five years moving average Highest recharge values

4.1.6.5 Five years moving average Lowest recharge values conceptual model

The five years moving average low recharge values for Clime soil is 28.368 mm/yr, Benfield is 12.842, and Ivan is 60.128mm/yr. All values were converted to m/d (see Figure 4.9).

Figure 4.9. Five years moving average Lowest recharge values.

4.2 GROUNDWATER MODEL CALIBRATIONS AND RESULTS

The Konza tallgrass prairie groundwater elevation model was calibrated using ad hoc method. Several hydraulic permeability (k) values were assumed and used in the groundwater model calculations. The groundwater elevation contours were matched with the historic field measurement of the two deep wells located inside Konza area. After several trials it was found that the SPLIT simulated groundwater elevation indicate a close match to the field groundwater measured value when the hydraulic permeability was between 0.5m/d and 0.6m/d. After calibration the hydraulic permeability value of 0.546 m/d was used to test what if scenarios. Scenarios considered were for the years with zero recharge, maximum recharge and moving average high and low recharge. These results were used to examine what will happen to the groundwater elevation if the recharge values changes.

4.2.1 Groundwater field measurement

The historical field measurement for two deep wells located at the Morrill Limestone in Konza prairie are presented on Figure 4.10 and figure 4.2.1.2. The average groundwater elevation value at a the well located at site 4-6 Morrill Limestone in figure 4.2.1.1, from year 1990 to year 2005 was 364.46 meters above sea level.

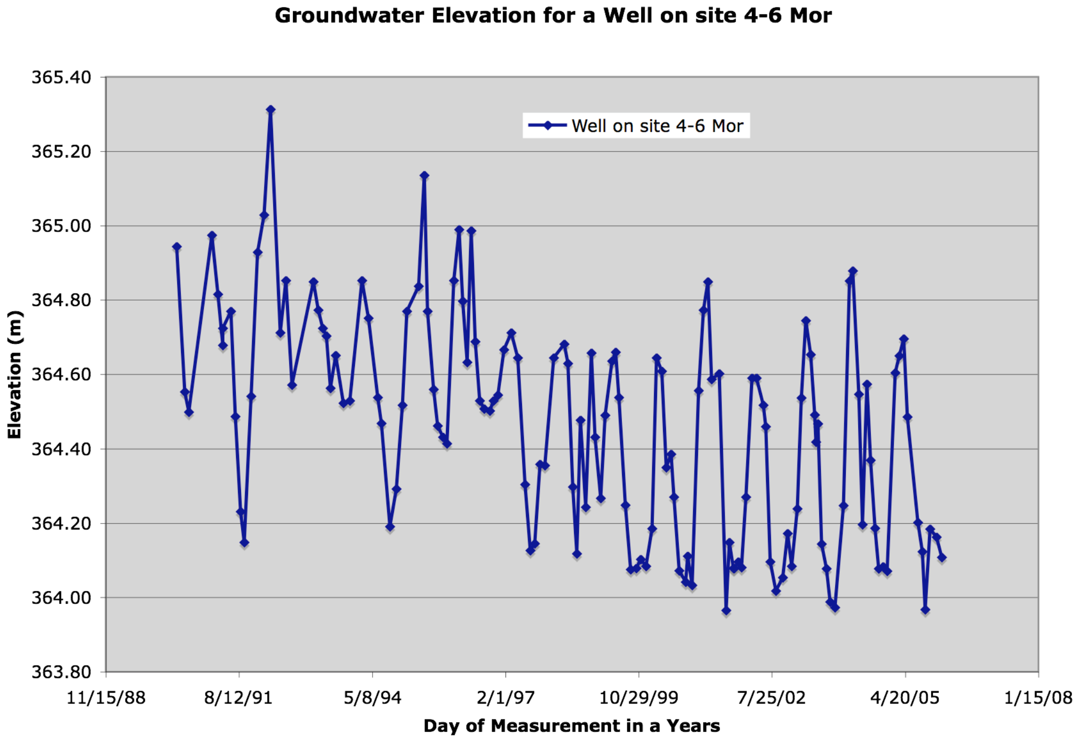

Figure 4.10. Groundwater elevation at well located in site 4-6 Morrill Limestone

(Data source, Gwen Macpherson , 2007 University of Kansas)

The average groundwater elevation for a well located at site 4-7 Morrill Limestone is presented on Figure 4.11. The average well water elevation based on measurement taken from year 2000 to 2005 was 364.15m.

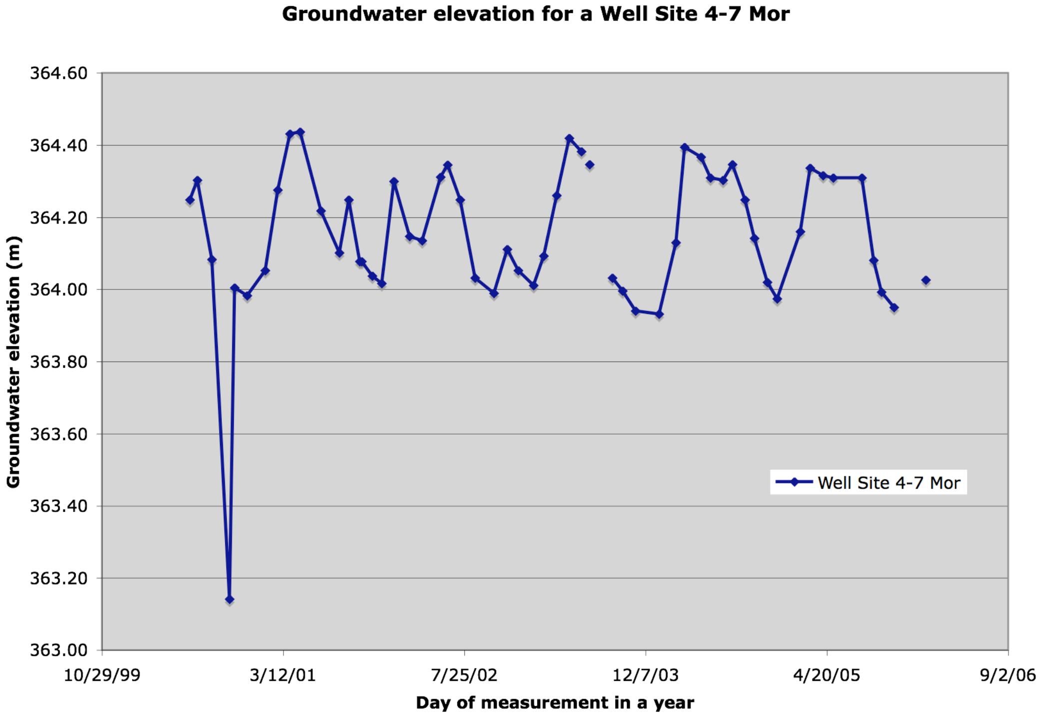

Figure 4.11. Groundwater elevation for the well at site 4-7 Morrill Limestone.

(Data source, Gwen Macpherson, 2007 University of Kansas)

4.2.2 Konza groundwater model Calibration

The SPLIT groundwater model elevation result for the average recharge, were adjusted based on Ad hoc method to match them with the field groundwater elevation measurements. Using the two deep wells historical average groundwater elevation measurements and varying the hydraulic permeability (k) values, different groundwater elevation results were obtained (see Figure 4.12 to Figure 4.15).

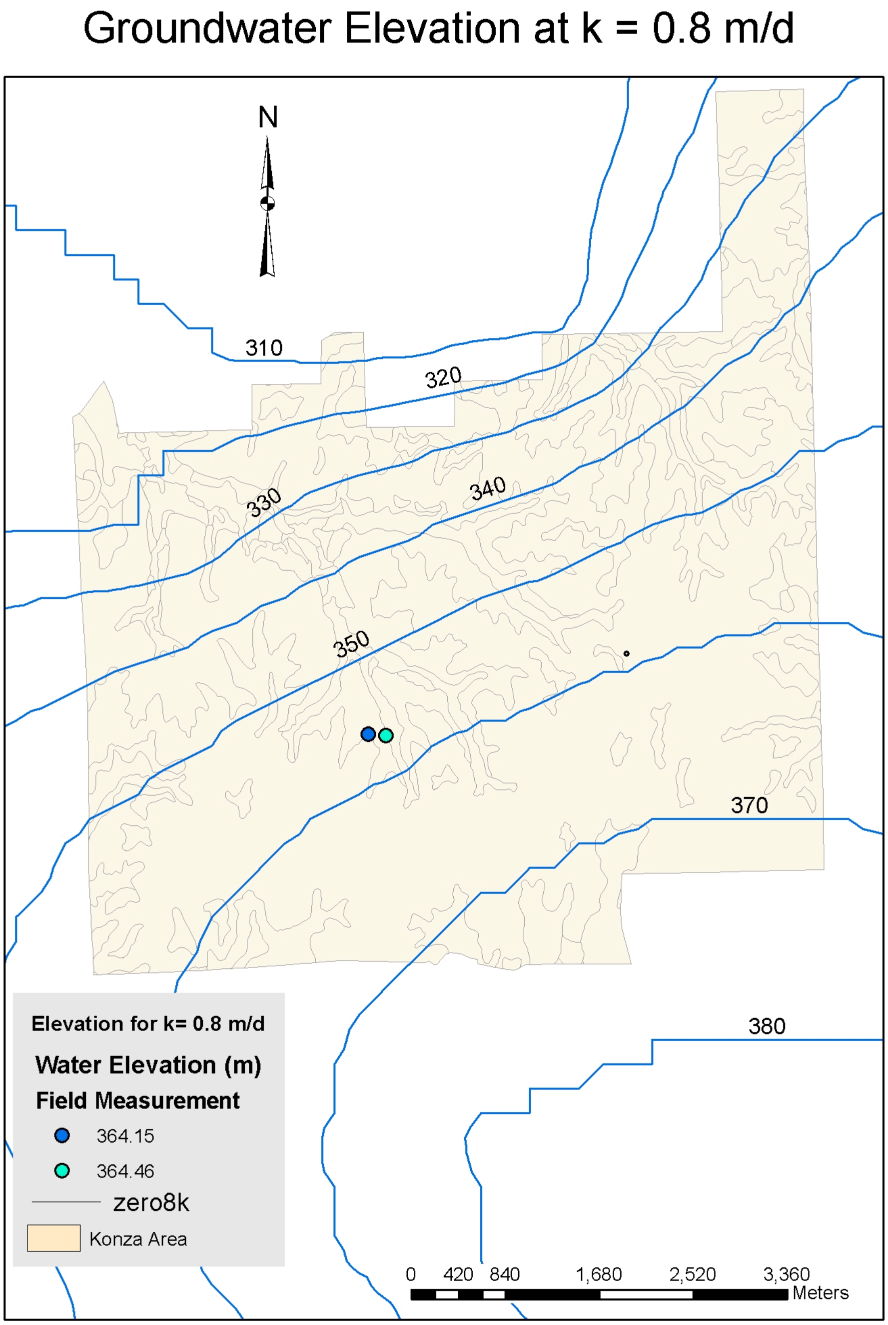

Figure 4.12. Groundwater elevation with 0.8 m/d hydraulic permeability

Different values of hydraulic permeability (k) were considered. Groundwater elevation start showing some convergence towards the field measured values when the value of k was less than 1m/d. Few results were selected to show the changes that took place in groundwater elevation as the k value changes. Figure 4.12 shows the groundwater elevation as k=0.8 m/d. From the model results, the site location lies between 350 and 360m which is below the field measured value of 364 m.

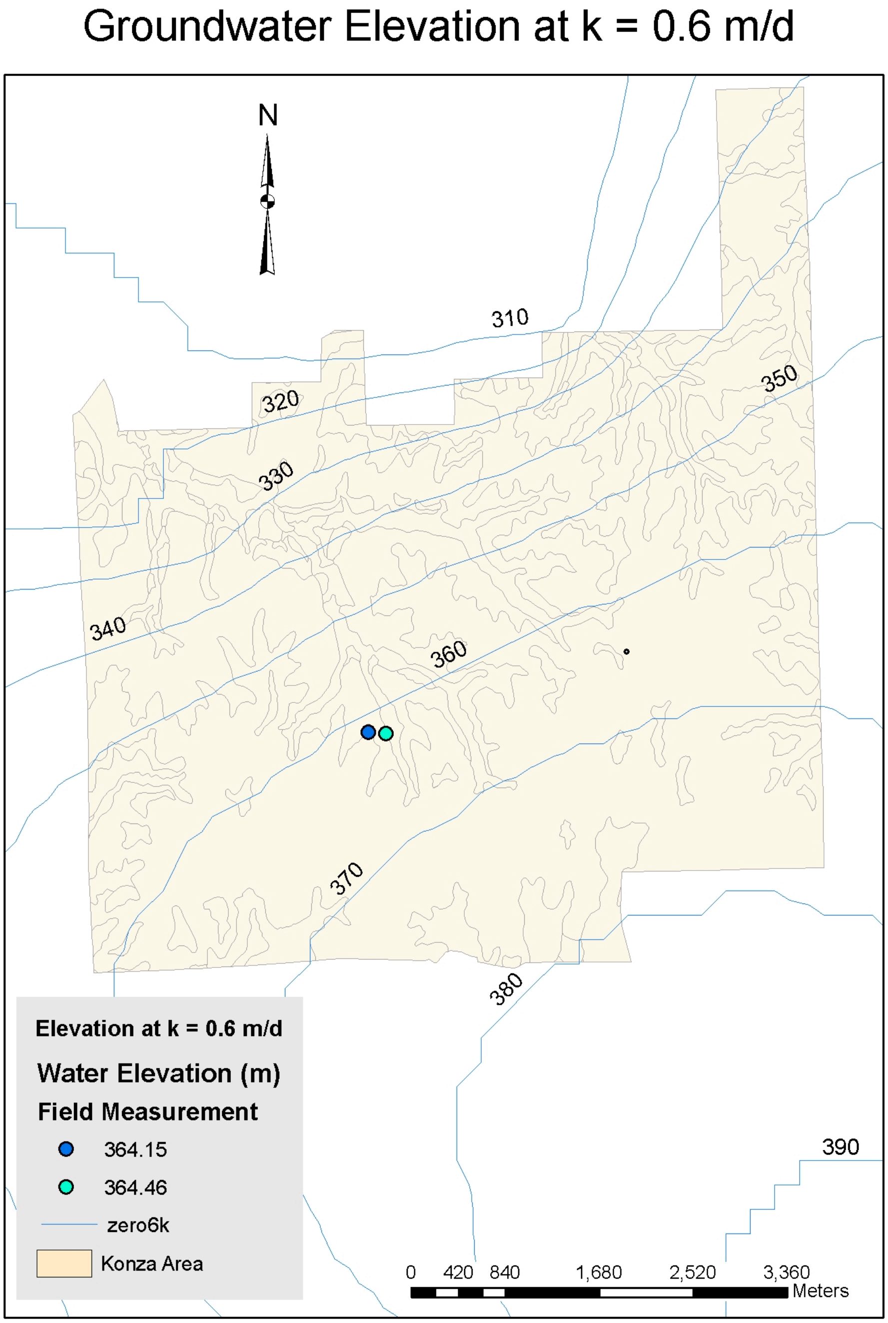

Figure 4.13. Groundwater elevation with 0.6 m/d hydraulic permeability

If the value of hydraulic permeability (k) value is reduced to 0.6m/d results indicates that at the well location groundwater elevation is between 360 to 370m (see Figure 4.13). It is clear from the map that the groundwater elevation at the well location is too close to 360m. Field measurement need to be at 364 meters above sea level.

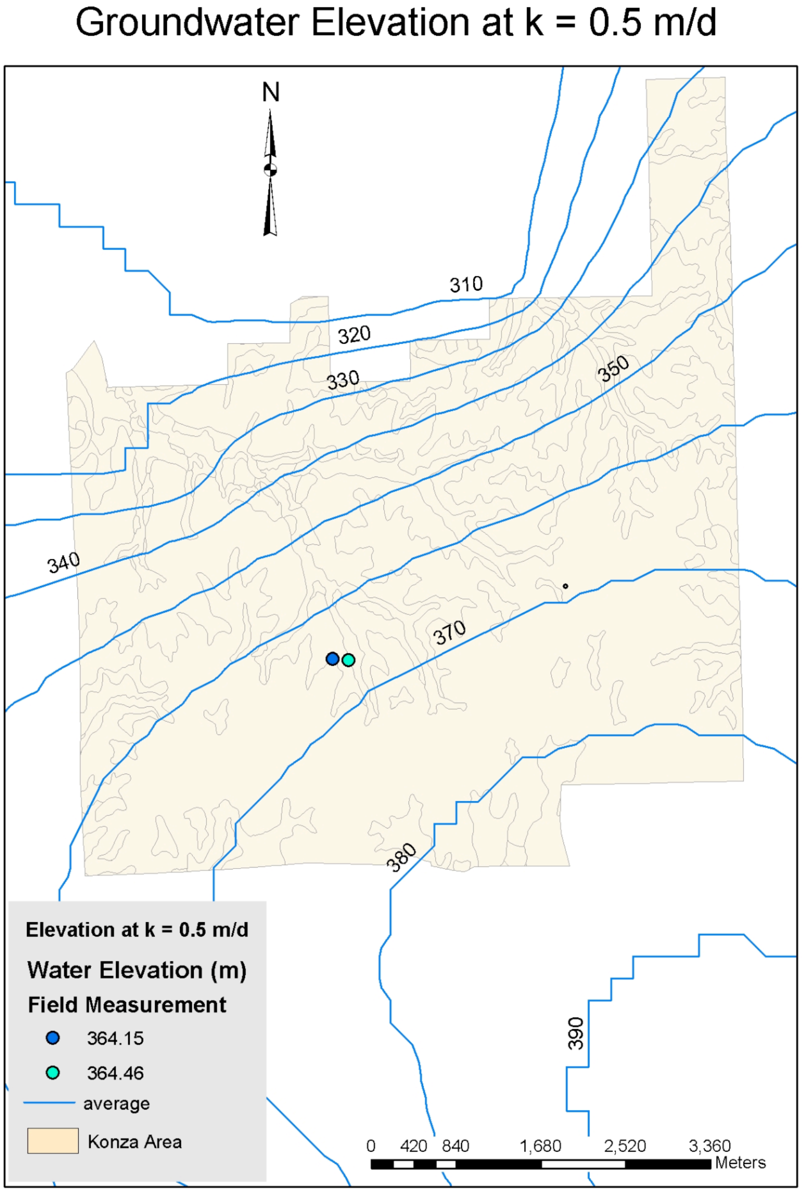

Figure 4.14. Groundwater elevation at 0.5 m/d hydraulic permeability.

Calculation of the groundwater elevation at the well location continues by changing the value of k to 0.5m/d. The groundwater elevation for Konza area using a k value of 0.5m/d is presented on Figure 4.14. This result shows that the groundwater elevation at the wells is between 360m and 370m. It also shows that the groundwater elevation at the location of the wells is in the magnitude of 364m. This result was considered to provide a match between the field measurement and the model results. This result also indicates that groundwater in Konza area flows from South east corner towards the North east corner of Konza prairie. When the groundwater flow reaches Kansas River valley it changes its flow direction towards that of Kansas River, which flows from West towards East. If the hydraulic permeability is changed to 0.4m/d (see Figure 4.15) results indicates that the groundwater elevation at the well location calculated by the model is closer to 370m. This value is considered to be higher than the field measurement which is approximately 364 meters above sea level.

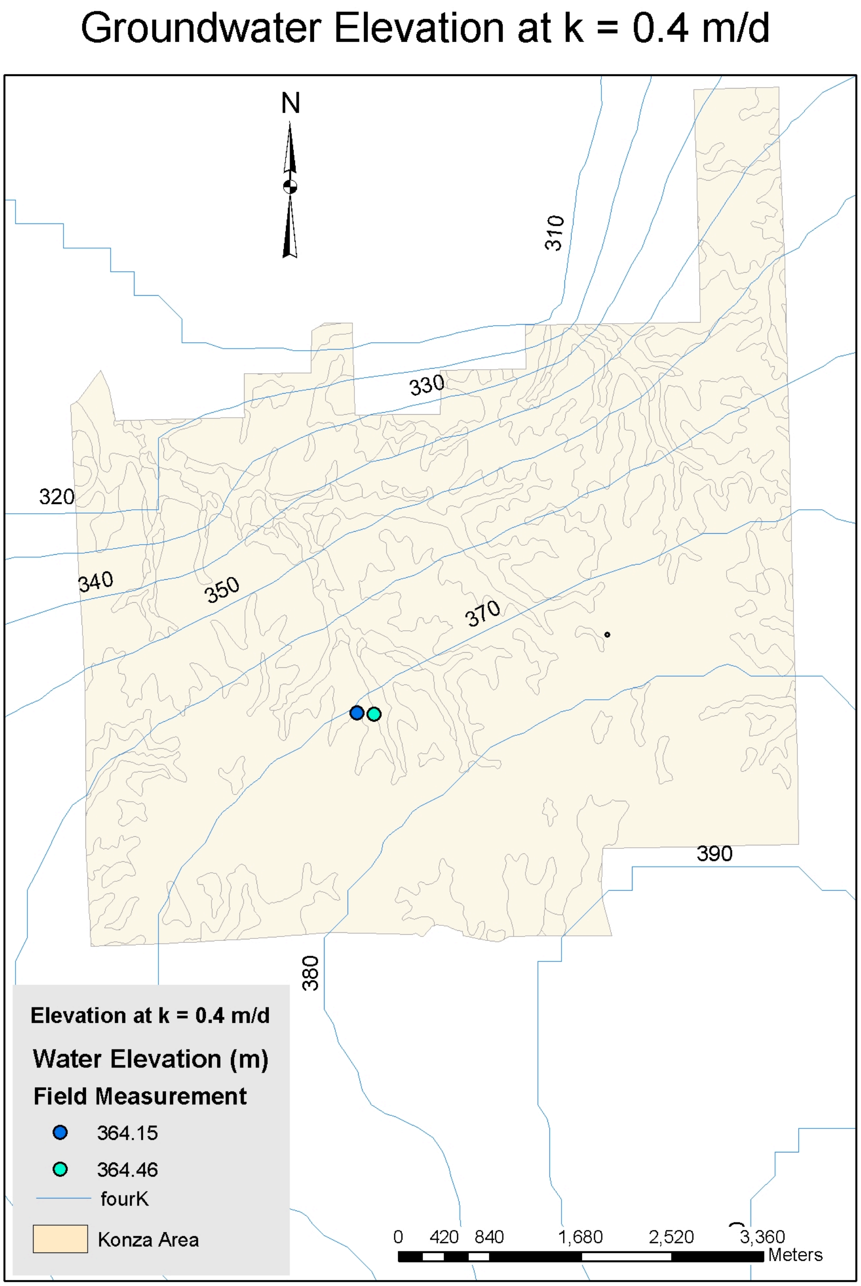

Figure 4.15. Groundwater elevation for 0.4 m/d hydraulic permeability

The above results show that, as the hydraulic permeability (k) value decreases the model groundwater elevation increases and the results gets closer and closer to the field measured value. The groundwater elevation values generated by SPLIT groundwater model with a hydraulic permeability (k) value equals to 0.5 m/d produce a match result as shown on Figure 4.14.

The regional groundwater elevation results for the average recharge estimated by SPLIT model after calibration are presented on Figure 4.16. This result shows a presence of groundwater divide at the middle of our study area, with the highest groundwater elevation of 460m at the divide. From this divide the regional groundwater flow towards the major river valleys. The northern portion of our groundwater results indicates that groundwater flows towards the Kansas River valley. On the southern part of the study area the regional groundwater flows towards Neosho river valley.

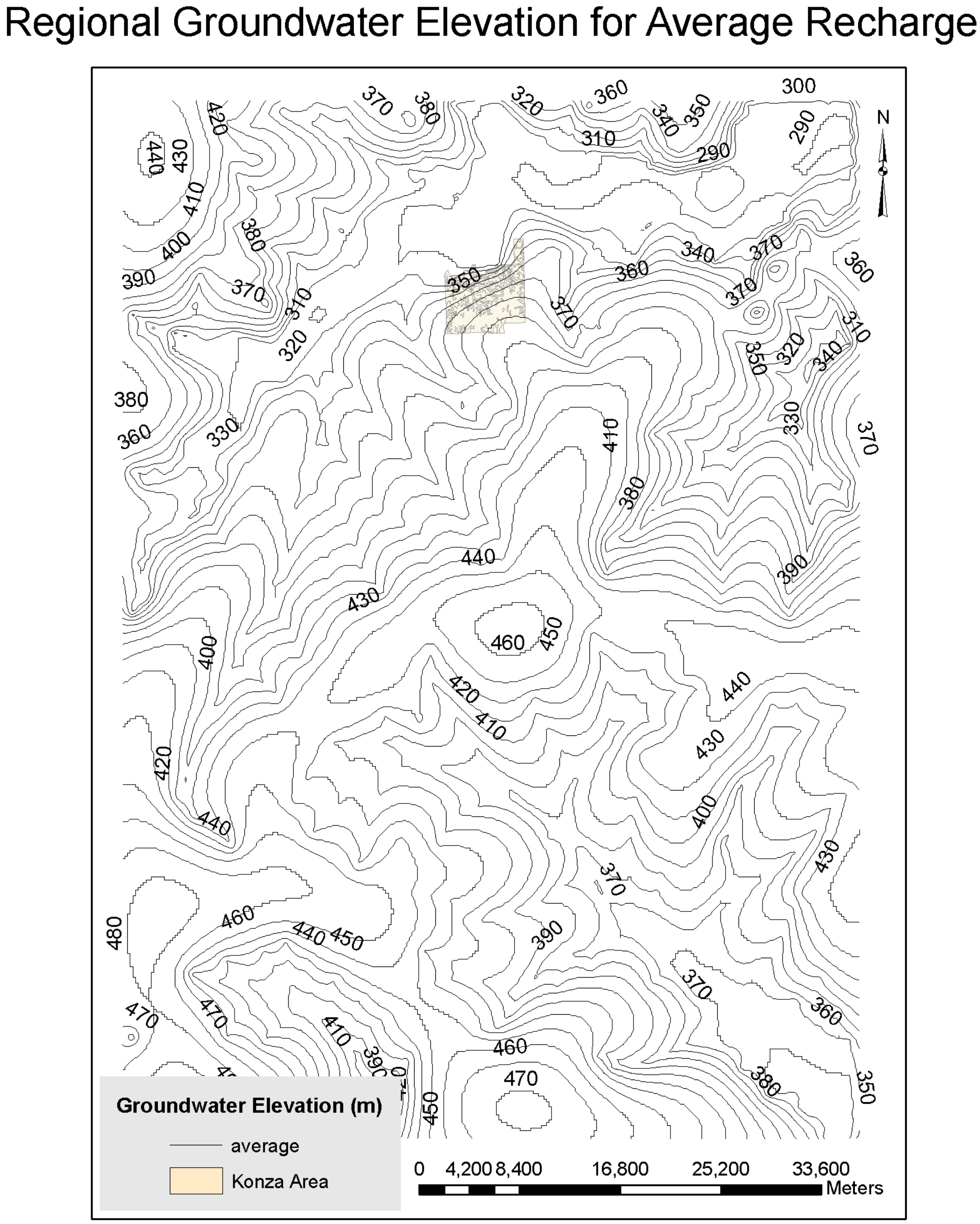

Figure 4.16. Regional Groundwater Elevation based on Average recharge

The depth to water for Konza prairie based on the average recharge after calibration is presented on Figure 4.17. This result was obtained by taking the difference between the Digital Elevation Model (DEM) and SPLIT groundwater elevation calculated using the 0.5m/d hydraulic permeability value.

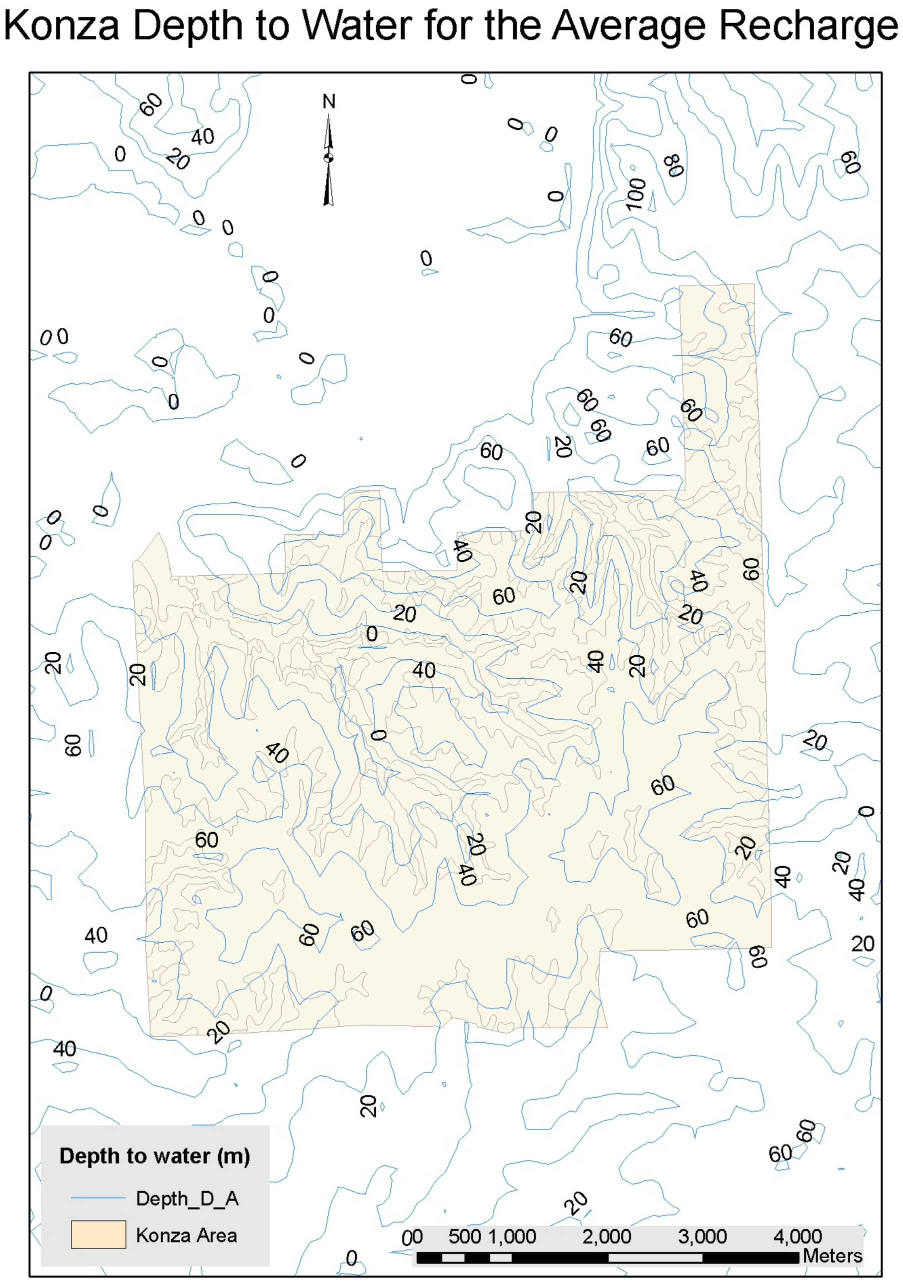

Figure 4.17. Konza Depth to water

At Konza prairie the depth to water is deeper on the hills and shallow along Kings Creek river valleys. Depth to water near the Mc Dowels creek is closer to the surface compared to other parts of Konza prairie. The deepest depth to water in Konza is about 60m below the ground surface and the shallow point is 0m. This results suggests that stream portion located at Kings creek valley near Mc Dowels creek are well connected to the groundwater aquifer, but the ones located in other parts of Konza area are not directly connected to the aquifer.

4.2.3 Minimum and Maximum annual recharge

The minimum annual recharge value was selected to represents driest year were the value of annual recharge calculated by EPIC model was zero for all three soil types. Results for the year with zero annual recharge are presented in Figure 4.18.

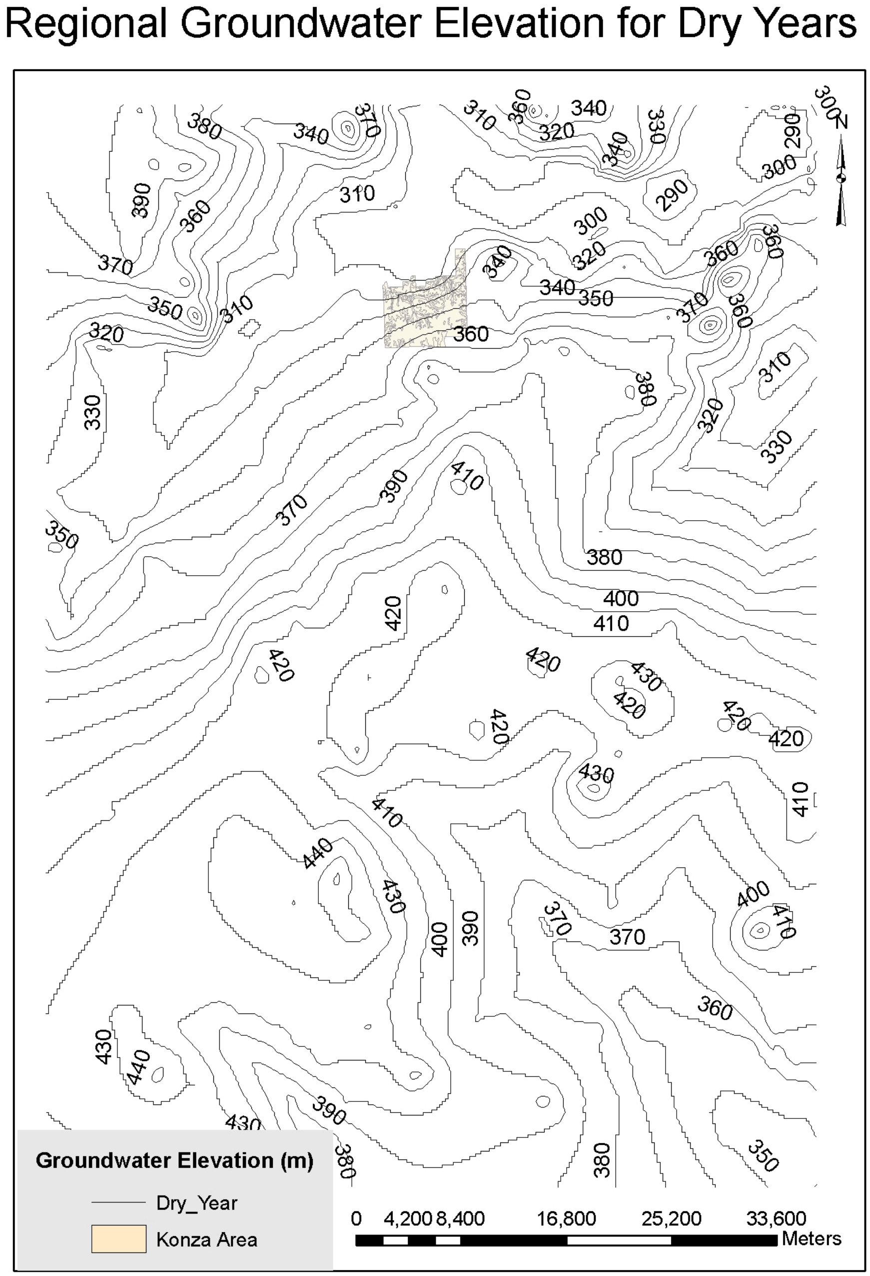

Figure 4.18. Regional groundwater elevation for a zero annual recharge value.

The regional groundwater flow regime indicates that there is a groundwater divide at the central part of our study area. The groundwater level at the divide is about 420m above sea level, which is about 40m deeper compared to the divide elevation for the average annual recharge. This divide separates the two flow regimes, one with flow towards the northern direction and the other with flow towards the southern direction.

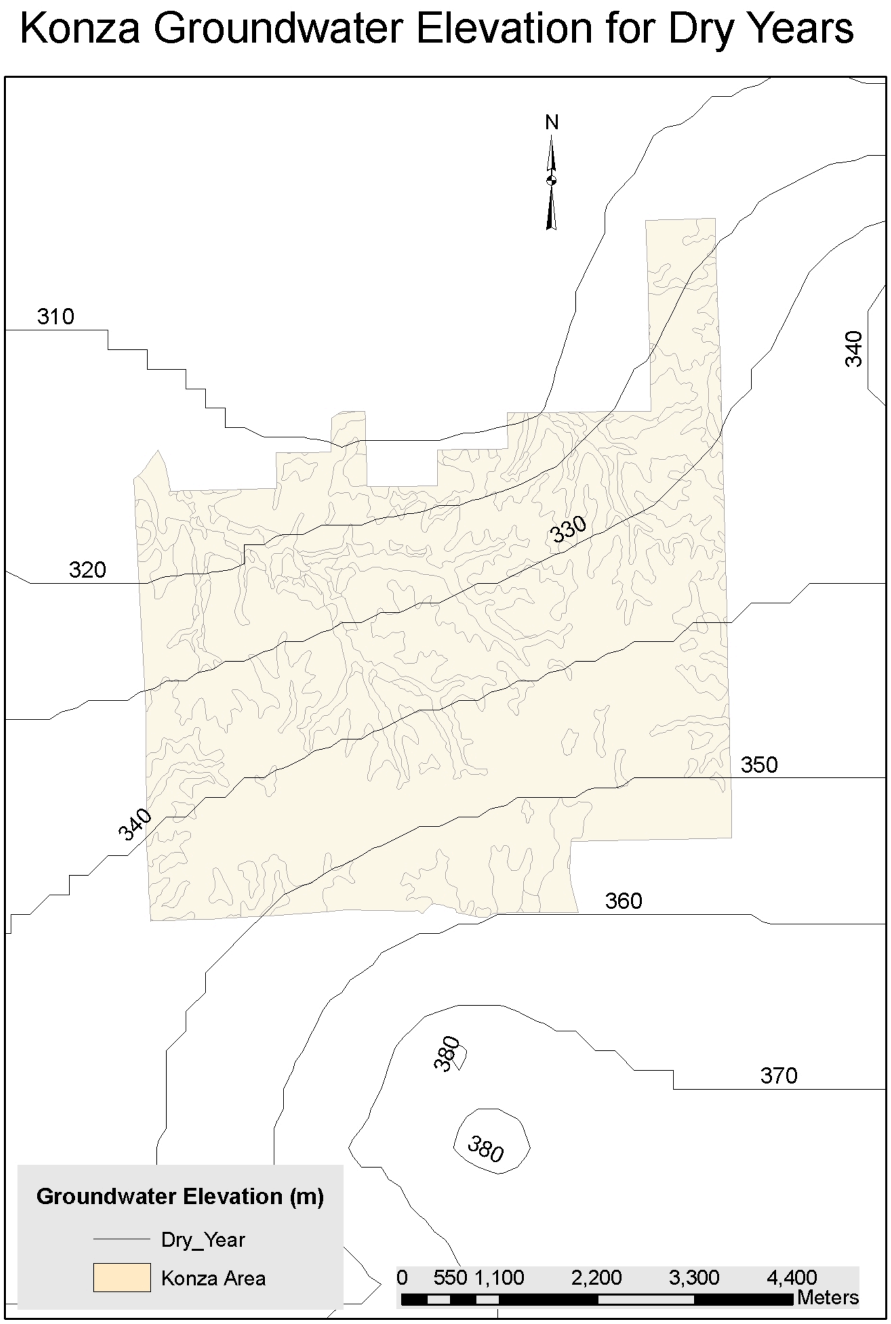

Figure 4.19. Konza groundwater elevation during driest year

In Konza Prairie area the groundwater elevation contour for zero recharge range between 360m at the southern side to about 310m above sea level near Kansas River (see Figure 4.19). The groundwater flow regime slightly follows the surface water flow regime. Results indicates that, the groundwater in Konza prairie area generally flows from South east to North west direction towards Kansas river and when it reaches Kansas River the flow direction changes to West-East flow direction following Kansas River. The groundwater flow direction results are similar to other results presented earlier.

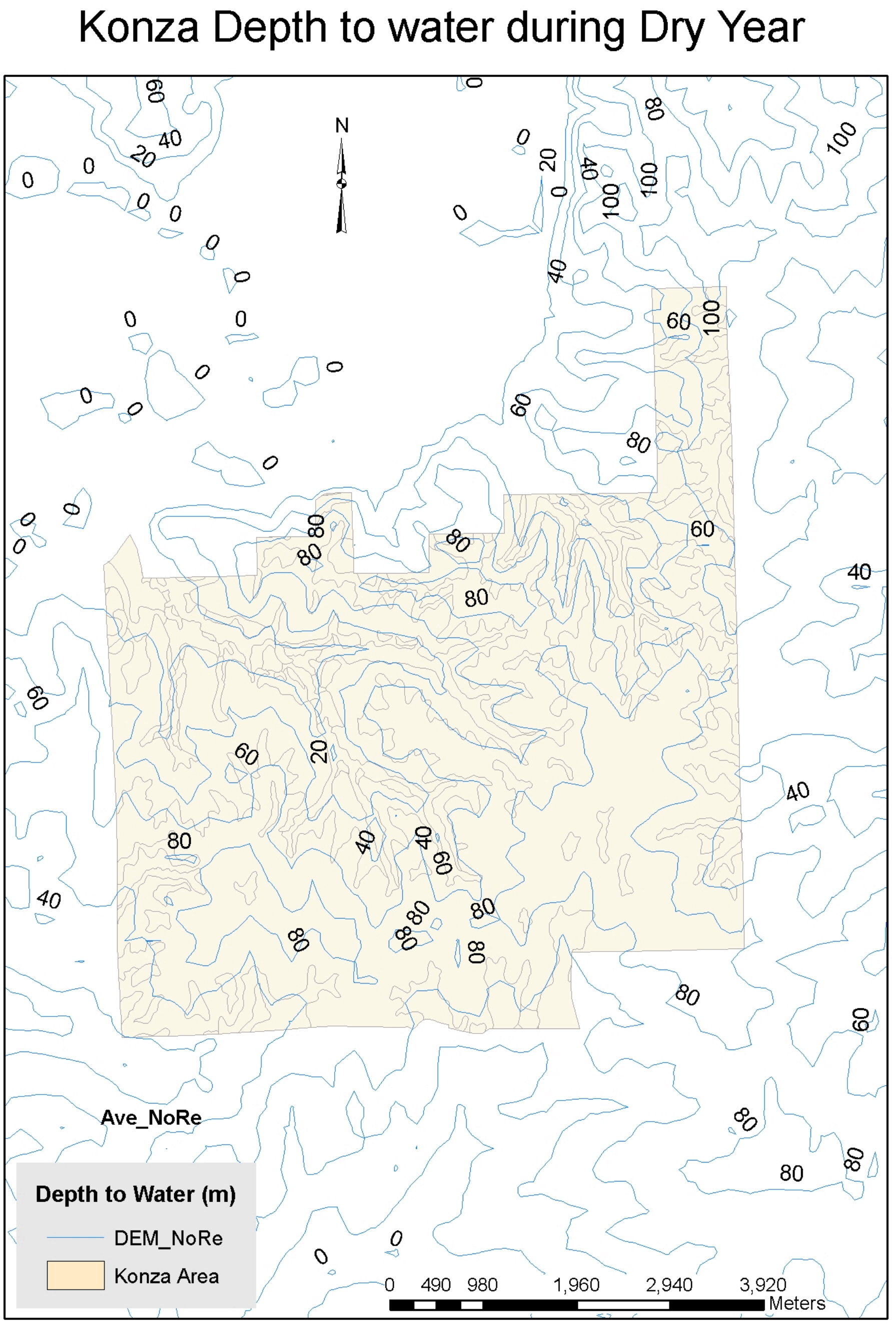

Figure 4.20. Konza Depth to water during dry year.

The difference between the Digital Elevation Model and Groundwater contour results indicates that, the depth from the ground surface to the groundwater table range between 0m near Kansas River to 100m at the places with high hills in Konza area (see Figure 4.20).

The regional calibrated average recharge groundwater grid minus No-recharge groundwater grid indicate a change in groundwater level between 0m and 77m (see Figure 4.21).

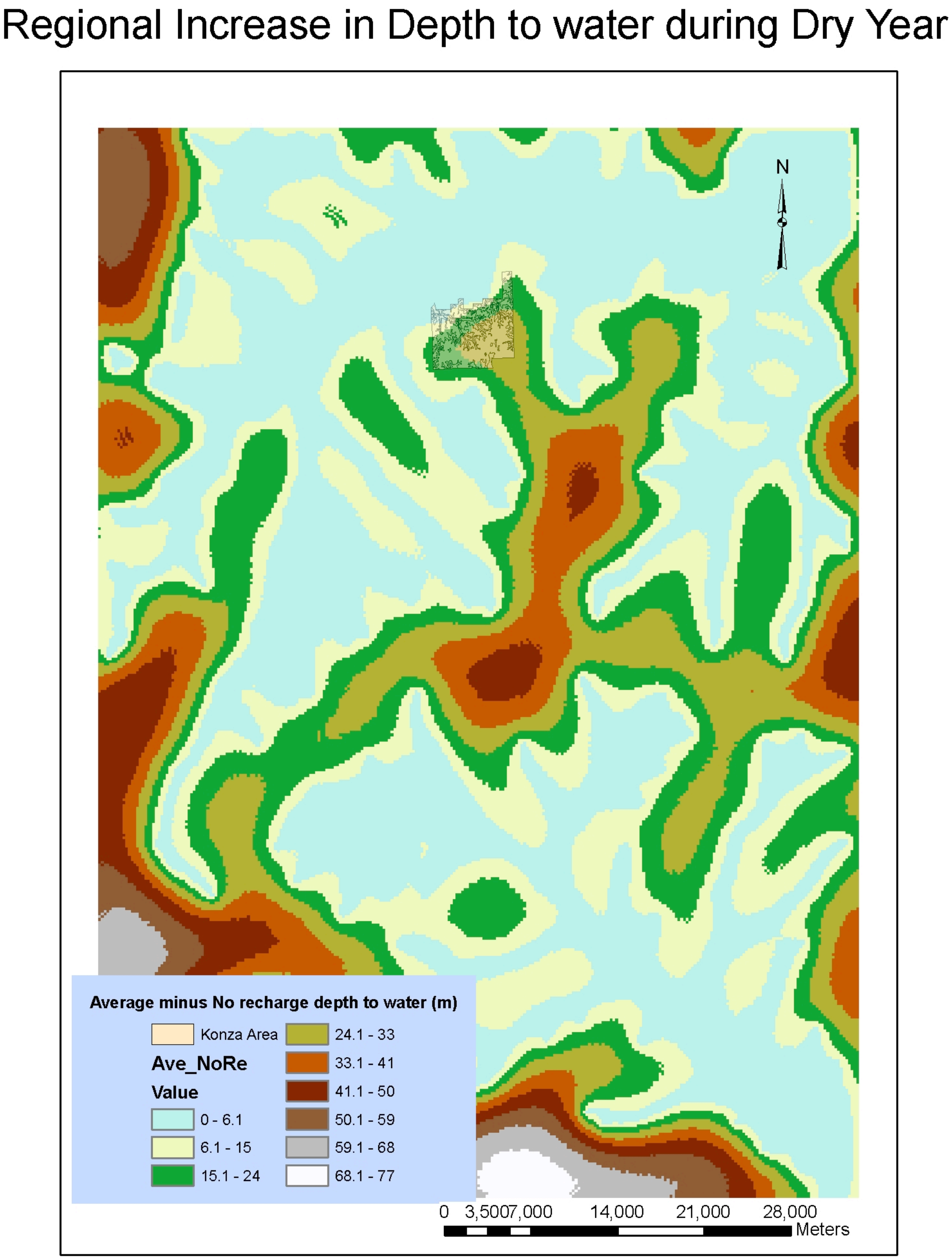

Figure 4.21. Regional increase to depth to water during dry year

If we consider our Konza Prairie alone the groundwater depth to water will increase between 0m and 33m according to the model results (see Figure 4.22).

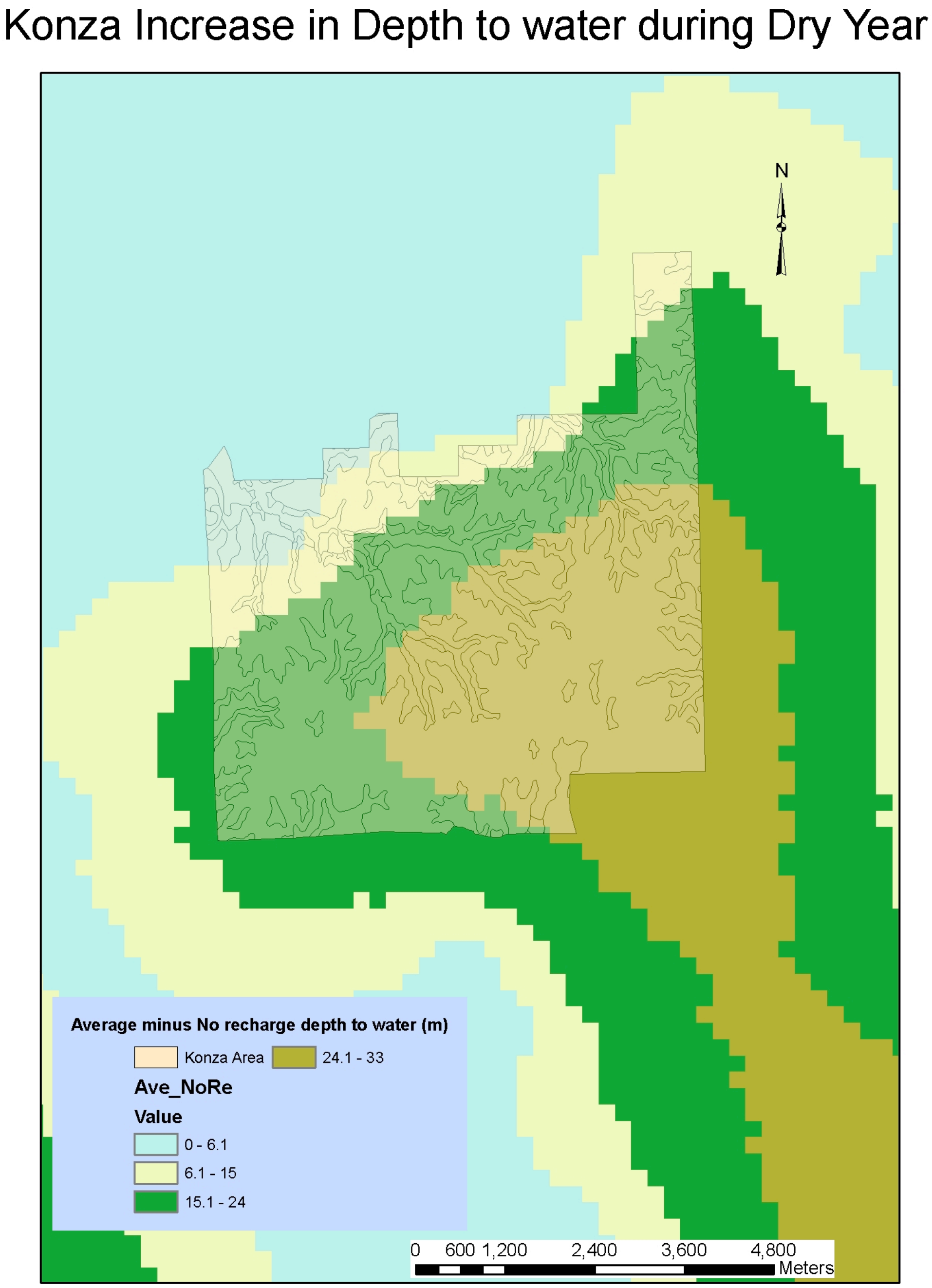

Figure 4.22. Konza increase in Depth to water during dry year

The model results for the groundwater elevation and depth to water during single dry years appear to be unrealistic if compared to the calibrated model of the 21years of record. The increase in depth to water to about 77m in the regional model and 33m in

Konza area for a single year appears to be too big and physically incorrect. The reason for this is the fact that groundwater elevation change responds very slowly to the increase or decrease in recharge. It normally takes years before the impact is realized. So to obtain a realistic groundwater level changes as recharge decreases a different approach is needed.

A maximum annual recharge value was selected to represent the wettest year in the record for 1985 to 2005. Annual recharge for year 1993 was selected to represent the most wet year. Results for the Maximum recharge indicates that the groundwater level increases significantly (see Figure 4.23). The groundwater flow regime resembles the previous cases. The main difference is the increased in head or decrease in depth to water. The model results indicates that the groundwater is getting closer to the earth surface and in some places it appears to be above earth’s ground surface.

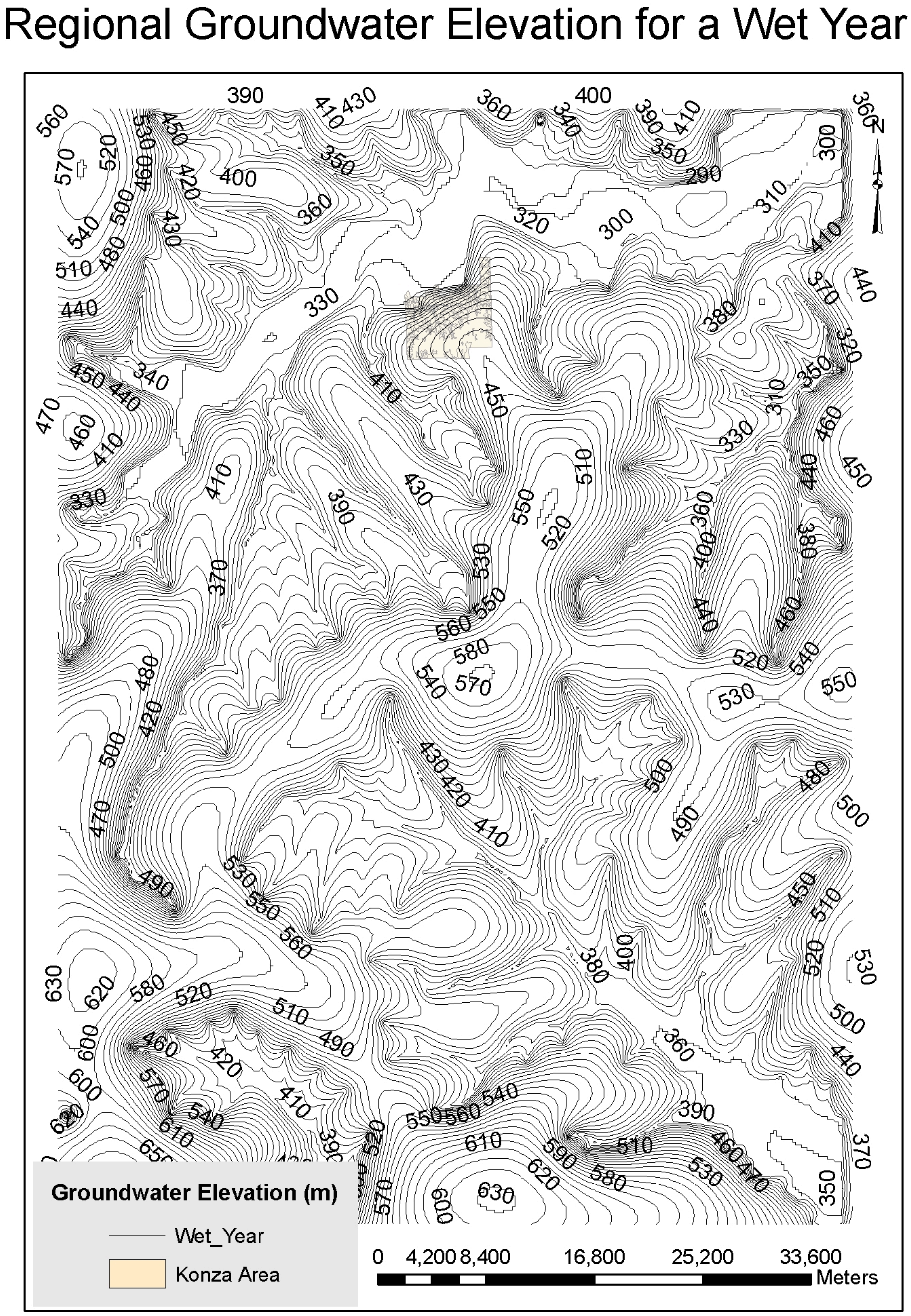

Figure 4.23. Regional groundwater elevation for year 1993.

In Konza the groundwater level range between 310m to 460m above sea level. The flow regime remain the same as the previous cases (see Figure 4.25).

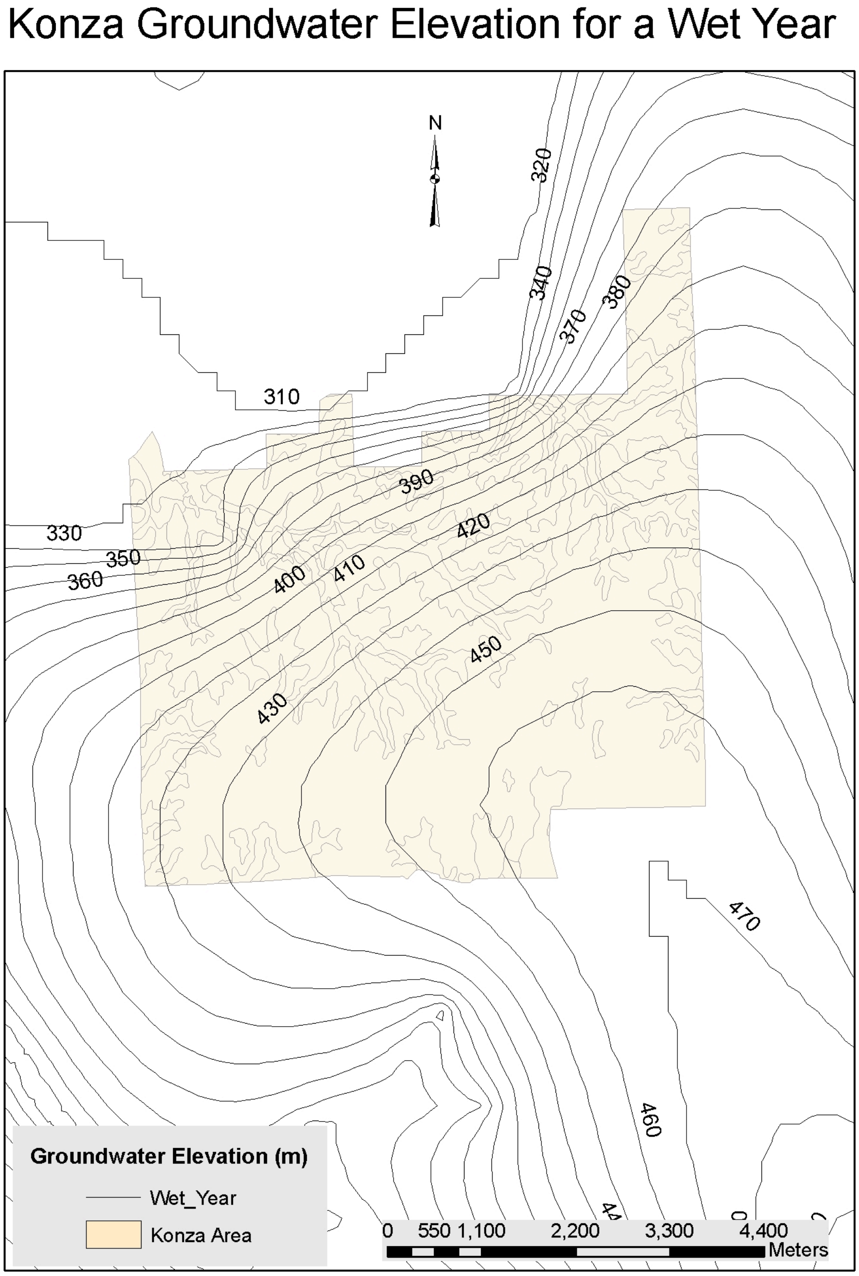

Figure 4.24. Konza groundwater elevation for the wet year of 1993

Taking the difference between the DEM and the SPLIT Groundwater level for the wet year (see Figure 4.25). The results indicate that the EPIC calculated groundwater elevations are higher than the DEM. This means the groundwater elevation is far above the ground surface. Again this is physically incorrect.

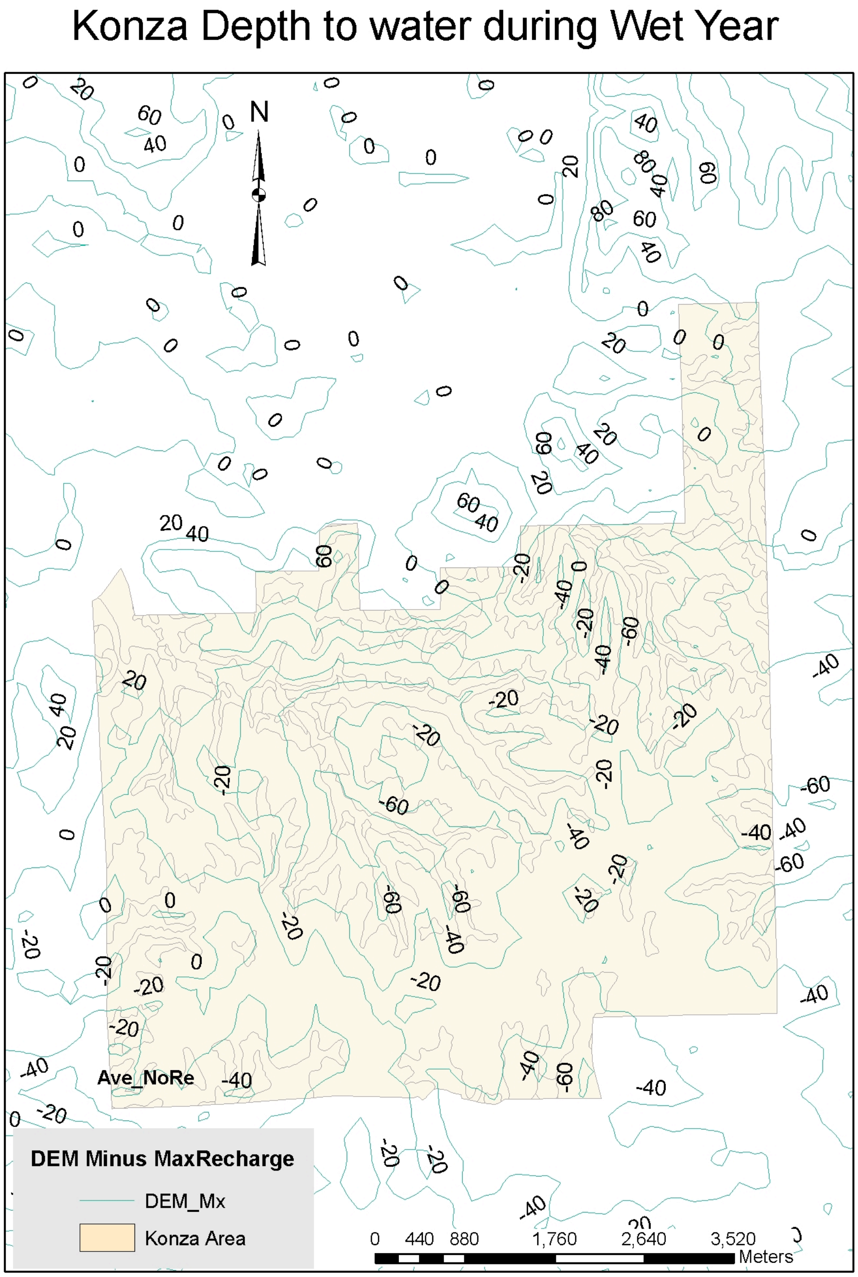

Figure 4.25. Depth to water for the wet year of 1993.

The groundwater elevation and depth to water calculated by SPLIT based on a single year that represent either the minimum or the maximum annual recharge value for a given historical data will not produce realistic results. As it was expressed earlier that the groundwater elevation changes takes couple of years of recharge changes to cause an effect. To calculate the groundwater elevation that will give more realistic results an average value for several years must be considered.

4.2.4 Lowest and Highest five years moving average recharge

To correct our groundwater elevation results for the purpose of accommodating changing annual recharges, a five years moving average approach was used. Based on this five years moving average recharge results, two groups were formed. The groups were formed by selecting the highest and the lowest five years moving average recharge point for the 21years considered in this study.

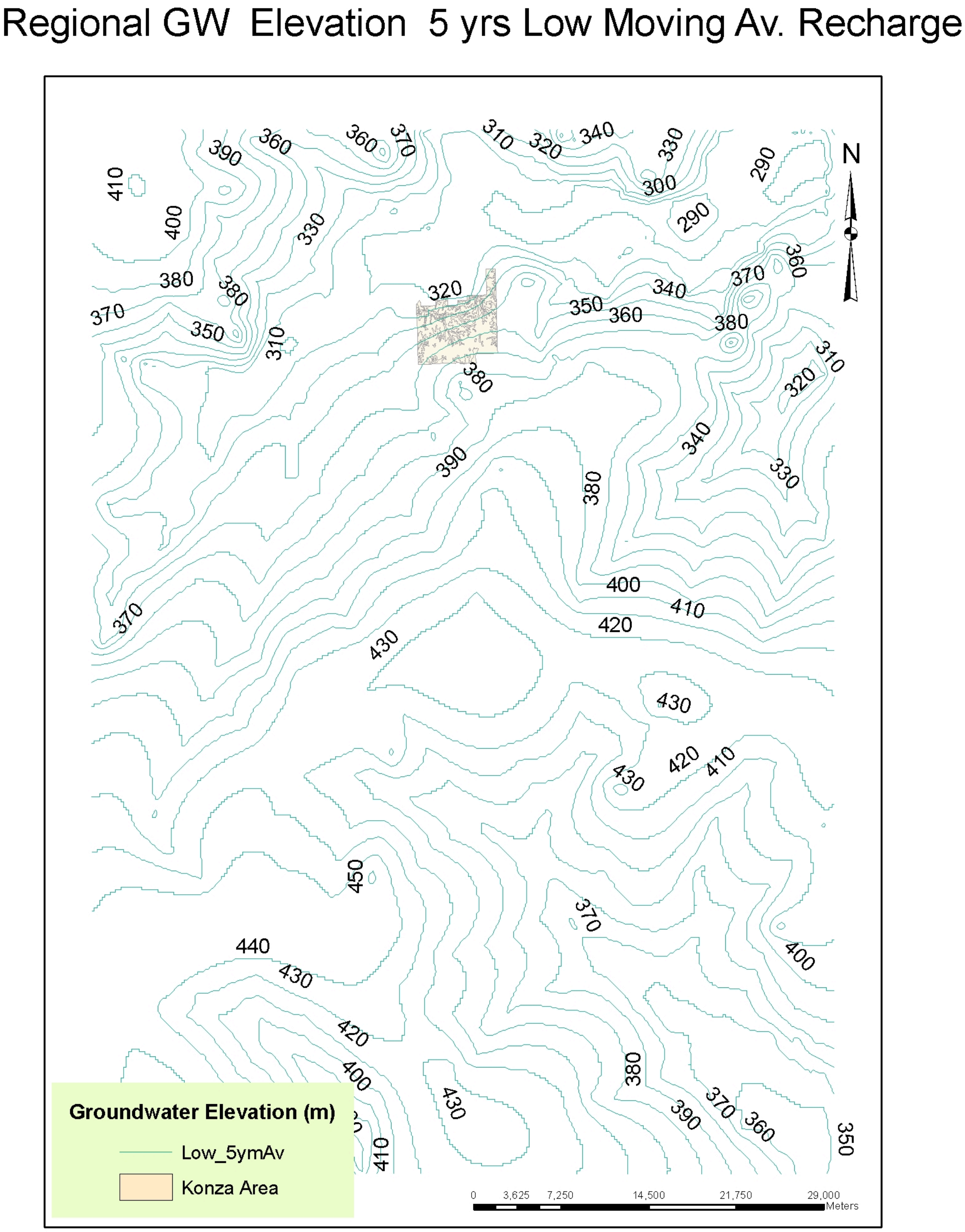

Figure 4.26. Groundwater Elevation for the Lowest five years moving average recharge.

The groundwater flow regime for the lowest five years moving average appear to have a water divide at the central part of the study area (Figure 4.26). This divide is located at the groundwater elevation of 430 meter above sea level. From this divide the groundwater tend to take two different directions, one towards Kansas River and the other towards Neosho River. This is very similar to the previous cases.

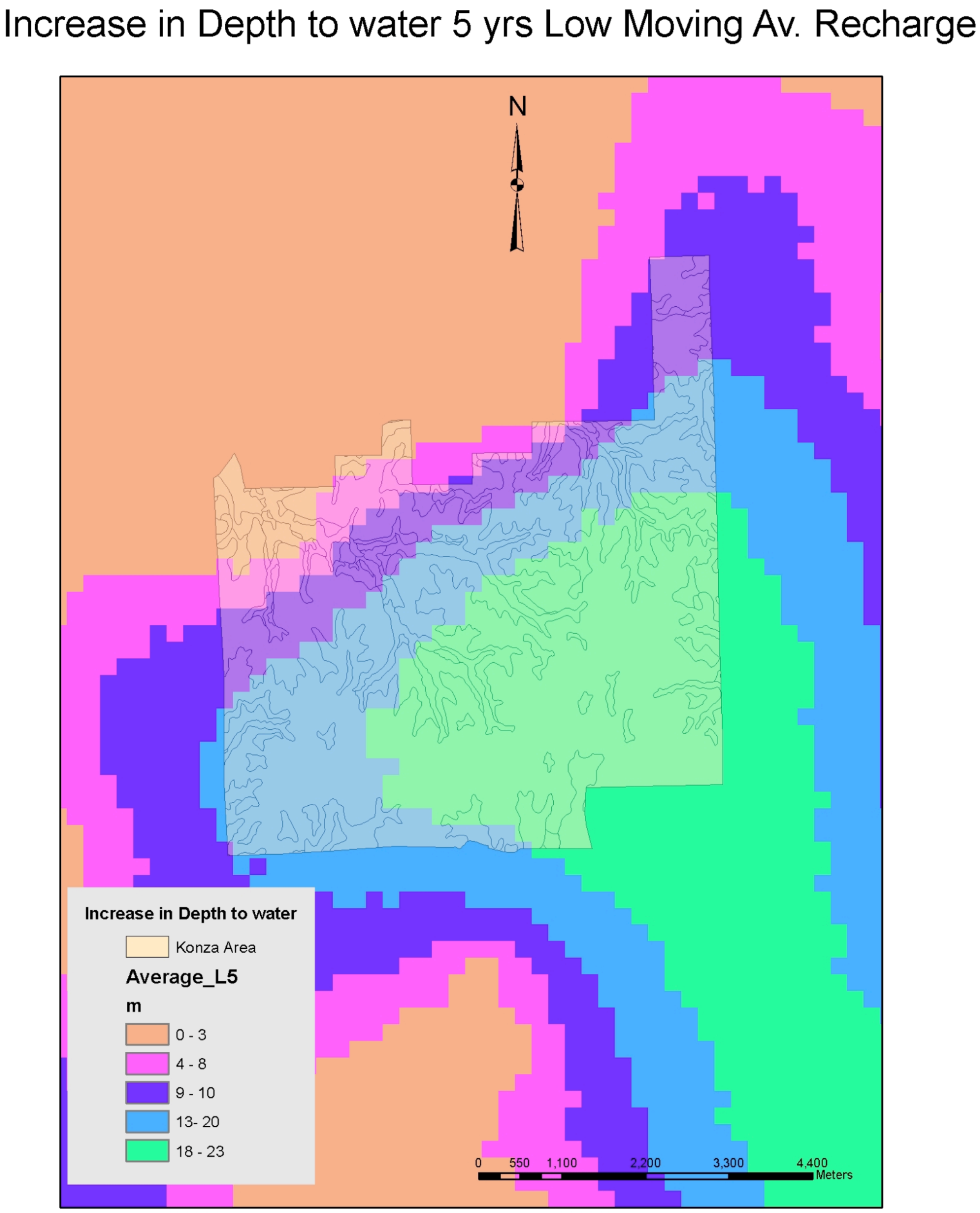

Figure 4.27. Increase in Depth to Water for the Lowest five years moving average recharge from the annual average recharge elevation.

The Konza depth to water based on lowest five years moving average range between 0 m and 23m below the annual average groundwater elevation observed in the field. (Figure 4.27)Remember that this annual average groundwater elevation field measurement is the same as the groundwater elevation contours simulated by SPLIT model based on average annual recharge after calibration.

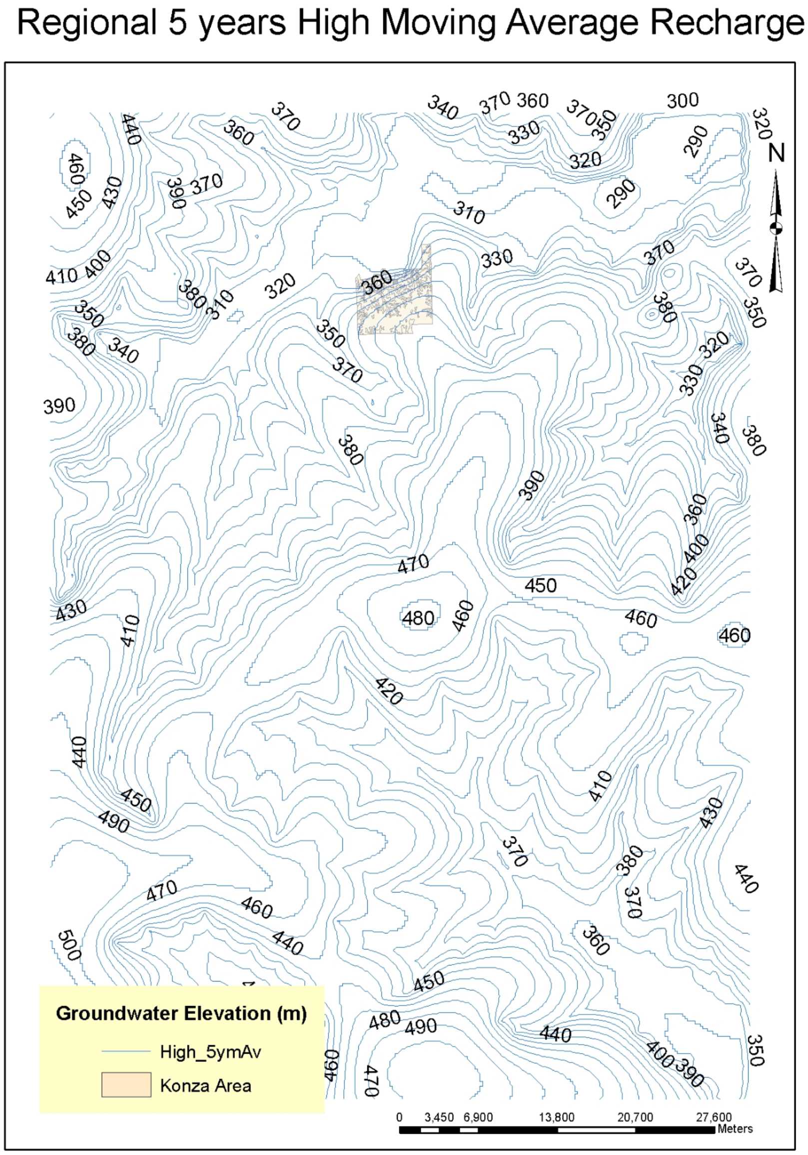

Figure 4.28. Groundwater elevation for the Highest five years moving average.

For the case of highest five years moving average groundwater elevation, SPLIT simulated results indicates that the groundwater flow is similar to the other cases were by in this case the groundwater divide was located at the groundwater elevation of 480m (see Figure 4.28).

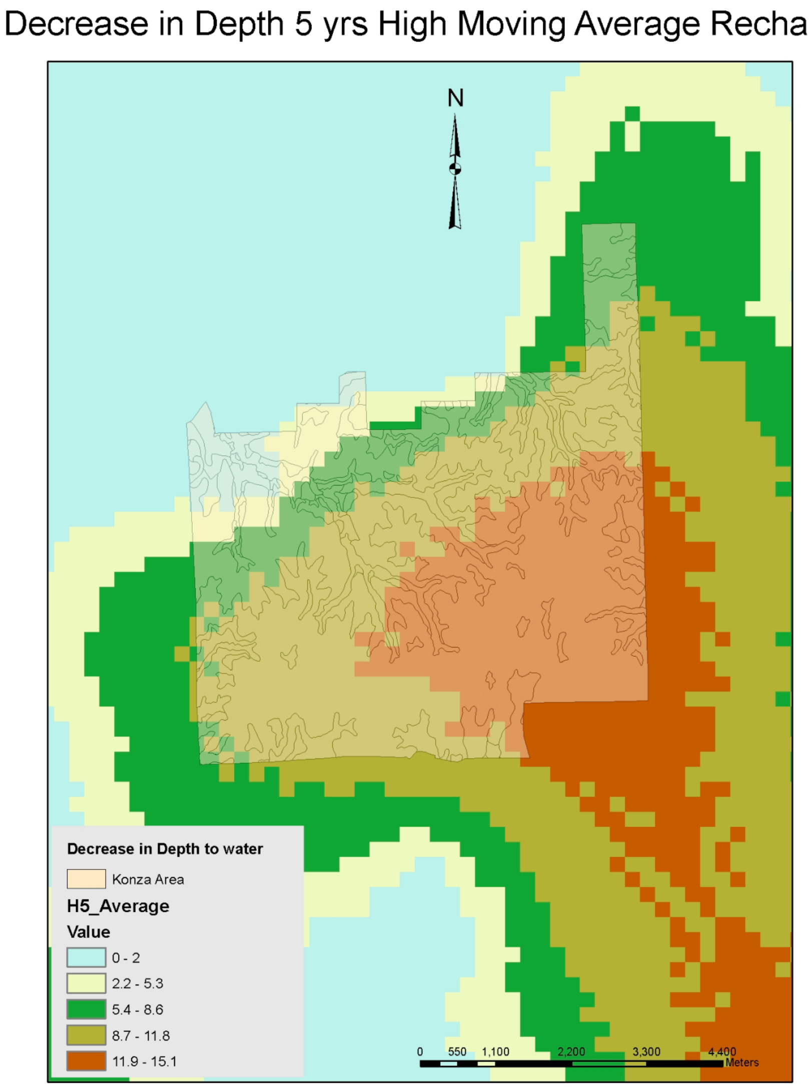

Figure 4.29. Decrease in Depth to Water for the Highest five years moving average recharge calculated from historical annual average recharge (Calibrated model results).

When the highest five years moving average recharge is used in the simulation. The groundwater elevation will rise between 0m and 15.1m above the annual average recharge elevation (see Figure 4.29).

CHAPTER 5 - DISCUSSION OF RESULTS

The average recharge rates generated by EPIC model indicates that different soil types have different recharge rates. Deep and well drain soils like Ivan has high permeability rate which lead them to generate high recharge rates. Shallow and slowly permeable soils like Clime results to low recharge rates (see Figure 4.1). On the other hand the same graph indicates that years with high precipitation has resulted to high recharge rates. This graph suggests that soil type and precipitation has direct relationship to annual recharge rates. The EPIC model estimates the average annual recharge rate using the North Agronomy farm weather historic data to be 0.000254 m/d which is about 12% of the annual average precipitation historic data (1985 to 2005). The EPIC calculated recharge rate is closer to the regional recharge value of 0.00032m/d suggested for the Eastern part of Kansas by Warren in 1995(Sophocleous, 1998).

The EPIC simulated annual average potential evapotranspiration (PET) result for the three soil for year 1985 to 2005 were; Clime soil annual average PET was 1133mm, Benfield soil was 1149mm and Ivan soil was 1166mm. The average annual PET for Konza prairie was estimated to be 1150mm. The PET for individual soil type appears to be very similar (see Figure 4.2). The EPIC model annual PET simulated results of 1150mm tend to fall within the PET range for the Eastern part of Kansas calculated by Farnsworth et al., 1982, using the Penman's Montain equation, with a green grass cover and the weather data for 1956 to 1970 and published by Sophocleous, 1998. The published annual PET range between 1100mm for the northeast Kansas to 1700mm in southwest Kansas.

The EPIC simulated annual ET for the Konza grassland was about 601 mm. This value fall within the range of annual ET values calculated for the state of Kansas by Wetter, 1987. (Sophocleus, 1998). The mean annual evapotranspiration (ET) values range between 450mm from west of Kansas and increase to the east of Kansas to 775mm. The annual ET 601mm fall within the proposed ET values for the state of Kansas.

The simulated biomass production by EPIC ecological model was based on several assumptions about the land management practice in Konza prairie. These assumptions were made to simplify the modeling process, they includes; burning treatment was performed in a one year rotation, second was the whole Konza area was considered to be used as grazing ground and closer to the end of the year about 95% of the grass were consumed by the animals grazed in this land. No irrigation and no fertilizer or pesticides were applied in Konza tall grass prairie. Results for the biomass production are presented on Figure 4.3. In average the annual average biomass production was 9.4 T/HA. More biomass was produced by Ivan soils about 10.7T/HA, followed by Benfield 9.8T/HA and Clime was the last with 7.6T/HA. This results suggests that soils with higher permeability produce more biomass than the low permeable soils. Changes in those management practice assumptions used in this investigation will change the biomass production in Konza prairie area. Comparison between precipitation and biomass production did not indicate any strong relationship between (see Figure 4.3). This suggests that other factors such as temperature and crop type may have influence in biomass production results than precipitation alone. No published data for biomass production are available for comparison.

The EPIC annual runoff calculations are presented on Figure 4.4. Based on literature review, EPIC model is considered to be not a good calculator for surface water runoff. The literature suggests that it underestimate the short term runoff results, but the annual runoffs estimation is expected to indicate strong association with the field measured values. For Konza prairie runoff results presented on Figure 4.4, can only be used as preliminary results. In this study annual runoff results were not calibrated due to the fact that in Konza only Kings Creek stream has field measured historic flow data. The other four streams do not have gage stations so no measurements are available for comparison. Run off results presented in Figure 4.4 suggests that soils like Clime which has low permeability produces more runoffs than soils with high permeability like Ivan. In year 1993 the runoffs were about 400mm/y. This happens to be the most wet year in our precipitation data records and it is reported that this year was associated with serious flooding in Konza streams. This result also suggests that, there is a strong relationship between annual precipitation and stream annual runoff rates.

The annual average runoff for Konza was considered to be 88.64mm, with Clime having the highest runoff of 159.7mm, followed by Benfield with 88.4mm and last was Ivan with 17.8 mm. If we include the value of annual lateral flow which was 7.45mm the surface annual runoffs may be considered to add up to 95.85mm. This is about 12% of the annual average precipitation. It is believed that in long term the groundwater recharge water will eventually drain into Konza streams. The combination of annual surface water runoffs and recharge in Konza prairie will give us an annual steam base flow with the value equals to 24% of the annual precipitation. From Figure 2.11, the stream annual base flow measured at Kings Creek USGS station for year 1985 to 2005 indicates that the stream base flow is about 25% of the annual precipitation.

Using the annual average recharge calculated from EPIC for year 1985 to year 2005, the hydraulic permeability values can be adjusted to find a match between the field measurement and SPLIT model simulated results. During this investigation it was found that by using the annual recharge calculated by EPIC model and other stream and aquifer information presented in chapter three. The hydraulic permeability value to be used in SPLIT groundwater model should be less than one meter per day to produce meaningful groundwater elevation results. Different hydraulic permeability values were used and different groundwater elevation results were produced (see Figure 4.12, Figure 4.13, Figure 4.14, and Figure 4.15). By changing the hydraulic permeability (k) values from 0.8m/d to 0.6m/d the SPLIT simulated results gets closer to the observation well field measurement. The k value was then changed to 0.5m/d and 0.4m/d. As shown in Figure 4.14, and Figure 4.15, respectively, it seams that the k value that will produce a match between the simulated results and field measured values lies between k = 0.5 and 0.6m/d.

The relationship between the groundwater elevation simulated results, field measured average elevation value, and changing hydraulic permeability are presented on Figure 5.1 and Figure 5.2. The value of hydraulic permeability that will produce a precisely match for an observation well located at site 4-6 Morrill limestone will be at k = 0.555m/d (see Figure 5.1).

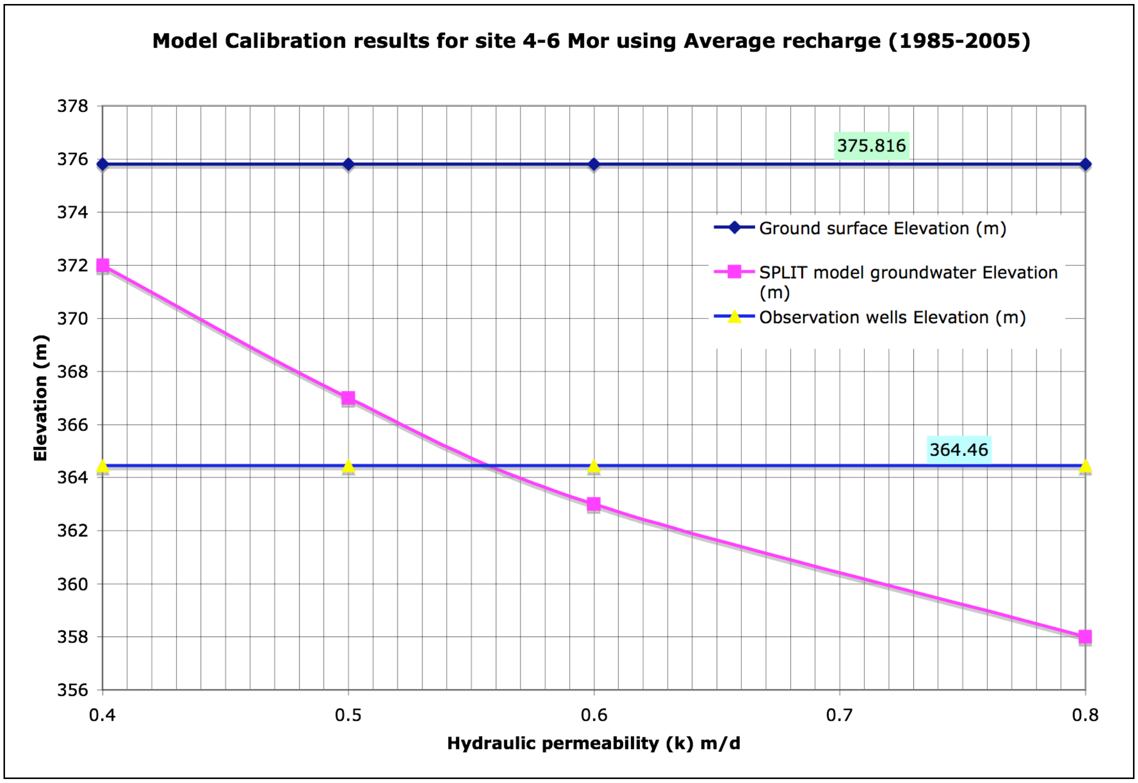

Figure 5.1. SPLIT model calibration for a well at site 4-6 Morrill using the average Recharge.

The groundwater observation well located at site 4-6 Morrill limestone indicates that the depth to water is about 11.356m below the ground surface. The well depth for this site is about 12.65m deep. Groundwater elevation results presented in Figure 4.12 to Figure 4.15, and Figure 5.1, indicates that keeping annual average recharge, stream information and aquifer properties constant. The groundwater elevation decreases as the hydraulic permeability increases.

During this investigation another well located at site 4-7 Morrill limestone was used together with the one located at site 4-6 Morrill limestone for the SPLIT model calibration. The well at site 4-7 Morrill has a historic average groundwater elevation at 364.13m above sea level. The depth of this well is 36.515m. The depth to water at this site is about 35.385m below the ground surface elevation. By using the similar approach were by annual average recharge, stream information, and aquifer properties were kept constant, the groundwater elevation SPLIT simulated results tend to decrease at the hydraulic permeability increases.

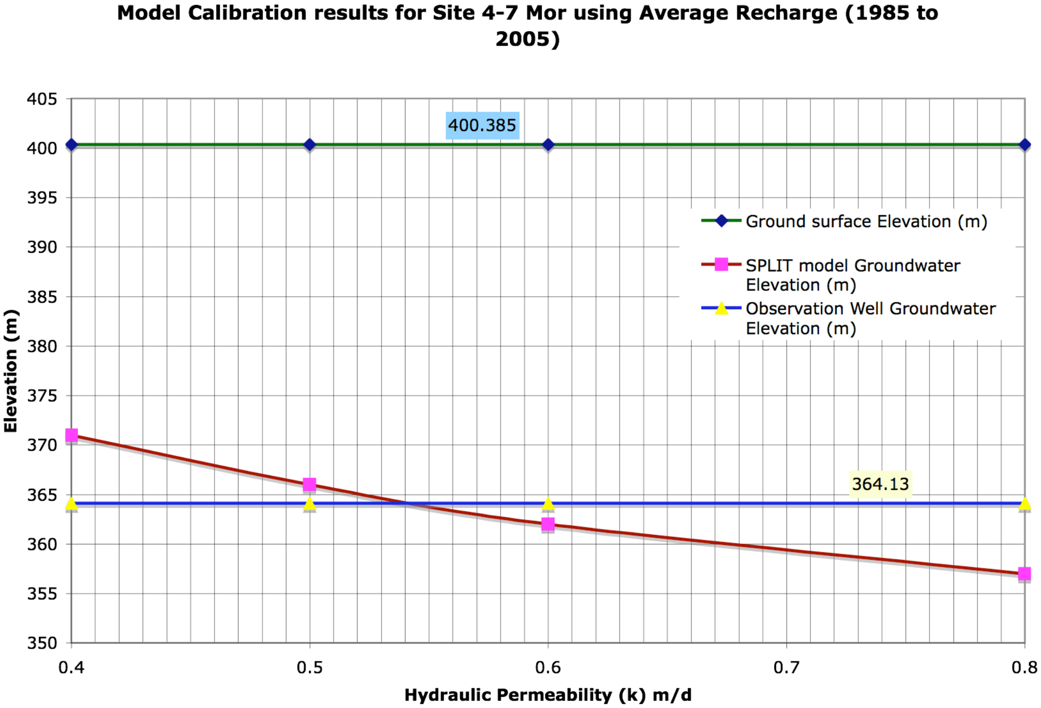

Figure 5.2. SPLIT model calibration using a well at site 4-7 Morrill and average Recharge for year (1985 to 2005).

By changing the hydraulic permeability value from 0.8m/d, 0.6m/d, 0.5m/d and 0.4m/d. The SPLIT simulated results tend to get closer to the field measured well elevation values. Results for the simulated groundwater elevation are presented in Figure 4.12 to Figure 4.15. From this figures it is clear that, a good match between the simulated SPLIT elevation results and the field measured values is located between k = 0.5m/d and 0.6 m/d as in the previous case. Figure 5.2 , presents a relationship of elevation and hydraulic permeability. To obtain a precision match between the field measured values and the model simulated results the hydraulic permeability value need to be equals to 0.54m/d. If we decide to take the average between the two values for the two sites were well measurements were taken for this calibration. The average hydraulic permeability will be k = 0.546m/d. This hydraulic permeability together with recharge and aquifer parameters were used in the SPLIT groundwater model to established a calibrated groundwater model for Konza (see Figure 5.3).

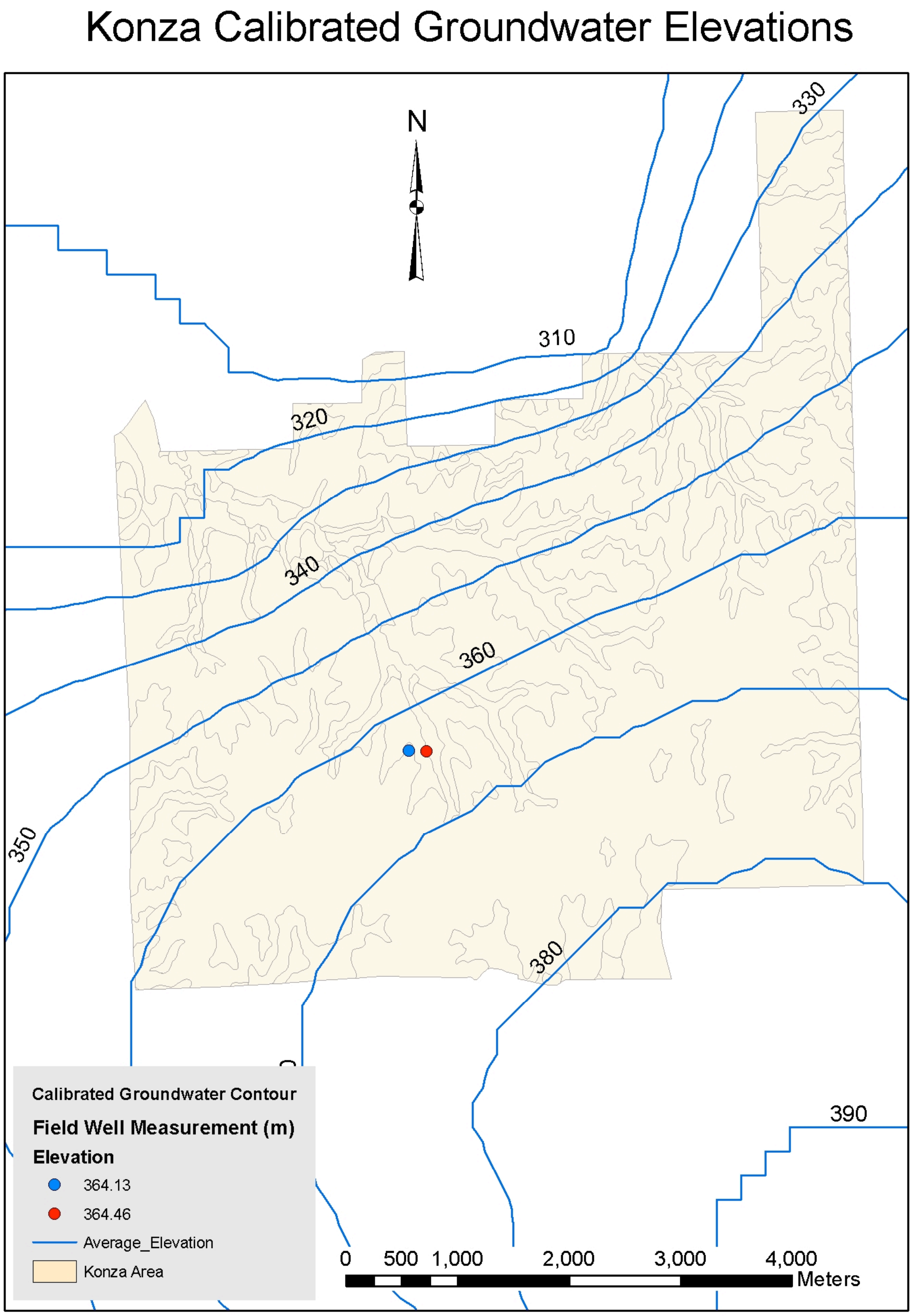

Figure 5.3 Calibrated Konza Groundwater Model

Investigation on what will happen to the groundwater elevation as the recharge to groundwater changes take place was also performed during this study. The calibrated hydraulic permeability for Konza of 0.546m/d, stream information and aquifer properties were kept constant. Four different case scenarios were considered. The what if case scenarios were for the extreme recharge from a year with the maximum annual recharge, a zero annual recharge (dry year), a low value for a five years moving recharge average and a high value for a five years moving recharge average.

The result obtained for the maximum annual recharge for the historic weather data used in this report indicates that during a single year with maximum recharge as it was in 1993. The groundwater elevation in Konza prairie will go up between 0 to 60m, above the average field well measured value or the average groundwater contours based on average recharge. During a dry year where recharge was zero the groundwater elevation in Konza will go down between 0 and 33m below the field well elevation of 364m. It is clear that both of these results for a single dry year or a single wet year are too high and too low, and they don’t make any physical meaning. The reason for these unrealistic results is the fact that for a low value of hydraulic permeability as 0.546m/d a groundwater elevation changes will need couple of years of recharge changes to cause a realistic effect. In other words if the hydraulic permeability is low the groundwater elevation can be significantly affected by a long term recharge changes rather than short term recharge change.

To calculate groundwater elevation that will give more realistic results between the responses of groundwater elevation as recharge changes, a 5-years moving average approach was used. The five years moving average recharge results were prepared and the highest and lowest five years moving average value of recharge was selected and used in the SPLIT groundwater model simulation. Results from the low value of five years moving average indicates that the groundwater elevation will go down to about 20m in Konza prairie (see Figure 5.4). For the high value of five years moving average the groundwater elevation will go up above the historic annual average well measurement by about 11m (see Figure 5.4).

A relationship between the simulated groundwater elevation results for no recharge, average recharge, maximum recharge, 5-years low and 5-years high moving average and the wells elevation at site 4-6, and site 4-7 Morrill are presented in Figure 5.4.These results indicates that the groundwater elevation obtained by five years moving averages are closer to the average annual field groundwater elevation measurement than the one obtained for no-recharge and maximum recharge elevations. If we consider the

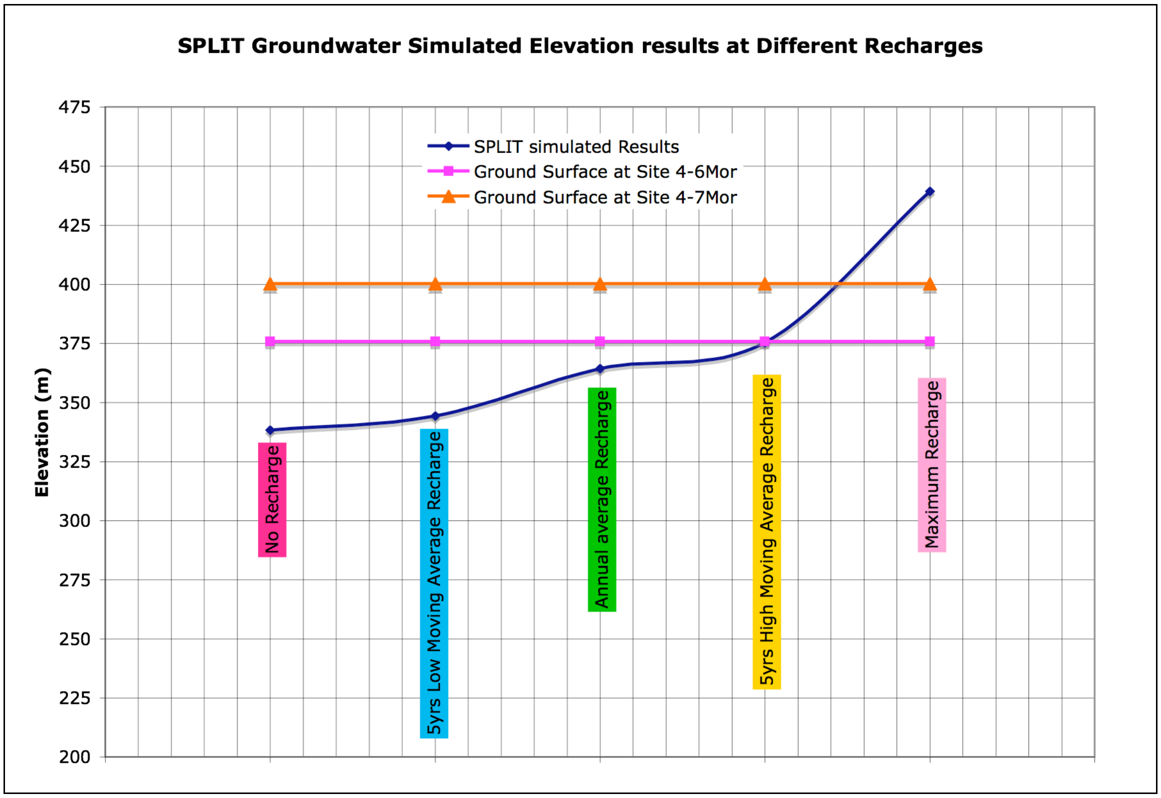

Figure 5.4 Groundwater elevation at the wells at different recharge rates.

observation well at site 4Mor, and the 5years high moving average recharge, the groundwater simulated result tend to coincide with the ground surface (see Figure 5.4). Based on these extreme cases results for the four case scenarios considered in this study; the no recharge, the maximum recharge and high and low 5-years moving average more investigation is required to be able to draw good concussions during an extreme recharge event.

CONCLUSIONS

This thesis puts forth a predictive modeling framework to investigate the interactions between weather, soils, vegetation and groundwater for the Konza Prairie area. Historical daily weather data from 1985 to 2005 were used for this study. The weather data includes daily precipitation, daily solar radiation, daily maximum and minimum temperature, daily relative humidity and daily wind speed. Weather data from a weather station at North Agronomy farm in Manhattan were used to create the weather input file for the model. To select the soil types to use for our model the existing 79 soils were grouped into seven soil groups. The grouping criteria were based on soil texture and percentage of soil surface slope. The seven soil groups formed were sandy soil, complex soils with slope greater than 3%, complex soils with slopes less than 3%, silt clay and silt clay loam with slope greater than 3%, silt clay and silt clay loam with slope less than 3%, silt loam with slope greater than 3%, and silt loam with slope less than 3%. The vegetation of our study area is made up of natural tall grass prairie ecosystem. To model the vegetation of this area rangeland was used to represent the conceptual vegetation model for this area. National Hydrologic Data (NHD) stream information and estimated aquifer parameters were used for the groundwater model.

The Erosion Productivity Impact Calculator (EPIC) ecologic model was used to model this natural tallgrass prairie ecosystem. EPIC ecologic model enables prediction of deep percolation (recharge) to groundwater based upon weather, soil type and management practice. EPIC model produces results based on input of single soil type. To develop a soil conceptual model for Konza area the seven soil groups were examined. Some of these soil group polygons cover small portion of land while other covers large area of land. Based upon the area of land covered by a particular group two dominant soil groups were selected. One of the soil group selected was dominant at the hill tops and hill slopes, the other soil group was found to be dominant in low land areas including streams and river channels surroundings. Within the two major groups three types of soils were found dominant in the groups. These dominant soils were Ivan, Clime and Benfield. These three soil types were used to create the conceptual soil model for the Konza tall grass prairie.

The ArcAEM groundwater model was used to create the input file for SPLIT groundwater model. The groundwater model SPLIT was used to investigate the impact of variations in deep percolation (recharge) to the groundwater elevation and flow regime together with base flow to streams and rivers. SPLIT model is created based on the Analytical Element Method. To develop the input file for SPLIT, the ArcAEM model uses estimated aquifer properties together with streams and rivers information. Aquifer estimated parameter includes aquifer hydraulic permeability, base elevation, and thickness. Rivers and streams information includes location, base elevation, water depth at the vertices, bed width, hydraulic permeability of the bed, and bed resistance. ArcAEM model has interface tool with ArcGIS software. This tool allows direct extraction of information from ArcGIS. Given the capability of this tool, streams and river information were extracted directly from the ArcGIS shape files. Aquifer information were provided to ArcAEM as user typed information.

This investigation found that by keeping management practice (burning and grazing) unchanged each year, recharge varies based upon climatic conditions and soil type. The recharge values were generated by EPIC model as a remainder after it calculates the surface runoffs, lateral flow and evapotranspiration components. Years with high precipitation results in high recharge values, and years with low precipitation results in low or no recharge see Figure 4.1 . The average recharge value for Konza Prairie generated by EPIC model was about 12% of the average precipitation of the historical data used. The Ivan soil that is found in low land and in river valley indicates a highest recharge rates followed by Benfield soil and Clime soil type was the least. Years with annual precipitation values less than 600mm and succeeding a dry year resulted to no recharge. A year 1993 which was the most wet year for the 21 years used in this study resulted to the highest recharge rate of about 425.09mm/yr. Annual evapotranspiration results show that there is no direct relationship between precipitation and evapotranspiration see Figure 4.2. Biomass production indicate some relation ship with precipitation but it seems that other factors such as temperature and soil type may have significant influence on the biomass production, see Figure 4.3.

Konza groundwater model results indicate that the regional groundwater flow for Konza Prairie is directed from southeast to northwest towards the Kansas River (see Figure 4.14). As the groundwater flow reaches the Kansas River it changes the direction of flow following Kansas River which flows from west towards the east see Figure 4.16. Groundwater lies near surface in the neighborhood of river valleys and low lands. This may be caused by the presence of deep and permeable soils in low land areas of Konza. Depth to water was large on high grounds compared to low lands see Figure 4.17. The groundwater results also indicates that years with less recharge results to low groundwater elevation and years with high recharge rates results to higher groundwater level see Figure 4.26 and Figure 4.28. Comparison between the annual average recharge result and the high and low 5-years moving average recharge indicates that the groundwater will go down between 1 to 23m during a year with recharge value less than average (see Figure 4.27) and the groundwater level will go up between 1 and 15m, during a year with annual precipitation values greater than average see Figure 4.29.

This study leads to understanding of the fluxes of water in a natural tallgrass prairie ecosystem. The combination of EPIC ecological model and SPLIT groundwater model provides a room for the integration of ecology and hydrologic processes including, plant growth, precipitation, evaporation, evapotranspiration, runoffs, groundwater recharge, and groundwater flow. The groundwater model was exercised over representative ranges of recharge to examine the impact of climate variability on groundwater resources. As the annual precipitation increases, the annual recharge increases and it result to increase in groundwater level. If the annual precipitation decreases the recharge value decreases and the groundwater level moves deeper.

A direction for the future is to use this developed Konza groundwater model and the global predicted weather daily data to assess the changes in groundwater level as climate change. Climate change will change the groundwater level and as a result change the tall grass prairie vegetation. Konza location provide a good study area on climate change, because as you move towards the west of Konza the United States climate become more dry and as you move to the east of Konza the US climate become more wet.

Recommendations

Existing deep wells in Konza need to be located and mapped. Groundwater elevation data for the existing deep wells in Konza prairie need to be collected continuously to facilitate future groundwater studies in Konza. New Monitoring wells may be drilled in areas were needed and no old wells exist. Gage station for other steams flowing outside Konza area need to be established. In the future when enough weather data are available in Konza, this model can be modified by using only the Konza weather data to run EPIC ecological model instead of the North Agronomy farm weather data which were used in this study based on the fact that this station was considered to be the most nearest station that happens to have all the data required by EPIC ecologic model.

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Appendix A - Benfield/Irwin soil, EPIC input data file

```
Konza SGrass Simulations
15:05 27feb 7
RANGE.DAT   EPIC optimization
RANGE
  21   2   1   1   3 5432  0   0   0    1   0    1   1   0   0   0         1
      1.    80.0     .10   .0500   .0500   .6000     1.0   39.00   396.5      .0
      .8    50.0   330.0
    50.0   .0100    1.00    3.00  1.5880   .5600   .5600   .1200
                     7.0      .0
  1.83  5.77 11.18 18.80 24.30 29.34 32.28 31.38 26.82 21.05 11.80  4.70
 -9.83 -6.70 -1.71  4.99 11.05 16.49 19.21 18.19 13.04  6.79  -.59 -6.59
  7.43  7.60  7.72  6.46  4.86  4.22  4.08  3.97  5.16  5.97  6.82  7.01
  6.94  6.69  6.26  5.63  4.91  4.04  3.43  3.61  5.09  5.65  5.91  6.44
  24.2  25.2  51.9  66.7 116.9 128.9 101.3 104.4 106.0  67.6  42.5  24.1
   5.8   6.3   9.1   9.7  14.2  16.3  17.8  14.5  16.0  15.5   9.1   8.6
   .13  -.04   .79  1.34  2.67  1.00  2.93  1.90  1.17  2.21   .17  4.45
  .120  .140  .170  .240  .280  .270  .230  .250  .210  .140  .130  .120
  .260  .200  .370  .390  .450  .440  .390  .420  .410  .390  .360  .180
  4.33  4.32  6.59  8.47 10.46  9.76  8.49  9.34  7.88  5.79  5.06  3.96
   4.6   7.1  14.7  24.1  35.1  29.7  31.8  32.0  41.4  33.0  14.2  13.7
  191.  262.  345.  429.  520.  549.  538.  517.  407.  292.  222.  156.
 -7.99 -5.46 -2.13  4.08 10.13 16.45 18.12 17.41 12.26  6.46 -1.17 -5.77
    2.00    2.00   90.00     .00
     .30     .00    1.00
  4.11  4.23  5.08  5.17  4.72  4.23  3.72  3.85  3.90  4.00  4.06  4.04
   13.   13.   12.    9.    7.    6.    7.    6.    9.   10.   10.   11.
    6.    6.    7.    6.    5.    4.    4.    5.    6.    5.    4.    6.
    5.    5.    6.    5.    5.    5.    5.    5.    6.    3.    3.    4.
    3.    4.    5.    5.    5.    5.    5.    5.    5.    2.    2.    3.
```

```
 4.    6.    7.    6.    7.    6.    8.    8.    6.    4.    3.    4.
 3.    4.    5.    5.    6.    6.    7.    6.    5.    5.    3.    3.
 4.    4.    4.    6.    7.    9.   10.    9.    7.    6.    4.    4.
 4.    4.    4.    7.    9.   12.   10.   11.   10.    8.    6.    5.
10.    8.   10.   13.   18.   21.   19.   20.   18.   17.   13.   10.
 9.    7.    6.    7.    7.    7.   10.   10.    8.   10.   10.    9.
 8.    6.    4.    4.    5.    4.    5.    4.    4.    5.    8.    7.
 4.    4.    3.    3.    3.    2.    2.    2.    2.    3.    4.    4.
 6.    6.    5.    5.    4.    3.    2.    2.    3.    4.    7.    7.
 6.    6.    6.    5.    4.    3.    1.    2.    2.    4.    7.    7.
 8.    8.    8.    7.    4.    3.    2.    2.    3.    6.    9.    8.
 9.    9.    8.    7.    5.    4.    3.    3.    4.    7.    9.    8.
  .13      0.     .00     .00     .00     .00     .00     .00      0.
 0.01    0.15    0.20    0.48    0.74    0.89    1.04    1.30    1.55    1.95
 1.40    1.40    1.40    1.45    1.45    1.45    1.45    1.45    1.45    1.45
0.183   0.183   0.189   0.246   0.237   0.228   0.225   0.247   0.270   0.318
0.309   0.309   0.316   0.367   0.363   0.355   0.354   0.373   0.393   0.444
  3.6     3.6     3.4     1.5     1.8     2.7     2.9     2.8     3.3     0.9
 64.8    64.8    63.4    51.4    53.3    54.6    55.2    49.8    43.7    31.7
1200.   1200.   1140.    820.    660.    450.    340.    360.    280.    240.
  6.3     6.3     6.3     7.1     7.8     8.0     8.0     7.8     7.7     7.7
 15.1    15.1    14.7    19.8    12.0    27.9    25.4    27.6    32.0    38.8
 1.38    1.38    1.32    0.91    0.63    0.45    0.34    0.36    0.28    0.24
  0.0     0.0     0.0     0.0     1.0     1.0     1.0     0.0     0.0     0.0
 15.1    15.1    14.7    19.8    23.0    27.9    25.4    27.6    32.0    38.8
  0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
  10.     10.      5.      5.      5.      5.      5.      5.      5.      5.
  30.     30.     10.     10.     10.     10.     10.     10.     10.     10.
0.034   0.434   0.398   0.481   0.207   0.040   0.005   0.001   0.001   0.001
 1.50    1.50    1.50    1.55    1.55    1.55    1.55    1.55    1.55    1.55
 0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
 0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
   0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
4   0   0   0   1   0   0
  0.0     0.0     0.0     0.0    0.00     0.00      0.    0.00     0.0     0.0
```

```
   3  1  58  36   0   0.000      0.
   4  1   2  36      0     0        0.00
   6  1  66           0.00                    0.0
   8  1  65           0.00                    0.0

   3  1  58  36   0   0.000      0.
   6  1  66           0.00                    0.0
   8  1  65           0.00                    0.0

   3  1  58  36   0   0.000      0.
   6  1  66           0.00                    0.0
   8  1  65           0.00                    0.0

   3  1  58  36   0   0.000      0.
   6  1  66           0.00                    0.0
   8  1  65           0.00                    0.0
manh8507.prn
```

Appendix B - Clime Soil, EPIC input data file

```
Konza SGrass Simulations
15:05 27feb 7
ManRange.DAT   EPIC optimization
RANGE
  21   1   1   1   3 5432   0   0   0   1   0   1   1   0   0   0               1
      1.    86.0     .10   .0500   .0500   .6000     1.0   39.00   396.5      .0
      .8    50.0   330.0
    50.0   .0100    1.00    3.00  1.5880   .5600   .5600   .1200
                     7.0      .0
  1.83  5.77 11.18 18.80 24.30 29.34 32.28 31.38 26.82 21.05 11.80  4.70
 -9.83 -6.70 -1.71  4.99 11.05 16.49 19.21 18.19 13.04  6.79  -.59 -6.59
  7.43  7.60  7.72  6.46  4.86  4.22  4.08  3.97  5.16  5.97  6.82  7.01
  6.94  6.69  6.26  5.63  4.91  4.04  3.43  3.61  5.09  5.65  5.91  6.44
  24.2  25.2  51.9  66.7 116.9 128.9 101.3 104.4 106.0  67.6  42.5  24.1
   5.8   6.3   9.1   9.7  14.2  16.3  17.8  14.5  16.0  15.5   9.1   8.6
   .13  -.04   .79  1.34  2.67  1.00  2.93  1.90  1.17  2.21   .17  4.45
  .120  .140  .170  .240  .280  .270  .230  .250  .210  .140  .130  .120
  .260  .200  .370  .390  .450  .440  .390  .420  .410  .390  .360  .180
  4.33  4.32  6.59  8.47 10.46  9.76  8.49  9.34  7.88  5.79  5.06  3.96
   4.6   7.1  14.7  24.1  35.1  29.7  31.8  32.0  41.4  33.0  14.2  13.7
  191.  262.  345.  429.  520.  549.  538.  517.  407.  292.  222.  156.
 -7.99 -5.46 -2.13  4.08 10.13 16.45 18.12 17.41 12.26  6.46 -1.17 -5.77
    2.00    2.00   90.00     .00
     .30     .00    1.00
  4.11  4.23  5.08  5.17  4.72  4.23  3.72  3.85  3.90  4.00  4.06  4.04
   13.   13.   12.    9.    7.    6.    7.    6.    9.   10.   10.   11.
    6.    6.    7.    6.    5.    4.    4.    5.    6.    5.    4.    6.
    5.    5.    6.    5.    5.    5.    5.    5.    6.    3.    3.    4.
    3.    4.    5.    5.    5.    5.    5.    5.    5.    2.    2.    3.
    4.    6.    7.    6.    7.    6.    8.    8.    6.    4.    3.    4.
```

```
    3.    4.    5.    5.    6.    6.    7.    6.    5.    5.    3.    3.
    4.    4.    4.    6.    7.    9.   10.    9.    7.    6.    4.    4.
    4.    4.    4.    7.    9.   12.   10.   11.   10.    8.    6.    5.
   10.    8.   10.   13.   18.   21.   19.   20.   18.   17.   13.   10.
    9.    7.    6.    7.    7.    7.   10.   10.    8.   10.   10.    9.
    8.    6.    4.    4.    5.    4.    5.    4.    4.    5.    8.    7.
    4.    4.    3.    3.    3.    2.    2.    2.    2.    3.    4.    4.
    6.    6.    5.    5.    4.    3.    2.    2.    3.    4.    7.    7.
    6.    6.    6.    5.    4.    3.    1.    2.    2.    4.    7.    7.
    8.    8.    8.    7.    4.    3.    2.    2.    3.    6.    9.    8.
    9.    9.    8.    7.    5.    4.    3.    3.    4.    7.    9.    8.
     .14      0.     .00     .00     .00     .00     .00     .00      0.
    0.01    0.15    0.18    0.28    0.48    0.73    0.00    0.00    0.00    0.00
    1.02    1.02    1.02    1.25    1.32    1.36    0.00    0.00    0.00    0.00
   0.259   0.259   0.259   0.259   0.291   0.208   0.000   0.000   0.000   0.000
   0.427   0.427   0.427   0.385   0.424   0.343   0.000   0.000   0.000   0.000
     9.9     9.9     9.9    13.4     4.0     6.5     0.0     0.0     0.0     0.0
    43.8    43.8    43.8    37.4    38.9    56.2     0.0     0.0     0.0     0.0
   3153.   3153.   3153.   1755.   1139.    643.      0.      0.      0.      0.
     7.8     7.8     7.8     8.0     8.1     8.2     0.0     0.0     0.0     0.0
    30.7    30.7    30.7    29.4    31.4    20.4     0.0     0.0     0.0     0.0
    3.88    3.88    3.88    2.03    1.14    0.64    0.00    0.00    0.00    0.00

     9.4     9.4     9.4    10.7     2.9     8.0     0.0     0.0     0.0     0.0
    30.7    30.7    30.7    29.4    31.4    20.4     0.0     0.0     0.0     0.0
     4.2     4.2     4.2    29.8     8.4    11.9     0.0     0.0     0.0     0.0
     10.     10.      5.      5.      5.      5.      0.      0.      0.      0.
     30.     30.     10.     10.     10.     10.      0.      0.      0.      0.
   0.034   0.434   0.366   0.350   0.273   0.110   0.000   0.000   0.000   0.000
    1.09    1.09    1.09    1.34    1.41    1.46    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   4   0   0   0   1   0   0
     0.0     0.0     0.0     0.0    0.00     0.00     0.    0.00     0.0     0.0
```

```
3  1  58  36   0   0.000      0.
4  1   2  36      0     0        0.00
6  1  66           0.00                    0.0
8  1  65           0.00                    0.0

3  1  58  36   0   0.000      0.
6  1  66           0.00                    0.0
8  1  65           0.00                    0.0

3  1  58  36   0   0.000      0.
6  1  66           0.00                    0.0
8  1  65           0.00                    0.0

3  1  58  36   0   0.000      0.
6  1  66           0.00                    0.0
8  1  65           0.00                    0.0
```

manh8507.prn

Appendix C - Ivan/Kenberk Soil, EPIC input data file

```
Konza Corn Simulations
15:05 27feb 7
KONZA.DAT   EPIC optimization
RANGE
  21   2   1   1   35432   0   0   0   1   0   1   1   0   0   0               1
      1.    61.0     .10   .0250    0.05   0.050     1.0   39.00   396.5      .0
      .8    50.0   330.0
    50.0  0.0100    1.00    3.00  1.5880   .5600   .5600   .1200
                     7.0      .0
  1.83  5.77 11.18 18.80 24.30 29.34 32.28 31.38 26.82 21.05 11.80  4.70
 -9.83 -6.70 -1.71  4.99 11.05 16.49 19.21 18.19 13.04  6.79  -.59 -6.59
  7.43  7.60  7.72  6.46  4.86  4.22  4.08  3.97  5.16  5.97  6.82  7.01
  6.94  6.69  6.26  5.63  4.91  4.04  3.43  3.61  5.09  5.65  5.91  6.44
  24.2  25.2  51.9  66.7 116.9 128.9 101.3 104.4 106.0  67.6  42.5  24.1
   5.8   6.3   9.1   9.7  14.2  16.3  17.8  14.5  16.0  15.5   9.1   8.6
   .13  -.04   .79  1.34  2.67  1.00  2.93  1.90  1.17  2.21   .17  4.45
  .120  .140  .170  .240  .280  .270  .230  .250  .210  .140  .130  .120
  .260  .200  .370  .390  .450  .440  .390  .420  .410  .390  .360  .180
  4.33  4.32  6.59  8.47 10.46  9.76  8.49  9.34  7.88  5.79  5.06  3.96
   4.6   7.1  14.7  24.1  35.1  29.7  31.8  32.0  41.4  33.0  14.2  13.7
  191.  262.  345.  429.  520.  549.  538.  517.  407.  292.  222.  156.
 -7.99 -5.46 -2.13  4.08 10.13 16.45 18.12 17.41 12.26  6.46 -1.17 -5.77
    2.00    2.00   90.00     .00
     .30     .00    1.00
  4.11  4.23  5.08  5.17  4.72  4.23  3.72  3.85  3.90  4.00  4.06  4.04
   13.   13.   12.    9.    7.    6.    7.    6.    9.   10.   10.   11.
    6.    6.    7.    6.    5.    4.    4.    5.    6.    5.    4.    6.
    5.    5.    6.    5.    5.    5.    5.    5.    6.    3.    3.    4.
    3.    4.    5.    5.    5.    5.    5.    5.    5.    2.    2.    3.
    4.    6.    7.    6.    7.    6.    8.    8.    6.    4.    3.    4.
```

```
 3.    4.    5.    5.    6.    6.    7.    6.    5.    5.    3.    3.
 4.    4.    4.    6.    7.    9.   10.    9.    7.    6.    4.    4.
 4.    4.    4.    7.    9.   12.   10.   11.   10.    8.    6.    5.
10.    8.   10.   13.   18.   21.   19.   20.   18.   17.   13.   10.
 9.    7.    6.    7.    7.    7.   10.   10.    8.   10.   10.    9.
 8.    6.    4.    4.    5.    4.    5.    4.    4.    5.    8.    7.
 4.    4.    3.    3.    3.    2.    2.    2.    2.    3.    4.    4.
 6.    6.    5.    5.    4.    3.    2.    2.    3.    4.    7.    7.
 6.    6.    6.    5.    4.    3.    1.    2.    2.    4.    7.    7.
 8.    8.    8.    7.    4.    3.    2.    2.    3.    6.    9.    8.
 9.    9.    8.    7.    5.    4.    3.    3.    4.    7.    9.    8.
  .11      0.     .00     .00     .00     .00     .00     .00      0.
 0.01    0.15    0.25    0.48    0.80    1.14    1.43    1.83    2.00    0.00
 1.40    1.40    1.40    1.35    1.30    1.35    1.34    1.37    1.36    0.00
0.152   0.152   0.152   0.148   0.163   0.162   0.173   0.185   0.176   0.000
0.269   0.269   0.269   0.273   0.310   0.305   0.315   0.329   0.331   0.000
  8.0     8.0     8.0    11.9     5.9     4.6     4.2     1.9     1.8     0.0
 67.4    67.4    67.4    65.0    70.2    71.6    67.2    66.7    69.3     0.0
1620.   1620.   1620.   1370.   1330.   1050.   1220.   1000.    100.      0.
  6.0     6.0     6.0     5.6     5.9     5.9     6.0     6.3     6.4     0.0
 16.0    16.0    16.0    15.1    15.6    15.6    18.7    20.6    18.9     0.0
 1.62    1.62    1.62    1.37    1.33    1.05    1.22    1.00    0.60    0.00
  0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
 18.9    18.9    18.9    17.8    18.4    18.4    22.0    24.2    22.2     0.0
  0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
  10.     10.      5.      5.      5.      5.      5.      5.      5.      0.
  30.     30.     10.     10.     10.     10.     10.     10.     10.      0.
0.034   0.434   0.475   0.431   0.191   0.033   0.002   0.001   0.001   0.000
 1.50    1.50    1.50    1.44    1.39    1.44    1.43    1.47    1.46    0.00
 0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
 0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
   0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
   0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
4   0   0   0   1   0   0
  0.0     0.0     0.0     0.0    0.00     0.00     0.    0.00     0.0     0.0
3  1   58  36   0   0.000      0.
```

```
4  1   2  36      0     0        0.00

6  1  66           0.00                    0.0

8  1  65           0.00                    0.0


3  1  58  36   0   0.000      0.

6  1  66           0.00                    0.0

8  1  65           0.00                    0.0


3  1  58  36   0   0.000      0.

6  1  66           0.00                    0.0

8  1  65           0.00                    0.0


3  1  58  36   0   0.000      0.

6  1  66           0.00                    0.0

8  1  65           0.00                    0.0
```

manh8507.prn